Indonesian Journal of Electrical Engineering and Computer Science
Vol. 18, No. 3, June 2020, pp. 1665~1672
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v18.i3.pp1665-1672

Comparison of two hybrid algorithms on incorporated aircraft routing and crew pairing problems

Mohamed N. F. [1], Mohamed N. A.[2], Mohamed N. H.[3], Subani N.[4]
[1,4]Kolej Genius Insan, Universiti Sains Malaysia, Malaysia
[2,3]Department of Mathematics, Faculty of Science & Mathematics, Universiti Pendidikan Sultan Idris, Malaysia

Article Info

Article history:

Received Des 3, 2019
Revised Jan 20, 2020
Accepted Jan 30, 2020

Keywords:

Aircraft routing problem
Crew pairing problem
Genetic algorithm
Integer linear programming
Particle swarm optimization

ABSTRACT

In airline operations planning, a sequential method is traditionally used in airline system. In airline systems, minimizing the costs is important as they want to get the highest profits. The aircraft routing problem is solved first, and then pursued by crew pairing problem. The solutions are suboptimal in some cases, so we incorporate aircraft routing and crew pairing problems into one mathematical model to get an exact solution. Before we solve the integrated aircraft routing and crew pairing problem, we need to get the aircraft routes (AR) and crew pairs (CP). In this study, we suggested using genetic algorithm (GA) to develop a set of AR and CP. By using the generated AR and CP, we tackle the integrated aircraft and crew pairing problems using two suggested techniques, Integer Linear Programming (ILP) and Particle Swarm Optimization (PSO). Computational results show that GA's executed of AR and CP and then solved by ILP obtained the greatest results among all the methods suggested.

Corresponding Author:

Nurul Farihan Mohamed,
Kolej Genius Insan,
Universiti Sains Islam Malaysia,
Bandar Baru Nilai, 71800 Nilai, Negeri Sembilan, Malaysia.
Email: farihan@usim.edu.my

1. INTRODUCTION

The aircraft routing problem is solved in order to decide the AR of the flight so each flight are operated by one aircraft with the aim is to limit the costs involved. While the crew pairing problem is to get a minimum costs for CP that operated by a certified team. More often than not, the AR and CP are solved sequentially in the airlines system. Sometimes, the outcomes acquired are suboptimal. In order to solve this problem, we proposed to incorporate aircraft routing and crew pairing problems in one model. By using the executed AR and CP from the GA, we will solve the incorporated model by using ILP and PSO.

There are many works that had been done in resolving aircraft routing and crew pairing problem individually which can be discovered in [1-9] presented the genetic algorithm in their works which is genetic algorithm is one of the proposed method in this research [10] extended the network time line or, for present flight and ground arcs, also known as the rotation tour network model that included maintenance arcs. Different flight lines were suggested at maintenance stations in [11]. Robustness is a goal in [12] and an incorporated model of flight retiming and aircraft routing had been put forward. In [13], the blend of GA and heuristic technique was tried on the real data in solving the airline crew scheduling. In [14] incorporated the crew pairing and rostering problem in a model that formulate as ILP. While in [15], crew pairing and rostering were integrated into one model, then clarified by branch and bound, shortest path algorithm and column generation. ILP had been proposed in [16] to create the CP and afterward comprehended by branch bound method. The crew pairing and rostering problem were incorporated as one model in [17] and the clarification was conducted by using the GA. In [18] defined the airline crew scheduling as travelling salesman problem and resolved it by ant colony optimization. The branch price and cut method was utilized by [19] for resolving the crew pairing problem. According to [20], there are three schedule plans in the airlines industry namely as strategic planning, operational management and tactical planning.

The first research that integrated the aircraft routing and crew pairing problems is proposed by [21]. They resolved the incorporated model by using column generation and a branch bound method. Other than that, [22] solved the issue of aircraft routing, crew pairing and scheduling by turning around the order, for instance by solving the issue of crew pairing before the issue of aircraft routing was solved. While [23] utilized the Benders decomposition method to reformulate the incorporated aircraft routing and crew pairing problem. They used the issue of crew pairing as the master problem of Benders and the issue of aircraft routing as the sub problem of Benders. In [24] resolved the aircraft and crew scheduling iteratively begin from an insignificant expense and a progression of solutions that can increase the robustness. The incorporated model of aircraft routing, crew pairing and re-timing is presented by [25]. A heuristic method had been presented in the new approach which is can change the time of any aircraft and crew schedule for reducing the delay propagation. [26] also used heuristic methods to generate a set of solutions which was then used in the new and more efficient set covering-based formulation, treated as an ILP. From the past researches, many of them not obtained the optimal solutions. Hence, our work will use the exact method in obtaining the optimal solution.

