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RESEARCH ARTICLE

BI-OBJECTIVE GOAL PROGRAMMING FOR AIRLINE CREW PAIRING

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ABSTRACT

The crew cost constitutes 20% of the direct operating cost in airline operations after the aircraft fuel cost. Effective crew scheduling can save tens of millions of dollars to the airlines and result in low-cost flight tickets for the passengers and improved quality of life for the crew. The crew pairing requires addressing union expectations, company rules, regulations of countries' civil aviation authorities. In this study, bi-objective goal programming is proposed to minimize the number of crew to perform flights and minimize the flight pairings cost while addressing the challenging issues mentioned above. The integer set-covering goal programming model is formulated and solved using GAMS mathematical programming software. The results showed that the bi-objective model could provide significant cost advantages to airlines. The computational experiments have been performed over a set of real data.

Keywords: Airline crew scheduling, Airline crew pairing, Air Transportation, Integer linear programming

1. INTRODUCTION

Airline scheduling and planning problems solved sequentially consist of several sub-problems: the flight schedule design, the fleet assignment, the aircraft routing, and the crew scheduling. The main objective of solving these problems is to maximization of airline's profit [1, 2]. The airline sector has a narrow profit margin and fierce competition. Due to the high operating costs in the aviation industry, airlines are attempting to cut their costs in today's highly competitive market. Considering expenditures such as aircraft acquisition cannot be decreased, airlines must concentrate on their operational costs. Crew expenditures are one of the costs that airlines can control. The airlines that solve the crew scheduling problem optimal have advantages against their competitors and save millions of dollars.

Airline operational planning begins with the flight schedule design. The fleet assignment problem is solved by considering the flight schedule and passenger demands. Afterwards, aircraft are assigned to routes separately for each fleet, considering the maintenance constraints. The crew scheduling issue is addressed in the next stage. The crew scheduling problem is frequently broken down into two subproblems: crew pairing and crew rostering, which are solved in that order. The crew pairing issue creates the lowest-cost pairs that cover the schedule's grouping of flight legs, whereas the crew rostering problem merges the pairings into monthly crew schedules and allocates them to single crew members. This study focused on optimizing parings since pairing quality is much more effective than crew rostering on crew costs. However, some planning may become impracticable in advance due to aircraft malfunction, crew members not being on flight duty due to excuses, bad weather, air traffic or airport congestion. This situation is resolved daily by handling the aircraft and crew separately under irregular operations scheduling. In managing irregular operations, flight-to-aircraft rescheduling and crew rescheduling are solved sequentially. In the solution process of the problems encountered, resolving the problem of finding the flight sequence, dividing the sequences in the problem of finding the previous flight sequence into parts, using the reserve team members and flying the team to join the flight at the airport needed in the status of a non-income passenger [1, 3, 4, 5].

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The crew scheduling problem is the assignment of the crew to flight legs so that flights on a given flight schedule can be performed. The flight legs in the flight schedule represent a flight departing from a particular airport and arriving at another airport. While the cockpit crew consists of the pilot, co-pilot and flight engineer depending on the type of aircraft, the cabin crew consists of the steward and the flight attendant. These crews are scheduled separately. The number of flight crew required on the flight varies according to the size of the aircraft, the duration of the flight, the level of service for the cabin offered, and the departure time of the flight. The crew scheduling problem is examined in two separate steps: the crew pairing and the crew rostering problem [6, 7, 8, 9].

The crew pairing is a sequence of consecutive flight legs that starts and ends at the same crew base. The major airline companies' usually have more than one crew base. The crew pairing is changed between one to five days, depending on the airline. In this period, the crew member can spend some of the night resting in the city, outside the crew base. The period between the duties is called as flight duty in the crew pairing. Flight duty can be considered as a sequence of one or more flight assignments. However, the flight duty can be terminated within a few hours and may start at midday [10, 11].

Figure 1 shows the two-day crew pairing for the crew whose crew base is in Istanbul. The first duty covers three flight segments, and the second one covers two flight segments. Sit in the crew pairing refers to the time spent between flight segments. Resting is the interval of time in between daily duty hours. The period before the first flight of the pairing is called briefing, and the period after the last flight is called debriefing, and the crew completes the necessary documents related to the flight in this process.

