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STUDY OF FLEET ASSIGNMENT PROBLEM USING A HYBRID TECHNIQUE BASED ON MONTE CARLO SIMULATION AND GENETIC ALGORITHM

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ABSTRACT
Fleet assignment problem (FAP) is the assignment of an aircraft model to each scheduled flight based on key operational variables such as cost, revenue, passenger travel demand and aircraft specifications. FAP is an important aspect of aircraft planning within an airline. While many developed economy have automated this planning task, developing economy such as Nigeria mainly depend on manpower to carry out this task. The aim of this paper is to solve a FAP using a hybrid technique based on the combination of Monte-Carlo (MC) simulation and Genetic Algorithm (GA). The objective function is total cost and variation in aircraft models and passenger traffic associated with different scheduled flight were considered. MC simulation which was carried out based on the numerical approximation of normal distribution cumulative distribution function (cdf) was used to estimate the expected passenger spill rate, while genetic algorithm was used for the optimization. The result was found to be satisfactory, as optimal fleet plan was achieved in approximately fifteen seconds of program run time, as against not less than an hour usually spend using human effort to solve FAP. Also the optimized plan resulted to a thirty percent saving in comparison to the actual plan implemented by the airline. It is therefore recommended that MC-GA optimization technique should be considered as an alternative technique applicable for FAP optimization.

Keywords: *Fleet assignment, genetic algorithm Monte-Carlo simulation, optimization*

1. INTRODUCTION

Fleet Assignment Problem is simply the assignment of an aircraft model to each scheduled flight based on the passenger demand, operating cost and planned revenue of each flight [1]. The outcome of an optimal fleet assignment exercise usually result to the establishment of the plan that minimizes the total operating cost or maximizes revenue as well as addresses linking problems between flight, such as flight gate assignment, aircraft maintenance route and crew assignment. Considering the important of fleet assignment, extensive research work has been carried out in many developing and developed countries located in Asia, Europe and America [2]. However, this trend of extensive FAP studies is presently lacking within countries located in Africa most especially Nigeria. The peculiar lack or limited FAP research scenario in Nigeria has been mainly attributed to smaller number of aircrafts among Nigerian airline operators, low local air travel patronage, which therefore result to limited route coverage. However, with some airline such Air Peace increasing their fleet size as well as opening more routes locally and internationally, the aviation competition on the increase, there is an urgent need for airlines especially in Nigeria to address airline operational, planning and management issues effectively. Generally, research on FAP has been studied in past from diverse perceptive.

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A robust mathematical model for FAP has been studied by Mou and Zhang [1]. Quiet a number of algorithms have been used by researchers globally to address FAP. Some of which includes improved Grover's algorithms, branch-and –price algorithm as well as genetic algorithm etc [2-5]. Li and Na [6] implemented partheno-genetic algorithm to solve flight string Vehicle Routing Problem (VRP) model using week as the time unit. Although quiet a number of literature and software based tool exist, which can be used for effective fleet planning, in Nigeria FAPs are usually performed with manpower, which therefore indicates a low level of automation. This paper therefore focuses on the use of Nigerian passenger traffic demand at various airports to establish foundation for aircraft planning and scheduling optimization research study within Nigeria. Hence, the aim of this paper is to solve FAP, through the establishment of the minimum total cost associated with using three (3) different aircraft models scheduled to fly thirty (30) flight legs within Nigeria. In this study optimization based on Monte-Carlo (MC)- Genetic Algorithm (GA) technique is proposed, to address FAP. In specific terms, Monte-Carlo simulation was used to estimate the expected passenger spill rate associated with using each aircraft model to fly each of the 30 scheduled flight, while GA was used to optimize the total cost.

2. METHODOLOGY

2.1 Research Design

This study employed historical research design. All collected data were analyzed using combination of Monte-Carlo (MC) simulation and Genetic Algorithm based optimization.

2.2 Data Collection

The seat capacity, revenue per available seat mile (RASM), cost per available seat mile (CASM) and the recapture rate were collected for three (3) aircraft models mainly B737-300, B737-500 and ERJ145. Furthermore 20 days passenger demand for 30 flight segment for an airline that prefers to remain anonymous as well as the distance between the two airports for each scheduled flight was collected.