This paper presents (i) a model formulation on the GA in executing a set of feasible AR and CP, (ii) an ILP model formulation for the incorporated problems, (iii) a PSO model formulation, and (iv) an empirical study to test and validate the effectiveness of the proposed approaches. The next section presents the GA approach in executing the set of AR and CP and ILP and PSO formulations in resolving the incorporated aircraft routing and crew pairing problem. In the final section, results and analysis including the conclusion of our study will be discussed.

2. RESEARCH METHOD

We divide this section into two subsection, the first subsection describes a proposed method in executing AR and CP which is GA, while the second subsection describes two methods in solving the integrated problem, which are ILP and PSO.

2.1. Executed Aircraft Routes and Crew Pairs Generated by GA

So as to unravel the incorporated model of aircraft routing and crew pairing problem, a set of feasible AR and CP are needed. Thus, we suggested GA in order to execute the set of AR and CP which will be explained in details. The solution approach of GA for AR and CP is denoted as Algorithm 1 and 2 respectively in the Table 2. Table 1 describes the notations used in Algorithm 1 and 2.

Table 1. The notations used in GA

TABLE I.	Notation	TABLE II.	Explanation
TABLE III.	cs	TABLE IV.	Size of population
TABLE V.	g	TABLE VI.	Flight leg's quantity that required in the flight table
TABLE VII.	fh	TABLE VIII.	Time of flight (hours)
TABLE IX.	tt	TABLE X.	Turn time for aircraft routes
TABLE XI.	dc	TABLE XII.	Crew duty period
TABLE XIII.	G_1	TABLE XIV.	Parent 1 generated by crossover
TABLE XV.	G_2	TABLE XVI.	Parent 2 generated by crossover
TABLE XVII.	$G_1^{'}$	TABLE XVIII.	Child 1 generated by crossover
TABLE XIX.	$G_2^{'}$	TABLE XX.	Child 2 generated by crossover
TABLE XXI.	cp	TABLE XXII.	Number of population chromosomes
TABLE XXIII.	J_B	TABLE XXIV.	Best results for the present population
TABLE XXV.	D_B	TABLE XXVI.	Best results for the solutions' cumulative

Table 2. The pseudocode of GA for AR and CP

Pseudocode of GA for aircraft routes (Algorithm 1)

```
Initially $cs = 0$.
Generate the initial population.
Evaluate the fitness of initial population by using $fh$ and $cp$.
While the $D_B$ are not repeated three times
        Select two parents $G_1$ and $G_2$
        Record $fh$ of $G_1$ and $G_2$
        Generate the children, $G_1'$ and $G_2'$ by crossover
        Evaluate the children by using $fh$ and $cp$
        Choose $J_B$ based on $fh$ and $cp$
        Generate the mutation of $G_1'$ and $G_2'$
        Evaluate the mutation of $G_1'$ and $G_2'$ by using $fh$ and $cp$
        Choose $J_B$ and $D_B$ based on $fh.cs = cs + 1$
End while
```

Pseudocode of GA for crew pairs (Algorithm 2)

```
Initially $cs = 0$.
Generate the initial population.
Evaluate the fitness of initial population by using $dc$
While the $D_B$ are not repeated three times
        Select two parents, $G_1$ and $G_2$
        Record $dc$ of $G_1$ and $G_2$
        Generate the children, $G_1'$ and $G_2'$ by crossover
        Evaluate the children by using $dc$.
        Choose $J_B$ based on $dc$
        Generate the mutation of $G_1'$ and $G_2'$
        Evaluate the mutation of $G_1'$ and $G_2'$ by using $dp$
        Choose $J_B$ and $D_B$ based on $dp.cs = cs + 1$
End while
```

2.2. Model Formulation of Incorporated Problem

In this subsection, the model formulation of integrated problem will be explained in details. There are two proposed methods in solving the integrated problem that will be presented in this subsection which are ILP and PSO.

