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OPTIMAL PAIRINGS SELECTION FROM FLIGHT SCHEDULE USING GENETIC ALGORITHM AND PARTICLE SWARM OPTIMIZATION WITH PENALTY

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Abstract— Indonesia is a large archipelago country with large population so that the demands of flight service are very high. Because the demands of flight service, 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 this research, optimal pairings selection will be applied by heuristic method like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) with penalty. GA uses natural selection process mechanism in chromosomes while PSO is optimization method inspired from the flock of fish or bird in searching food source. Both GA and PSO can be applied on constrained optimization. In order that satisfying constraints, chromosome in GA or particle in PSO will be given penalty if the constraint isn't satisfied. Simulations are applied by generating the set of pairings and selection using GA and PSO with penalty. Simulation result shows GA and PSO method with penalty can select optimal pairings in approaching.

Keywords— Flight schedule, Pairings selection, Genetic Algorithm, Particle Swarm Optimization, penalty

1. INTRODUCTION

Indonesia is a large archipelago country with large population so that the demands of flight service are very high. Because the demands of flight service, flight industry should minimize operational cost. There are two highest costs in flight industry. The highest cost is fuel cost and the second is crew cost. Crew cost depends on pairings 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. Therefore 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 [3]. The constraints used are all flight numbers should be covered by one pairing. Because the decision variable is binary such as pairing is selected or not selected, then it is called

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binary programming. Linear integer programming can be solved by exact method like simplex method, branch and bound method, and cutting plane method [5],[13]. Other method used in optimal pairings selection is greedy algorithm. In this research, optimal pairings selection will be applied by heuristic method like Particle Swarm Optimization (PSO) with penalty. PSO has been applied in many optimization problems such as transportation problem [8], control system [4], and forecasting data [9],

Genetic Algorithm (GA) was discovered by Goldberg at 1989. How GA works is using natural selection process mechanism in chromosomes. Some process of GA are initialization chromosome population, selection, crossover and mutation chromosome [2], [11]. Particle Swarm Optimization (PSO) was discovered by Kennedy and Eberhart in 1995. PSO is inspired by the behavior of flocks of birds, swarm of insects, or school of fish in which individuals are called particles and the population is called a swarm. The PSO is initialized with a group of random candidate solutions as a swarm of particles. Each particle is given initial position and velocity. When particle finds a direction to the source of food, other particles will follow them [6].

Both GA and PSO can be applied on constrained optimization. In order that satisfying constraints, chromosomes in GA or particle in PSO will be given penalty if the constraint isn't satisfied [7]. GA and PSO are optimization, but development of Kalman Filter for estimation [14, 15, 16, 17], and combination with GA.

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 GA and PSO with penalty if the flight number is covered more than one pairing. Simulation result shows GA and PSO method with penalty 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, Figure 2, Figure 3, Figure 4, and Figure 5. Pairing A^n consists of n flight numbers [10].

Pre Journey (90 mnt)	Flight 1 (A → B)	Transit Time (TT)	Flight 2 (B → A)	Post Journey (90 mnt)
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Fig. 1 Pairing A^2 consisting of 2 flight numbers

Pre Journey (90 mnt)	Flight 1 (A → B)	Transit Time (TT)	Flight 2 (B → C)	Transit Time (TT)	Flight 3 (C → A)	Post Journey (90 mnt)
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Fig. 2 Pairing A^3 consisting of 3 flight numbers

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)
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Fig. 3 Pairing A^4 consisting of 4 flight numbers

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 → E)	Transit Time (TT)	Flight 5 (E → A)	Post Journey (90 mnt)
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Fig. 4 Pairing A^5 consisting of 5 flight numbers

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 → E)	Transit Time (TT)	Flight 5 (E → F)	Transit Time (TT)	Flight 6 (F → A)	Post Journey (90 mnt)
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Figure 5. Pairing A^6 consisting of 6 flight numbers

In the optimal pairing selection, there are some cases the flight numbers are deadhead on Figure 6. 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.

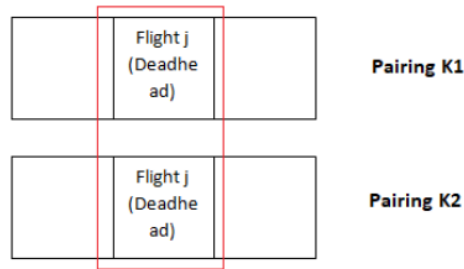


Fig. 6 Deadhead Situation

3. MATHEMATICAL MODEL OF SET COVERING PROBLEM

Optimal pairings selection can be done by generating the set of possible pairing 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 number are covered by one pairing. The model is called set covering problem.