2.3 Data Analysis

The fleet assignment optimization problem in this study was solved using genetic algorithm (GA). Section 2.3.1 - 2.3.7provides a detailed description of the study problem formulation as well as the GA implementation procedure.

2.3.1 Problem Formulation

This study fleet assignment problem was formulated in agreement with the simplified FAP proposed by ref [7] as given in Equation (1).

$$min \sum_{i \in y} \sum_{j \in h} c_{ij} x_{ij}$$

Subject to

$$\textstyle\sum_{i \in y} x_{ij} = 1 \qquad for\ j \in h \tag{1}$$

where:

$$x_{ij} = \begin{cases} 1 & if\ flight\ j\ is\ assigned\ to\ fleet\ i \\ 0 & otherwise \end{cases}$$

c_{ij} is the cost associated with assigning fleet type *j* to flight *i*

The total cost associated with operating an aircraft on any flight segment was computed as given in Equation (2).

$$c_{ij} = oc_{ij} + sc_{ij} \tag{2}$$

Where oc_{ij} and sc_{ij} are the operating and spill cost respectively. oc_{ij} and sc_{ij} were computed using Equation (3) and (4) respectively.

$$oc_{ij} = CASM_j + d_i + ns_j \tag{3}$$

$$sc_{ij} = esp_j + RASM_j + d_i + rr \tag{4}$$

Where $CASM_j$ is the cost per available seat miles for the *j* fleet type, $RASM_j$ is the revenue per available seat miles for the *j* fleet type, ns_j number of aircraft seat in aircraft model *j*, $d_i$is the distance between two airports in miles, esp_j is the expected passenger spill rate and rr is the recapture rate. The $esp_j$was computed using Monte-Carlo simulation, which was based on numerical approximation of a normal distribution cumulative distribution function (*cdf*), in agreement with ref [8]. Accordingly the normal distribution *cdf* was computed as shown in Equation (5)

$$z = \varphi^{-1}(p) = \begin{cases} 5.556 \times \left(1 - \left(\frac{1-p}{p}\right)^{0.1186}\right), & p \geq 0.5 \\ 5.556 \times \left(1 - \left(\frac{p}{1-p}\right)^{0.1186}\right), & p < 0.5 \end{cases} \tag{5}$$

Where Z is the normal distribution Z-score value and p is the probability value which was randomly generated in this work. Implementation of the MC simulation was carried out using an algorithm whose codes were written using MATLAB as presented below:

MC-Simulation Algorithm

Set value for $\bar{x}$ and σ
Set sum = 0
For I = 1-1000

Generate random number p

If $p \geq 0.5$

$$z = \varphi^{-1}(p) = 5.556 \times \left(1 - \left(\frac{1-p}{p}\right)^{0.1186}\right)$$

Else

$$z = \varphi^{-1}(p) = 5.556 \times \left(1 - \left(\frac{p}{1-p}\right)^{0.1186}\right)$$

End

$X = z \times \sigma + \bar{x}$

If $X \leq ns_j$

$b = 0$

Else

$b = X - ns_j$

End

Sum = Sum + b

End

$$esp_i = \frac{Sum}{1000}$$

where $\bar{x}$ and σ represent the mean and standard deviation associated with 20 days passenger demand on each flight segment considered (See appendix I).

2.3.2 Solution Encoding

The three (3) aircraft models used are represented by 1, 2, and 3, which correspond to B737-300, B737-500, ERJ145 respectively. The solution was encoded in a chromosome represented by a (1,30) matrix. Thirty (30) used represents the total number of scheduled flight. A possible FAP solution encoding is shown Figure 1. This represents a possible fleet assignment plan for the 30 scheduled flight with B 737-300, B737-500 and ERJ145 scheduled for flight legs (3,6,11,16,23,30), (5,8,14,17,21,28,29) and (1,2,4,9,10,12,13,15,18,19,20,23,24, 25,26,27) respectively.

[3 3 1 3 2 1 1 2 3 3 1 3 3 2 3 1 2 3 3 3 2 1 3 3 3 3 3 2 2 1]

Figure 1: Solution encoding

2.3.3 Initial Population

A population size of twenty (20) was used in this study.

2.3.4 Crossover

A crossover probability of 0.75 was used in this work as the breeding operator. A random number [0-1] window of same size with the chromosome was generated based on the breeding operator. Genes were exchange between parents at all points in the random number window corresponding to a random numbers greater is equal to the crossover probability (0.75) as shown in Figure 2.