2.2.1 Integer Linear Programming

The formulation of the incorporated aircraft routing and crew pairing problem is demonstrated in this subsection. Table 3 summarizes the notations used in incorporated model. The ILP model of integrated aircraft routing and crew pairing problem are shown as follows:

$$\text{Min} \sum_{n\in N}\sum_{\mu\in\alpha^n} c_{\mu n}\xi_\mu + \sum_{d\in D}\sum_{\varphi\in\alpha^d} c_{\varphi d}\eta_\varphi + \sum_{\mu\in\alpha^n}\sum_{(g_i,g_j)\in R} z_{ij}P_{ij} \tag{1}$$

$$\text{s.t.} \sum_{n\in N}\sum_{\mu\in\alpha^n} w^g_{\mu n}\xi_\mu = 1,\ g\in G \tag{2}$$

$$\sum_{d\in D}\sum_{\varphi\in\alpha^d} w^g_{\varphi d}\eta_\varphi = 1,\ g\in G \tag{3}$$

$$\sum_{n\in N}\sum_{\mu\in\alpha^n} l_\mu\xi_\mu \le \omega^X \tag{4}$$

$$\sum_{n\in N}\sum_{\mu\in\alpha^n} s_\mu\xi_\mu \le \omega^Z \tag{5}$$

$$\sum_{d\in D}\sum_{\varphi\in\alpha^d} v_\varphi\eta_\varphi \le \omega^Y \tag{6}$$

$$\sum_{d\in D}\sum_{\varphi\in\alpha^d} n^{ij}_{\varphi d}\eta_\varphi - \sum_{n\in N}\sum_{\mu\in\alpha^n} n^{ij}_{\mu n}\xi_\mu \le 0,\ g_i, g_j \in S \tag{7}$$

$$\sum_{d\in D}\sum_{\varphi\in\alpha^d} n^{ij}_{\varphi d}\eta_\varphi - \sum_{n\in N}\sum_{\mu\in\alpha^n} n^{ij}_{\mu n}\xi_\mu - P_{ij} \le 0,\ g_i, g_j \in R \tag{8}$$

$$P_{ij} \in \{0,1\},\ g_i, g_j \in R \tag{9}$$

$$\xi_{\mu} \in \{0,1\},\ n \in N; \mu \in \alpha^{n} \tag{10}$$

$$\eta_{\varphi} \in \{0,1\},\ d \in D; \varphi \in \alpha^{d}. \tag{11}$$

Table 3. The notations in incorporated model of aircraft routing and crew pairing problem

Notation	Explanation
N	Maintenance stations
D	Crews' bases
R	Two flight with restricted connection
S	Two flight with short connection
G	Flights in the timetable
p_n^A	The AR source nodes
q_n^A	The AR sink nodes
p_d^C	The crew pairs source nodes
q_d^C	The crew pairs sink nodes
α^n	AR from p_n^A to q_n^A in N_n^A
α^d	CP from p_d^C to q_d^C in N_d^A
$w_{\mu n}^{g}$	Equivalent to 1 if flight g associated with AR $\mu \in \alpha^n$, or else is equal to 0
$w_{\varphi d}^{g}$	Equivalent to 1 if flight g associated with CP $\varphi \in \alpha^d$, or else is equal to 0
$c_{\mu n}$	Expense by using the AR $\mu \in \alpha^n$
$c_{\varphi d}$	Expense by using the CP $\varphi \in \alpha^d$
$n_{\mu n}^{ij}$	Equivalent to 1 if flights g_i and g_j are perform back to back in AR $\mu \in \alpha^n$, or else is equal to 0
$n_{\varphi d}^{ij}$	Equivalent to 1 if flights g_i and g_j are perform back to back in CP $\varphi \in \alpha^d$, or else is equal to 0
l_{μ}	The quantity of required aircrafts in the AR $\mu \in \alpha^n$
ω^X	The quantity of accessible aircrafts
ω^Y	The quantity of duty periods permitted in one CP
ω^Z	The quantity of short connections permitted in one AR
v_{φ}	The quantity of duties in CP $\varphi \in \alpha^d$
s_{μ}	The quantity of short connections in AR $\mu \in \alpha^n$
z_{ij}	Penalty expense involved with $(\mathrm{g}_i, \mathrm{g}_j) \in R$
ξ_{μ}	Binary variable that state the process on the AR $\mu \in \alpha^n$
η_{φ}	Binary variable that state the process on the CP $\varphi \in \alpha^d$
P_{ij}	Binary variable that state the penalty expenses for $(\mathrm{g}_i, \mathrm{g}_j) \in R$