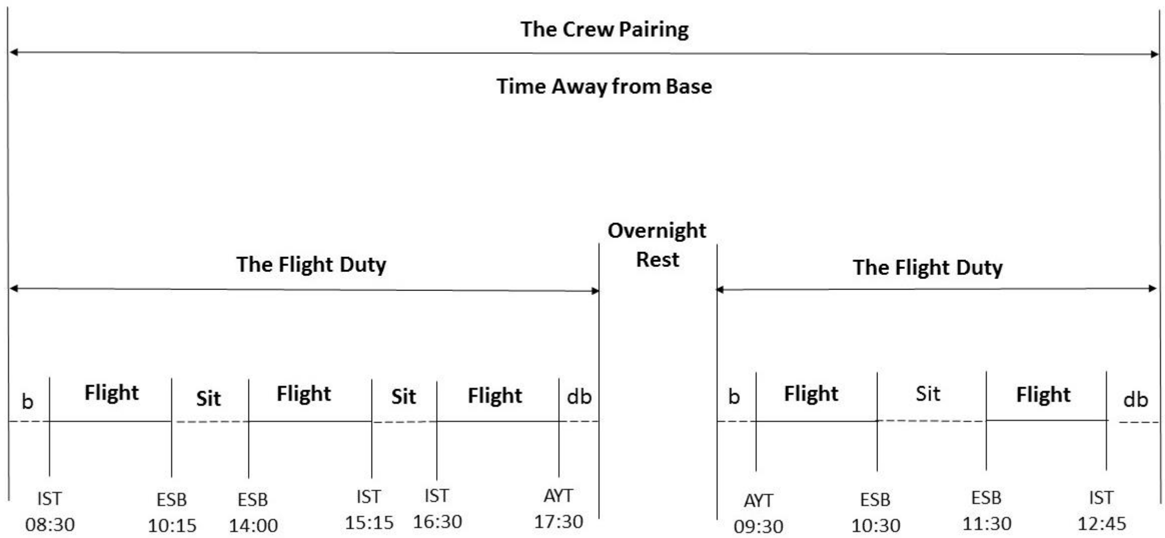

Figure 1. The two-day flight program for Istanbul crew base

The objective of the crew pairing is to find a set of crew pairings that cover all flight segments that the airline minimizes the crew cost. The crew cost covers the total flight cost, accommodation and meals cost between the duty period and the transportation cost to the airports. The time spent in flight by the crew is tried to maximize while the sitting time between the flight segments is attempted to minimize. The airlines try to keep the crews in the same aircraft in many flight legs as long as possible. As a result of the crew's participation in various aircraft, the risk of problems occurring due to flight cancellation or flight delays is reduced. The flight attendant must fly as a non-profit passenger to the necessary airport in these situations [10, 11, 12].

The crew scheduling problem in the literature is solved by using column generation algorithm, metaheuristics based on genetic algorithm and simulated annealing algorithm technics. Yan and Tu (2002) with a network model [13], Emden-Weinert and Proksch (1999) with simulated annealing [14], Caviqu et al. (1999) with tabu search algorithm [15] solved the crew scheduling problem. Vance et al. (1997) using Dantzig-Wolfe decomposition algorithm in the first stage of the flight duty periods and in the second stage by getting pairing from the duty period, provided a tighter linear programming boundary according to the set partitioning [16]. Desaulniers et al. (1999) modelled the main problem of the column generation algorithm as a set partition model and the sub-problem as a multi-commodity network model [17]. Klabjan et al. (2001) add a second object to the problem, which aims to repeat the flight plan along a weekly time axis [18]. Yan and Chang (2002) used the column generation method to solve the airline cabin crew scheduling problem [19]. Cordea et al. (2001) solved crew scheduling and aircraft routing problems simultaneously in their proposed approach, have benefited column generation algorithm [20]. Yildiz et al. (2017) developed a fatigue-based crew pairing model and conducted a comprehensive numerical analysis using real-world data [21]. Deveci and Demirel (2018) conduct a study of generic issue settings as well as operations research (OR) modeling and solution approaches for airline crew scheduling problem [22]. Quesnel et al. (2019) developed a branch-and-price heuristic, which solves the crew pairing problem on a monthly basis, considering the language constraint [23].

Wen et al. (2020) analyzed the effects of flight time fluctuation on crew pairings and proposed two novel pairing model based on column generation [24]. Parmentier and Meunier (2020) modified the integrated aircraft routing, and crew pairing problem-solving algorithm for Air France and solved the problem near to optimal [25].

Bi-objective goal programming is presented in this study to reduce the number of crew needed to run flights while also lowering the cost of flight pairs. The integer set-covering goal programming model is formulated and solved using GAMS mathematical programming software. The computer experiments have been carried out on a series of real-world scenarios. The crew pairing problem is addressed assuming that each flight segment is flown every day.