Mathematical model of optimal pairings selection is as follows [10]:

$$\min \sum_{k=1}^{N_p} c_k x_k + \sum_{i=1}^{N_f} d_i \left(\sum_{k=1}^{N_p} a_{ik} x_k - 1 \right) \quad (1)$$

Subject to :

$$\sum_{k=1}^{N_p} a_{ik} x_k = 1, \quad i = 1, 2, \dots, N_f \quad (2)$$

$$x_k \in \{0, 1\}, \quad k = 1, 2, \dots, N_p \quad (3)$$

The objective function in equation (1) is : $\sum_{k=1}^{N_p} c_k x_k$ is objective function and

$\sum_{i=1}^{N_f} d_i \left(\sum_{k=1}^{N_p} a_{ik} x_k - 1 \right)$ is penalty term [2]. Variables used are :

N_p : The number of possible pairings

N_f : Total flight numbers

c_k : Cost of pairing k

d_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 :

$$x_k = \begin{cases} 1, & \text{if pairing } k \text{ is selected} \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

4. INITIALIZATION THE PARTICLE

Optimal pairings selection is applied by Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). In the GA and PSO, we need to initialize population of the sets of selected pairings in equation (4) as particle by greedy algorithm. Greedy algorithm is applied because it can result binary solutions based on equation (3) and it can cover all flight numbers at least one pairing based on equation (2). There are cases where the particle position can not satisfy the constraint in equation (2) so that penalty value

$\sum_{i=1}^{N_f} d_i \left(\sum_{k=1}^{N_p} a_{ik} x_k - 1 \right)$ to added in fitness function $\sum_{k=1}^{N_p} c_k x_k$. Because the solutions of this

problem are binary then the mathematical model is binary programming. The algorithm to initialize population of the sets of selected pairings as decision variables is as follows :

For $j=1$: max *pop*

1. Suppose U is the set of uncovered flight number, S_i , $i=1,2,\dots,N_f$ is the pairing covering flight number i , 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. GENETIC ALGORITHM WITH PENALTY

Genetic Algorithm (GA) was discovered by Goldberg at 1989. How GA works is using natural selection process mechanism in chromosomes. Some process of GA are initialization chromosome population, selection, crossover and mutation chromosome [2].

6. POPULATION SELECTION

In GA, selection process is replacing some chromosomes with the others to create new population [2]. Selection process works like roulette wheel. Selection process can be explained as follows:

1. Calculate the fitness value $f(X^j)$, $j=1,2,\dots,\max pop$

2. Calculate the total fitness for the population

$$F = \sum_{j=1}^{\max pop} f(X^j) \quad (5)$$

3. Calculate the selection probability p_j

$$p_j = \frac{f(X^j)}{F}, \quad j=1,2,\dots,\max pop \quad (6)$$

4. Calculate cumulative probability q_j

$$q_j = \sum_{i=1}^j p_i \quad (7)$$

5. Generate a random number r randomly between 0 and 1

6. If $r \leq q_1$, select first chromosome X^1 , otherwise, select the k -th chromosome X^j such that $q_{j-1} < r \leq q_j$

7. CROSSOVER CHROMOSOMES

In GA, crossover process is exchanging the element position of two parent chromosomes to become new chromosomes based on crossover probability p_c [2]. Crossover operator can improve optimal solution resulted by GA because crossover operator can explore the new solution. Crossover operator must be designed to satisfy constraints in equation (2) and equation (3). There are cases where the chromosomes can not satisfy the constraint in equation (2) so that penalty value $\sum_{i=1}^{N_p} d_i \left(\sum_{k=1}^{N_p} a_{ik} x_k - 1 \right)$ to added

in fitness function $\sum_{k=1}^{N_p} c_k x_k$. The algorithm of crossover operator is :

1. Select two chromosomes randomly x_k^{j1} , $k=1,2,\dots,N_p$ as first parent and x_k^{j2} , $k=1,2,\dots,N_p$ as second parent
2. Determine the element position of two parents $1 \leq k \leq N_p$ which have value $x_k = 1$
3. Exchange the element position of two parents so that result new x_k^{j1} and x_k^{j2}