The objective function (1) means to get the negligible expenses for both of the aircraft routing and crew pairing problems, and also the penalty expenses. Equations (2) and (3) are to assure that each flight leg utilize one AR and CP only. Equation (4) is to make sure that all flight that worked at the same time do not beyond the accessible aircrafts. Equation (5) imposed that the short connection in the aircraft route $\mu \in \alpha^n$ is only restricted to ω^Z . Equation (6) guarantees that every single CP does not outperform the quantity of permissible duty periods for each crew. Equation (7) satisfies the condition that when the connection is too short, a crew does not switch the aircraft. If the same CP is used in the second flight but not the same aircraft, (8) is to constrain a penalty. At last, (9), (10) and (11) are the used binary decision variables.

2.2.2 Particle Swarm Optimization

PSO is easy to implement but difficult to execute and there are not many parameters need to modify contrasted with other heuristic methods. Algorithms 3 and 4 provide the overview of the algorithm for binary particle swarm optimization. Algorithm 3, Step 1 is defined in Algorithm 4.

Algorithm 3

Input: The objective function which is the algorithms' parameters that consisting of AR and CP.
Output: The best solution achieved.
Step 1: By using Algorithm 4, the population of trial solutions, local best and global best will be initialized.
Step 2: The velocity will be calculated by using (12) and (13).
Step 3: By using (14), the next move will be calculated.
Step 4: Assessment of the current solution will be done, as the local best and global best as the current solution
Step 5: If the algorithm criterion has been met, then stop. If not, go to step 2.

In Algorithm 4, M is the quantity of population and H is the problem's dimension. In the Algorithm 4, the corresponding fitness function f will be evaluated by calculating the objective function for each trial solution. By using the violation of constraints of the problem, function z is calculated. After that, the solution evaluations are carried out by using the amount of these functions and Deb's rule [27]. Possible alternatives with lower fitness are desirable as the goal is to achieve minimal expenses. Compared to the unfeasible solution, the feasible solution is desirable. But if infeasible alternatives for both alternatives are acquired, the one with lower violation are chosen.

Algorithm 4

Input: Algorithm parameters, objective function.
Output: Trial solution population, global best, and local best.
Step 1. A set of number at random, $s \in \left\{0, \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1\right\}$. $x_{ij} \in \{0,1\}$ will be initialized.
Step 2. $i = 1$ to $M/2$ and $j = 1$ to H, then $s = 4s(1-s)$, and $x_{ij} = round(\mathrm{s})$.
Step 3. $i = M/2$ to M and $j = 1$ to H, then $x_{ij} = 1 - x_{i-1,j}$.
Step 4. Assess x_{ij} for $i = 1,2,...,M$ and $j = 1,2,...,H$. The local best and global best will be calculated.

Step 2, velocity in Algorithm 3 is either initialized without any method or put as zero. Next, the velocity will be updated iteratively using parameters α and β. The parameters are fixed as $\alpha = 2$ and $\beta = 20$. First, produce a set of random number s, if $s < \alpha$, then update the velocity z based on the (12).

$$z_{ij} = z_{ij} + (x_{gbj} - x_{ij}), \tag{12}$$

where $i = 1,2,...,M$ and $j = 1,2,...,H$ and x_{gb} as the solution's global best. When $s < \beta$, the velocity z is revised by the (13).

$$z_{ij} = z_{ij} + (x_{lbj} - x_{ij}), \tag{13}$$

where x_{lb} is the solution's best local in the present population. If none of these circumstances are met, the velocity z is put as zero. The following stage after the velocity update is to revise the present population by using the (14).

$$x_{ij} = x_{ij} + v_{ij}. \tag{14}$$

3. RESULTS AND ANALYSIS

The study findings are described in this subsection and at the same moment the extensive debate is provided. We regarded four aircraft types involving multiple Malaysian-based destinations. A GA method is used to execute the AR and CP. The incorporated aircraft routing and crew pairing problem was then resolved by using two methods, namely the ILP and the PSO, by using the viable AR and CP. All methods have been resolved on a 2.10 GHz Intel Core Duo processor using Microsoft Visual Studio C++ interface with ILOG CPLEX Callable Library.