[3 3 1 2 2 1 1 2 3 2 1 3 3 2 3 1 2 3 3 3 2 1 3 3 3 3 3 2 2 1]

[1 1 3 1 3 1 2 1 1 1 3 2 1 3 2 1 2 1 1 2 1 2 1 1 2 1 2 1 2 3]

[0.70 0.03 0.28 0.05 0.10 0.82 0.69 0.32 0.95 0.03 0.43 0.38 0.76 0.79 0.18 0.48 0.44 0.65 0.71 0.75 0.28 0.68 0.65 0.16 0.12 0.49 0.96 0.34 0.58 0.22]

[3 3 1 2 2 1 1 2 1 2 1 3 1 3 3 1 2 3 3 2 2 1 3 3 3 3 2 2 2 1]

[1 1 3 1 3 1 2 1 3 1 3 2 3 2 2 1 2 1 1 3 1 2 1 1 2 1 3 1 2 3]

Figure 2: Crossover

2.3.5 Mutation

The mutation operator executes random alterations to the generated off-spring using a simple mutation condition. The value within the solution matrix was randomly modified at a randomly generated mutation rate with values less or equal to 0.05. Random mutation operator of same size with the chromosome were generated with a MatLab function ***rand (1, 30)***. A gene with fleet type (FT) 1 or 2 at all points in which mutation can occur is converted to *FT+1* respectively. Otherwise are converted to *FT-1 (see Figure 3)*.

2.3.6 Genetic Algorithm

The genetic algorithm implemented in this study is given as shown below

Step 1*: Start with a randomly generated initial population of size. Set,*

Step 2: *Assign a fitness value for solution, by performing the following steps:*

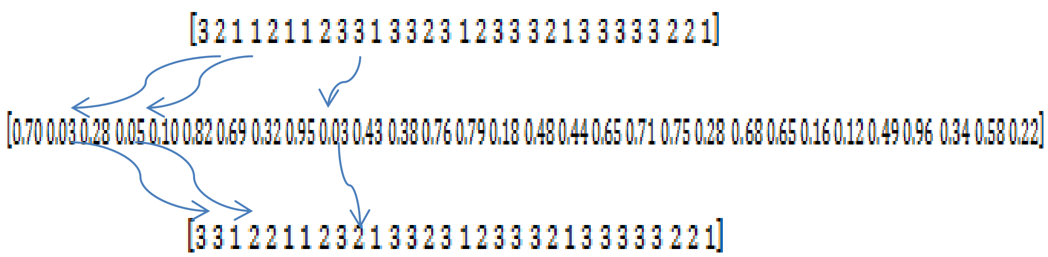

Figure 3: Mutation

- ***Step 2.1:*** *Calculate the fitness of the solution as*
- ***Step 2.2:*** *Calculates the selection probability of each solution as follow:*
- ***Step 2.3*** *Perform crossover and mutation on the selected parents based on their selection probability.*
- ***Step 2.4*** *Compute the fitness of the two offspring generated using Equation (6).*

$$\rho_{sx} = (f(x) - f^{min}) / \sum_{y \in P} (f(y) - f^{min}) \;\; where\ f^{min} = rr \qquad (6)$$

Step 3: *Insert the two offspring into an archive of size P, then compare the fitness values of the current off-spring with that of the existing solution in the archive and eliminate the weakest 2 solutions.*

Step 4: *If the stopping criterion is satisfied, return chromosome with the minimum total cost. Else go to Step 2.*

2.3.7 Termination Criteria

In this study the termination criteria is chosen to be 1000. This means that the program will stop after one thousand (1000) iterations.

3. RESULTS AND DISCUSSION

The FAP considered in this study was carried out using 2 Boeing and 1 Embraer aircraft models. The choice of these aircraft models was based on the fleet composition of the major domestic carrier in Nigeria (See Appendix II). Table 1 shows key information for the aircraft types considered.

Using Equations (2-4) the total operating cost per segment for the 30 segment considered in this work were obtained for the three (3) aircraft models (see **T**able 2). All airports were designated in agreement with International Air Transport Association (IATA) airport code as shown in **T**able 2. Implementation of the genetic algorithm described in section 2.3, the minimum cost required to operate the 30 scheduled flight was found to be approximately ₦26,453,060. This cost was reached after 443 iteration of the algorithm as shown in **F**igure 4.