For $k=1,2,\dots,N_p$

If ($x_k^{j1} = 1$ XOR $x_k^{j2} = 1$)

$$temp = x_k^{j2}$$

$$x_k^{j2} = x_k^{j1}$$

```

         $x_k^{j1} = temp$ 
    end
    end
4. 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
End

```

8. MUTATION CHROMOSOMES

In GA, mutation process is changing some element of origin chromosome to become new chromosome based on mutation probability p_m [2]. Mutation operator can improve optimal solution resulted by GA because mutation operator can explore the new solution. Mutation operator must be designed to satisfy constraints in equation (2) and equation (3). There are cases where the chromosomes can not satisfy the constraint in equation (2) so that penalty value $\sum_{i=1}^{N_f} d_i \left(\sum_{k=1}^{N_p} a_{ik} x_k - 1 \right)$ to added in fitness function $\sum_{k=1}^{N_p} c_k x_k$. The algorithm of mutation operator is :

```

1. Select  $x_k^j, k = 1, 2, \dots, N_p$ 
2. Determine the number of changed elements  $1 \leq k \leq N_p$  which have value  $x_k = 1$ 
3. Change with new elements with value 0 or 1 so that result new  $x_k^j$ 
4. 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  $i \in F_q$ 
       End
   End

```


e. Update $U \leftarrow U - F_q, x_q = 1$

End

End

9. PARTICLE SWARM OPTIMIZATION WITH PENALTY

PSO is an optimization method discovered by Kennedy and Eberhart in 1995. PSO is inspired by the behavior of flocks of birds, swarm of insects, or school of fish in which individuals are called particles and the population is called a swarm. The PSO is initialized with a group of random candidate solutions as a swarm of particles. When particle finds a direction to the source of food, other particles will follow them.

The basic PSO algorithm is as follows [12]:

1. Generate initialization particle position $x_k^j(0), j=1,2,\dots,\max pop$
2. Generate initialization particle velocity $v_k^j(0), j=1,2,\dots,\max pop$
3. Set local best particle $p_k^j = x_k^j(0), j=1,2,\dots,\max pop$
4. Set global best particle $g_k = \arg \min_p (f(p_k^j), j=1,2,\dots,\max pop)$
5. Update particle along time t .
for $t = 0 : \max_t$
for $k = 1,2,\dots,\max pop$

- Calculate the transformed particle velocity $v_k^j(t+1)$

$$v_k^j(t+1) = \omega v_k^j(t) + c_1 r_1 (p_{best}^j - x_k^j(t)) + c_2 r_2 (g_{best} - x_k^j(t)) \quad (8)$$

With the value of ω is the inertia between 0.9-1.2, $c_1 = c_2 = 2$, r_1 and r_2 are random number between (0,1).

- Update the particle position $x_k^j(t+1)$

$$x_k^j(t+1) = x_k^j(t) + v_k^j(t+1) \quad (9)$$

- Calculate the fitness of particle $f(x_k^j(t+1))$ with penalty
- Update local best particle p_k^j

$$p_k^j = \arg \min_x (f(x_k^j(0)), f(x_k^j(1)), \dots, f(x_k^j(t)), f(x_k^j(t+1))) \quad (10)$$

end

Update global best particle g_k

$$g_k = \arg \min_p (f(p_k^j), j=1,2,\dots,\max pop) \quad (11)$$

end

10. UPDATE THE PARTICLE

We need to modify the particle position and velocity update on PSO so that new particle can satisfy constraints in equation (2) and equation (3). The modification of particle position and velocity update can be designed as follows [1]:

1. Compute the velocity update equation

$$v_k^j(t+1) = \omega v_k^j(t) + c_1 r_1 (p_{best}^j - x_k^j(t)) + c_2 r_2 (g_{best} - x_k^j(t)) \quad (12)$$

With the value of ω is the inertia between 0.9-1.2, $c_1 = c_2 = 2$, r_1 and r_2 are random number between (0,1).

2. Compute the particle position update equation. The modifications are required so that the particle position may satisfy the constraints. There are cases where the particle position can not satisfy the constraint in equation (2) so that penalty value

$$\sum_{i=1}^{N_f} d_i \left(\sum_{k=1}^{N_p} a_{ik} x_k - 1 \right) \text{ to added in fitness function } \sum_{k=1}^{N_p} c_k x_k.$$

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

$$sigm(v_k^j) = \frac{1}{1 + \exp(-\lambda v_k^j)} \quad (13)$$

with steepness $\lambda = 1$

- c. Calculate particle position $x_k^j(t+1)$ based on equation (14)

$$x_k^j(t+1) = \begin{cases} 1, & \text{if } z < sigm(v_k^j(t+1)) \\ 0, & \text{otherwise} \end{cases} \quad (14)$$

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

For $i = 1 : N_f$

If ($w_i = 0$)

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

End

End

11. 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, we generate a set of possible pairings of each flight number. 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 by one pairing. When the set of selected pairing does not satisfy the constraint in equation (2), then it occurs deadhead and penalty cost will be given.