3.1. Data Sets

There are four variety of aircraft that are taken as our data sets. The aircraft are B738, B735, A72 and B734 which are operated for local flight by an airline in Malaysia. The aircraft type B738, B735, A72 and B734 have 70, 70, 364 and 588 number of flight legs respectively.

3.2. Solution Approach for Generating AR and CP

We produce AR and CP by using GA method. The numerical codes are coded in C++ Language. The obtained results for the quantity of executed AR and CP for each variety of aircraft by using GA are presented in Table 4.

Table 4. The quantity of executed AR and CP for each variety of aircraft generated by GA method

Aircraft variety	AR			CP		
	Quantity of flight legs	Quantity of executed AR	Computational time (seconds)	Quantity of flight legs	Quantity of executed CP	Computational time (seconds)
B738	70	70	100	70	70	96
B735	70	56	60	70	49	45
A72	364	252	305	364	245	289
B734	588	370	422	588	357	410

The computational time is more significant when tackling the genuine information / data sets for bigger aircraft as they involved bigger number of flight legs. Based on the results, we note that the running time by computer performs linear relation with the quantity of flight legs. Therefore, we expect that when we increase the quantity of flight legs, the computational time will be increased linearly.

3.3. Solution Approaches for Solving Incorporated Aircraft Routing and Crew Pairing Problem

We solve the incorporated aircraft routing and crew pairing problem by using the executed AR and CP gained from using GA method. The approaches that we use are ILP and the PSO which are coded in C++ Language interface with ILOG 12.4 CPLEX. We demonstrate the solution for ILP and PSO in terms of cost involved and computational time taken for each type of aircraft. All the estimated expenses utilized Malaysia's currency i.e. Ringgit Malaysia.

Table 5. Comparison results between ILP and PSO based on the executed AR and CP acquired by GA ethod

Aircraft type	Quantity of flight legs	ILP with executed AR and CP by GA				PSO with executed AR and CP by GA			
		Quantity of executed AR	Quantity of executed CP	Estimated expenses (RM)	Time (secs)	Quantity of executed AR	Quantity of executed CP	Estimated expenses (RM)	Time (secs)
B738	70	70	70	152734	0	70	70	153143	0
B735	70	56	49	156714	0.42	56	49	157911	0.45
A72	364	252	245	332065	240.6	252	245	334722	178.9
B734	588	370	357	821678	673.9	370	357	827264	668.1

In this subsection, the results of ILP and PSO for executed AR and CP obtained from GA are presented. As presented in Table 5, the costs of all approaches for executed AR and CP for ILP are lower than PSO. From all the approaches that have been used in this work, it can be concluded that the results obtained from ILP have the lowest costs for all type of aircraft. In terms of computational time for aircraft type B738, the results from all the approaches compute the lowest computational time which are zero second. For aircraft type B735, ILP requires the lowest computational time. For aircraft type with the bigger size of flight legs which is A72 computes the lowest computational time by using PSO. Lastly, the aircraft type with the highest number of flight legs, B734 computes the minimum computational time by using PSO. It can conclude that the results PSO requires less computation time, however, the costs obtained are slightly high.

4. CONCLUSION

This paper presents a comparison of two hybrid algorithms for incorporated aircraft routing and crew pairing problems. In this paper, GA method is presented in executing the AR and CP. Then, two solution approaches in solving the incorporated problem are presented, one includes an ILP formulation, while the other one is based on PSO. Both approaches are empirically examined on four variety of aircraft operated for Malaysian local flights. The solutions obtained are advocated strongly in solving the complex incorporated problems, however the integrated formulation gives off an impression of being generally quicker on those tested flights. Besides that, the solutions from ILP are optimal, compare to the solutions from the PSO are not optimal. One conceivable future research is to examine the bigger occurrences from the worldwide airline companies. One way to address this is to incorporate a parallel genetic algorithm within the PSO to speed up the process. Although this is challenging in practical and academic but it will be helpful for the bigger occurrences.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Sains Islam Malaysia (USIM), Universiti Pendidikan Sultan Idris (UPSI) and Ministry of Education Malaysia for their financial contribution in respect for this study under Fundamental Research Grant Scheme (FRGS) (code no: 2019-0010-107-02) (FRGS/1/2018/STG06/UPSI/02/4).