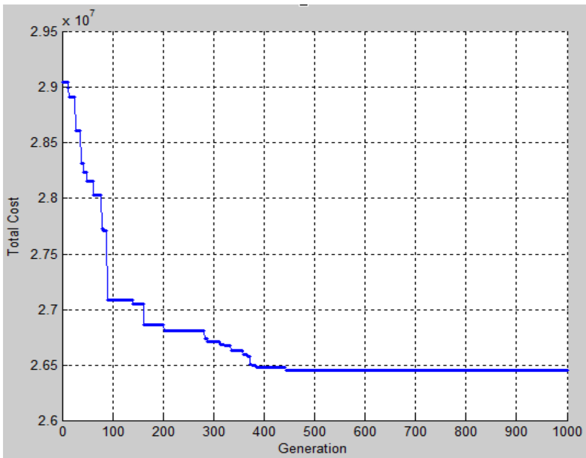

Figure 4: A plot of total cost against GA number of iteration

Subsequently, the fleet assignment plan that brought about the minimum cost of ₦26,453,060 associated with successfully running 30 segment is given in **T**able 3. The ₦26,453,060 optimized cost reached from this study represented approximately 30% saving when compared to the fleet plan implemented by the airline, which resulted to a cost ₦37,790,085. Thus, any deviation from this fleet assignment shown in table will result to a higher operational cost and should be discouraged. While in this study only three (3) and thirty (30) segments were considered. The written program can be adjusted to reflect any number of aircrafts and flight segment. The total time required to develop a flight plan using the condition set out in this study was 15seconds, which is considered extremely efficient in terms of time associated with reaching a flight plan in comparison to a minimum time of one (1) hour using human effort to solve the same problem.

Table1: Key information on the three aircraft models used in this study

Aircraft code	Aircraft model type	CASM	RASM	Recapture rate (*rr*)	Maximum passenger
1	B 737-300	27.1925	58.4	0.1	126
2	B 737-500	29.93	51.1	0.1	110
3	ERJ 145	33.215	43.8	0.1	50

Table 2: Cost associated with using each aircraft model to fly each scheduled flight

S/N	Scheduled flight	B737-300 (Naira)	B737-500 (Naira)	ERJ-145 (Naira)
1	LOS– ABV	1.1046e+06	1.0978e+06	1.2064e+06
2	ABV – LOS	1.1023e+06	1.0861e+06	1.1674e+06
3	LOS – BNI	5.2597e+05	5.1285e+05	4.8394e+05
4	ENU – LOS	9.9844e+05	9.6985e+05	9.8679e+05
5	KAD – LOS	1.3495e+06	1.3140e+06	1.4023e+06
6	QUO – ABV	9.5825e+05	9.2234e+05	7.6399e+05
7	QOW – LOS	8.9472e+05	8.8590e+05	9.1091e+05
8	ABV – BNI	7.8098e+05	7.5247e+05	6.0219e+05
9	PHC - ABV	1.0257e+06	9.9763e+05	8.7177e+05
10	KAN – ABV	7.7801e+05	7.4784e+05	5.6375e+05
11	LOS – PHC	9.4387e+05	9.2431e+05	9.8837e+05
12	CBQ – ABV	9.8581e+05	9.4736e+05	7.1549e+05
13	ABV – ABB	6.7430e+05	6.7073e+05	4.0168e+05
14	AKR – LOS	4.6136e+05	4.4336e+05	3.3047e+05
15	ABV – ENU	6.1910e+05	5.9546e+05	5.4191e+05
16	YOL – ABV	1.2130e+06	1.1761e+06	1.0670e+06
17	LOS – QUO	1.1199e+06	1.0765e+06	9.1814e+05
18	ABV – QOW	8.4455e+05	8.2172e+05	8.6562e+05
19	LOS – CBQ	1.2145e+06	1.1671e+06	7.9073e+05
20	QOU - LOS	1.1199e+06	1.0762e+06	7.4063e+05
21	QOW – YOL	1.5568e+06	1.4961e+06	9.4476e+05
22	ABV – YOL	1.2106e+06	1.1634e+06	8.9671e+05
23	LOS – ABB	7.8865e+05	7.5798e+05	5.1706e+05
24	CBQ – LOS	1.2145e+06	1.1671e+06	8.8613e+05
25	ABV – PHC	1.0219e+06	9.8878e+05	9.4339e+05
26	KAN – LOS	1.7921e+06	1.8232e+06	2.0912e+06
27	QOW – ABV	8.4446e+05	8.1898e+05	8.0991e+05
28	LOS – ENU	1.0026e+06	9.8673e+05	1.0119e+06
29	LOS – KAD	1.3486e+06	1.2981e+06	1.2605e+06
30	YOL - LOS	2.2283e+06	2.1414e+06	1.5244e+06