Cost of pairing is constructed as follows :

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

In Boeing 738 airline, 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 fewer. 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. This problem causes a set of crews is transferred to destination airport with other flight in different pairing. In the optimal pairing selection, deadhead is penalty so that cost of deadhead is higher than cost of pairing.

Figure 7 shows the simulation of GA on optimal pairings selection optimization. In early time, the chromosomes are chosen randomly. In the optimization process, the chromosomes are updated by selection, crossover, and mutation so that fitness will decrease and converge. In updating chromosomes, in order that satisfying constraints, chromosome will be given penalty if the constraint isn't satisfied.

From the GA simulation with the number of population is 10, crossover probability is 0.5, mutation probability is 0.5, and maximum iteration is 50, the objective value as fitness is 1050. The cost of pairings as main objective function is 190 and cost of deadhead as penalty is 860. The number of pairings selected are :

Pairing A^2	: 1 pairings of 337 pairings
Pairing A^3	: 3 pairings of 44 pairings
Pairing A^4	: 51 pairings of 3549 pairings
Pairing A^5	: 5 pairings of 91 pairings
Pairing A^6	: 10 pairings of 1269 pairings
Deadhead	: 86 flight numbers

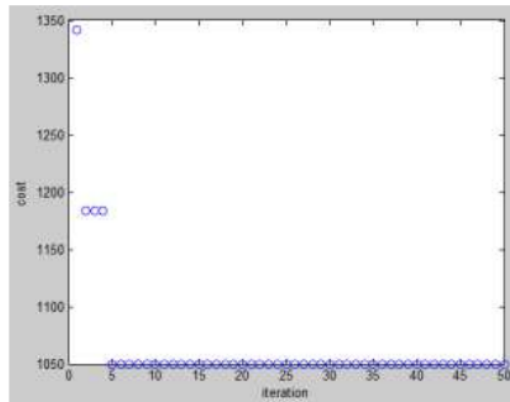


Fig. 7 GA Optimization Process

Figure 8 shows the simulation of PSO on optimal pairings selection optimization. In early time, the particle positions are chosen randomly. In the optimization process, position and velocity particle are updated so that fitness will decrease and converge. In updating particle position, in order that satisfying constraints, particle will be given penalty if the constraint isn't satisfied.

From the PSO simulation with the number of population is 10 and maximum iteration is 50, the objective value as fitness is 944. The cost of pairings as main objective function is 194 and cost of deadhead as penalty is 750. The number of pairings selected are :

- Pairing A^2 : 3 pairings of 337 pairings
- Pairing A^3 : 4 pairings of 44 pairings
- Pairing A^4 : 50 pairings of 3549 pairings
- Pairing A^5 : 1 pairings of 91 pairings
- Pairing A^6 : 11 pairings of 1269 pairings
- Deadhead : 75 flight numbers

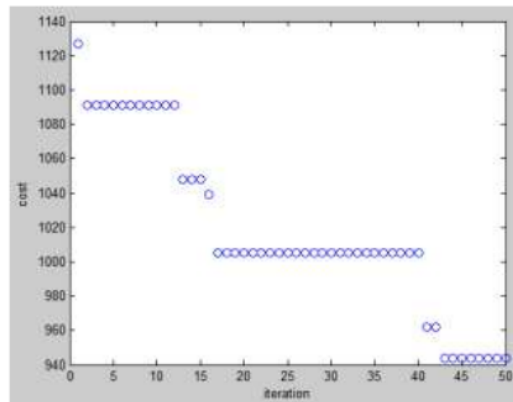


Fig. 8 PSO Optimization Process

12. CONCLUSION

Optimal pairings selection is one of constrained optimization with decision variable is binary. The constraints are all flight numbers should be covered by one pairing.

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 GA and PSO with penalty if the flight number is covered more than one pairing. Modified crossover and mutation in GA or particle position and velocity in PSO are required because the decision variable is binary. Simulation result shows GA and PSO method with penalty can select optimal pairings in approaching. The developments from these results are assigning the set of crew for operating the pairings.

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