REFERENCES

[1] B. Gopalakrishnan and E. L. Johnson, “Airline Crew Scheduling: State of The Art,” *Annals of Operations Research*, vol. 140, pp. 305-337, November 2005.

[2] I. Muter, *et al*., “Solving a Robust Airline Crew Pairing Problem with Column Generation,” *Computers & Operations Research*, vol. 40, no. 3, pp. 815-830, March 2013.

[3] M. Saddoune, *et al*., “Integrated airline crew scheduling: A bi-dynamic constraint aggregation method using neighborhoods,” *European Journal of Operational Research*, vol 212, no. 3, pp. 445-454, August 2011.

[4] K. Jenab and J. Pineau, “Automation of Air Traffic Management Using Fuzzy Logic Algorithm to Integrate Unmanned Aerial Systems into the National Airspace,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, pp. 3169-3178, October 2018.

[5] A. Schaefer, “Airline Crew Scheduling Under Uncertainty,” *Transportation Science*, vol. 39, no. 3, pp. 340-348, August 2005.

[6] J. W. Yen and J. R. Birge, “A Stochastic Programming Approach to the Airline Crew Scheduling Problem,” *Transportation Science*, vol. 40, no. 1, pp. 3-14, February 2006.

[7] S. Shebalov and D. Klabjan , “Robust Airline Crew Pairing: Move-up Crews,” *Transportation Science*, vol. 40, no. 3, pp. 300-312, August 2006.

[8] M. J. Varnamkhasti, “A genetic algorithm rooted in integer encoding and fuzzy controller,” *International Journal of Robotics and Automation (IJRA)*, vol. 8, pp. 113-124, June 2019.

[9] T. C. Rajendra, R. Sivaramakrishnan, “Fuzzy neuro-genetic approach for feature selection and image classification in augmented reality systems,” *International Journal of Robotics and Automation (IJRA)*, vol. 8, pp. 194-204, September 2019.

[10] Z. Liang *et al*., “On a New Rotation Tour Network Model for Aircraft Maintenance Routing Problem,” *Transportation Science*, vol. 45, no. 1, pp. 109–120, 2011.

[11] M. Lapp and A. Cohn, “Modifying Lines-Of-flight in the Planning Process for Improved Maintenance Robustness,” *Computers & Operations Research*, vol. 39, no. 9, pp. 2051-2062, 2012.

[12] M. Basdere and U. Bilge, “Operational Aircraft Maintenance Routing Problem with Remaining Time Consideration,” *European Journal of Operational Research*, vol. 235, no. 1, pp. 315-328, 2014.

[13] D. Levine, “Application of a Hybrid Genetic Algorithm to Airline Crew Scheduling,” *Computers & Operations Research*, vol. 23, no. 6, pp. 547-558, 1996.

[14] F. M. Zeghal and M. Minoux, “Modeling and Solving a Crew Assignment Problem in Air Transportation,” *European Journal of Operational Research*, vol. 175, pp. 187-209, 2006.

[15] C. P. Medard and N. Sawhney, “Airline Crew Scheduling from Planning to Operations,” *European Journal of Operational Research*, vol. 183, no. 3, pp. 1013-1027, 2007.

[16] S. AhmadBeygi *et al*., “An Integer Programming Approach to Generating Airline Crew Pairings,” *Computers & Operations Research*, vol. 36, pp. 1284-1298.

[17] N. Souai and J. Teghem, “Genetic Algorithm Based Approach for the Integrated Airline Crew-Pairing and Rostering Problem,” *European Journal of Operational Research*, vol. 199, no. 3, pp. 674-683, 2009.

[18] G. D. Deng and W. T. Lin, “Ant Colony Optimization-Based Algorithm for Airline Crew Scheduling Problem,” *Expert Systems with Applications*, vol. 38, no. 5, pp. 5787-5793, 2011.