***T**able 3: Optimized fleet assignment plan*

S/N	Scheduled Flight	Assigned Aircraft
1	LOS– ABV	B737-500
2	ABV – LOS	B737-500
3	LOS – BNI	ERJ145
4	ENU – LOS	B737-500
5	KAD – LOS	B737-500
6	QUO – ABV	ERJ145
7	QOW – LOS	B737-500
8	ABV – BNI	ERJ145
9	PHC - ABV	ERJ145
10	KAN – ABV	ERJ145
11	LOS – PHC	B737-500
12	CBQ – ABV	ERJ145
13	ABV – ABB	ERJ145
14	AKR – LOS	ERJ145
15	ABV – ENU	ERJ145

S/N	Scheduled Flight	Assigned Aircraft
16	YOL – ABV	ERJ145
17	LOS – QUO	ERJ145
18	ABV – QOW	B737-500
19	LOS – CBQ	ERJ145
20	QOU - LOS	ERJ145
21	QOW – YOL	ERJ145
22	ABV – YOL	ERJ145
23	LOS – ABB	ERJ145
24	CBQ – LOS	ERJ145
25	ABV – PHC	ERJ145
26	KAN – LOS	B737-300
27	QOW – ABV	ERJ145
28	LOS – ENU	B737-500
29	LOS – KAD	ERJ145
30	YOL - LOS	ERJ145

4. CONCLUSIONS AND RECOMMENDATION

In this study fleet assignment problem was considered using three (3) aircrafts models and 30 scheduled flight within Nigerian. Monte-carlo simulation was used to predict the expected passenger spill rate for each aircraft model used in the study, which was subsequently used to compute the total cost, while genetic algorithm was used to optimize the total cost required to operate the three (3) aircraft models for the 30 scheduled flights considered. From the result it was concluded that the sum ₦26,453,060 is required to successfully use B737-300, B737-500 and ERJ145 to operate the 30 scheduled flights based on the optimized flight plan reached in this study. Also the optimized plan resulted to a thirty percent saving in comparison to the actual plan implemented by the airline. It is therefore recommended that MC-GA optimization technique should be considered as an alternative technique applicable for FAP optimization.

5. ACKNOWLEDGEMENTS

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APPENDIX I: TWENTY DAYS PASSENGER DEMAND FOR THE STUDY THIRTY SCHEDULED FLIGHTS