[19] V. Duck et al., “Implementing a Branch and Price And Cut Method for The Airline Crew Pairing Optimization Problem,” *Public Transport*, vol. 3, no. 1, pp. 43-64, 2011.

[20] S. Ruther, “*Integrated Aircraft Routing, Crew Pairing, Tail Assignment*,” PhD thesis. The University of Newcastle, United Kingdom; 2013.

[21] J. F. Cordeau, *et al*., “Benders Decomposition for Simultaneous Aircraft Routing and Crew Scheduling,” *Transportation Science*, vol. 35, no. 4, pp. 375-388, November 2001.

[22] D. Klabjan, *et al*. “Airline Crew Scheduling with Time Windows and Plane-Count Constraints,” *Transportation Science*, vol. 36, no. 3, pp. 33-48, August 2002.

[23] A. Mercier, *et al*., “A Computational Study of Benders Decomposition for The Integrated Aircraft Routing and Crew Scheduling Problem,” *Computers & Operations Research*, vol. 32, no. 6, pp. 1451-1476, June 2005.

[24] O. Weide, *et al*., “An Iterative Approach to Robust and Integrated Aircraft Routing and Crew Scheduling,” *Computers & Operations Research*, vol. 37, no. 5, pp. 833-844, May 2010.

[25] M. Dunbar, *et al.*, “An Integrated Scenario-Based Approach for Robust Aircraft Routing, Crew Pairing and Re-Timing,” *Computers & Operations Research*, vol. 45, pp. 68-86, May 2014.

[26] N. H. Mohamed, *et al.*, “A Matheuristic Approach for the Split Delivery Vehicle Routing Problem: An Efficient Set Covering-based Model with Guided Route Generation Schemes,” *International Journal of Mathematics in Operational Research*, vol. 15, no. 1, pp. 65–91, 2019.

[27] K. Deb, “An Efficient Constraint-Handling Method for Genetic Algorithms,” *Journal Computer Methods in Applied Mechanics*, vol. 186, pp. 311–338, 2000.

BIOGRAPHIES OF AUTHORS

Dr. Nurul Farihan Mohamed obtained her BSc from Universiti Teknologi Malaysia (UTM), Malaysia in 2010. She later received her PhD in Mathematics from Universiti Teknologi Malaysia (UTM) in 2017. Currently, she is working as a Senior Lecturer at Universiti Sains Islam Malaysia (USIM), Malaysia. Her main research interests are heuristic and exact methods for the integrated aircraft routing and crew pairing problems.

Dr. Nurul Akmal Mohamed was born in Kelantan, Malaysia, in 1983. She received her B.sc and M.sc from University of Technology Malaysia, Skudai, Johor, Malaysia in 2005 and 2007, respectively. Later she obtained her P.hD in mathematics from Brunel University, West London, United Kingdom in the year 2013. She is currently a senior lecturer at Sultan Idris Education University, Perak, Malaysia. Her research interests include operational research, analysis and numerical solution of partial differential equations, complex analysis and mathematics education.

Dr. Nurul Huda Mohamed received her BSc from Universiti Teknologi Malaysia, Skudai (UTM), Malaysia in 2002. In 2004, she was awarded an MSc in Operational Research from The University of Edinburgh, United Kingdom. She later obtained her PhD in Operational Research from University of Kent, UK in 2012. Currently, she is working as a senior lecturer at Universiti Pendidikan Sultan Idris (UPSI), Malaysia. She has taught many courses which include Linear Programming, Games and Networks, C++ Programming and Operational Research. Her main research interests are heuristics and hybrid methods for vehicle routing problems, analytical hierarchy process and supply chain management.

Dr. Norazlina Subani was born in Johor, Malaysia, in 1988. She received her B.sc in Mathematics (Honors) from University of Technology MARA (UiTM), Shah Alam, Malaysia. Later, she received her M.sc and P.hD in Mathematics from University of Technology Malaysia, Skudai, Johor, Malaysia in 2012 and 2017, respectively. She is currently a senior lecturer at GENIUS Insan College, Islamic Science University of Malaysia, Nilai, Negeri Sembilan, Malaysia. Her research main interests include mathematics (solving the analytical and numerical solution of partial differential equations in heat equation), applied mathematics (leakage detection in a pipeline), business mathematics and operational research.