S/N	Segment	d_i (Miles)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	$\bar{x}$	σ
1	LOS– ABV	278.7	120	100	87	115	90	105	85	110	80	90	122	125	105	98	110	125	126	88	97	100	103	14.4
2	ABV – LOS	278.7	125	95	105	75	86	110	99	89	105	120	110	97	79	86	126	105	110	96	103	84	100	14.1
3	LOS – BNI	133	57	73	62	110	97	86	110	105	77	96	120	69	84	106	59	92	83	104	120	68	88	19.6
4	ENU – LOS	253	75	100	97	120	83	79	101	99	87	73	105	116	93	81	107	88	96	74	98	115	94	13.8
5	KAD – LOS	342	120	80	100	92	97	86	96	105	94	115	81	90	118	120	99	102	87	96	106	91	98	11.9
6	QUO– ABV	243	57	64	59	73	84	100	92	79	64	86	54	100	63	82	99	78	59	100	96	69	77	15.8
7	QOW– LOS	225	64	79	126	121	97	84	105	69	110	94	78	86	120	115	120	125	74	99	87	102	97	19.2
8	ABV – BNI	198	46	63	57	100	82	93	72	59	48	100	99	63	91	77	86	90	94	64	48	55	74	18.5
9	PHC - ABV	259	120	105	79	96	105	49	61	73	56	49	110	105	96	81	70	47	59	82	66	115	81	23.3
10	KAN– ABV	197.3	53	82	90	72	66	89	48	71	88	90	42	61	81	74	67	54	47	90	84	70	70	15.5
11	LOS – PHC	239	120	97	105	81	92	113	84	96	117	86	94	101	120	112	87	92	82	105	91	120	99	13.1
12	CBQ– ABV	250	80	75	61	73	66	62	77	68	72	80	77	64	72	63	79	63	69	74	80	71	71	6.4
13	ABV– ABB	177	65	70	41	56	36	63	57	70	39	45	68	54	69	38	70	38	70	54	62	42	55	12.5
14	AKR – LOS	117	73	54	82	68	85	71	62	59	79	83	62	70	59	63	85	73	57	71	64	85	70	9.9
15	ABV– ENU	157	93	100	73	82	100	64	87	75	92	99	80	64	79	92	71	86	92	100	71	96	84	11.9
16	YOL– ABV	307	62	84	59	71	97	101	88	120	112	87	92	54	63	82	98	71	118	97	72	63	84	19.4
17	LOS – QUO	284	96	72	100	87	64	92	63	79	81	90	72	85	74	63	60	72	78	92	84	93	79	11.8
18	ABV–QOW	214	81	96	87	110	105	86	93	120	82	107	98	80	96	113	87	92	116	86	94	117	97	12.5
19	LOS – CBQ	308	56	62	40	72	69	80	79	58	64	71	75	65	48	63	52	74	43	67	80	77	64	11.8
20	QOU - LOS	284	80	53	74	50	64	72	67	73	55	69	80	52	70	62	59	73	50	62	79	72	65	9.8
21	QOW–YOL	394.8	53	47	54	74	35	60	80	52	49	79	55	73	61	49	62	59	37	54	72	66	59	12.4
22	ABV– YOL	307	64	77	50	85	59	90	72	87	57	82	78	84	71	63	59	78	53	69	89	73	72	12.1
23	LOS – ABB	200	81	90	76	42	57	82	71	35	48	61	57	69	83	71	51	87	39	48	63	57	63	16.2
24	CBQ – LOS	308	63	50	71	66	84	90	77	63	83	57	72	87	64	57	72	83	58	74	88	74	71	11.5
25	ABV – PHC	259	105	83	72	98	60	88	104	120	93	112	69	89	75	69	86	92	110	93	79	87	88	15.6
26	KAN – LOS	451	108	110	97	121	113	120	102	126	99	126	124	111	92	108	125	123	100	117	93	90	110	12
27	QOW–ABV	214	96	102	86	77	110	97	72	86	70	113	120	92	88	79	86	74	74	93	121	89	91	15.1
28	LOS – ENU	253	102	98	87	110	78	70	86	122	124	114	96	82	70	97	117	78	88	79	98	124	96	17.3
29	LOS – KAD	342	92	85	70	92	100	97	72	83	110	92	107	78	100	92	86	92	73	81	102	91	89	11.1
30	YOL - LOS	565.1	73	64	80	57	40	63	74	80	76	63	59	69	49	68	72	89	80	53	65	72	67	11.6

Appendix II: Nigerian Airline Operators Fleet Size

Aircraft models→	Airbus	ATR		Beechcraft	Boeing										Bombardier			Dornier	Embraer		McDonnell Douglass		De Havilland			Total
Airlines↓	A319-100	ATR 42	ATR 72	1900D	737-300	737-400	737-500	737-700	737-800	737-Max	747-400	767-300ER	777-200ER	777-300	CRJ 900	CRJ 1000	Q 400	328-300	ERJ 145	Legacy 600	MD 82	MD 83	Dash 8-Q200	Dash 8-Q300	Dash 8-Q400	
Aero Contractor						1	2																1	1	2	**7**
Arik								9	4						4	1	4									**22**
Air Peace					8		5						1	1				1	6							**22**
Azman Air					2	2																				**4**
DANA Air																					1	3				**4**
First nation	2																									**2**
Medview							2	1				1	1													**5**
Overland		4	3	2																						**9**
Max Air					3	4														1						**8**