2. MATEMATICAL MODEL and DATA

The mathematical model developed for the problem discussed is given in this section. The primary objective of the crew pairing problem is to assign the crew to the flights to minimize the total crew costs, considering the crew scheduling regulations of the civil aviation authority. The objective function to be employed and the cost values or quantities to be used instead is one of the most important decisions to address the problem. Some studies use monetary value as the crew cost [26, 27]. On the other hand, some studies use time cost instead of monetary terms in crew pairing cost in the literature. The cost is determined in terms of time rather than money in these models, known as "pay-and-credit" models [28, 29, 30, 31, 32]. A pairing's cost is normally computed using the maximum value of flying time, the total elapsed time of the duty periods, and the TAFB. The Equation (1) was utilized to compute the crew pairing cost in this study [28, 29, 30, 31, 32, 33].

$$Crew\ Pairing\ Cost = Max\{TAFB \times TAFB_{Factor}, MDG, TFT\} \tag{1}$$

where,

- TAFM: Time Away from Base (minute)
- TAFM Factor = 0.6
- MDG: Minimum Duty Guarantee (180 minute)
- TFT: Total Flight Time (minute)

The daily crew cost is equivalent to duty cost since the daily crew pairing comprises one duty period. Three costs are calculated first for the pairing cost. The first pairing cost is 60% of the total time away from the base. The second is the minimum duty guarantee cost that should not be lower than 180 minutes for each pairing. The third one is the total actual flying time cost. The cost of the duty period is a certain percentage of the whole task time. If the real flight time in a duty period is greater than this value, the cost of the duty period is taken as this value, as this will create an extra cost. This value should not be less than the minimum time determined for each duty period. Therefore, when calculating the cost of the duty period, the maximum of these three values is taken. Thus, the costs of pairing are not linear.

The regulations of the countries' aviation authorities and the contractual rules of the airline companies with the unions determine the structure and cost of the legal duty periods and legal matching. The minimum guarantee pays and the guaranteed percentage of duty time or total percentage of flying time for the crew is determined by the agreements of the airline company with the unions within the scope of the criteria defined by the aviation authorities. These values for TAFM and MDG in this study were taken from studies in the literature [29, 30, 31, 32, 33]. Using different TAFM and MDG values will undoubtedly affect the costs and the number of teams required as it will change the rules to be generated in the pairing.

Apart from the constraints and rules that must be considered when creating crew pairings, cabin crew and cockpit crew pairings must be created separately. Pilots are only allowed to fly particular types of aircraft for which they have been trained. On the other hand, cabin crew can be assigned to any aircraft, as they are trained to work in basically any aircraft. In this study, crew pairing is considered for cabin crew.

In the model, the following notation is used:

Indices

- j index for the pairing ($j = 1, 2, \ldots, n$)
- i index for the flight ($i = 1, 2, \ldots, m$)

Sets

- F the set of flights
- P the appropriate set of the pairing

Parameters

- c_{j1} the cost of the pairing j ($c_{j1} = 1$, for all $j \in P$)
- c_{j2} the cost of the pairing j (c_{j2}, calculated according to Equation (1))
- $a_{ij} = \begin{cases} 1, & \text{if the flight } i \text{ is covered by the pairing j} \\ 0, & \text{the others} \end{cases}$
- Z^{*1} The optimal value of the minimum pairing ($c_j = 1$, for all $j \in P$)

Decision Variables

$$x_j = \begin{cases} 1, & if\ the\ pairing\ j\ is\ selected, \quad j = 1, 2, \ldots, n. \\ 0, & the\ others \end{cases}$$

With this notation, the problem formulation becomes

$$\sum_{j \in P} a_{ij}\, x_j \geq 1 \qquad \text{For all } i \in F \tag{2}$$

$$\sum_{j \in P} x_j \leq Z^{*1} \tag{3}$$

$$x_j \in \{0, 1\} \qquad \text{For all } j \in P \tag{4}$$

$$Min \sum_{j \in P} c_{j1} x_j \qquad (5)$$

$$Min \sum_{j \in P} c_{j2} x_j \qquad (6)$$

The constraint set (2) guarantees at least one crew pairings cover the flights. The constraint group (3) ensures that the crew pairing number is equal to or less than the minimal crew pairing number. Decision variables are defined as binary variables by constraint (4).

The first mathematical model minimized the number of crew numbers. This model consists of the objective function (5), the constraint (2) and (4). In this model, the crew pairing cost equals 1 for all pairing.

The second mathematical model minimized the cost of the crew pairing. This model consists of the objective function (6), the constraint (2), (3) and (4). The cost of crew pairing is computed using the equation (1).

The bi-objective model consists of two models that are solved sequentially. The first model minimizes the number of crew in the solution space formed by the decision variables. The second model is run in a way that minimizes costs in the same solution space, considering the minimum number of crew required to perform the flights with constraint (4).

2.1. Problem Data

The pairing and the duty period must comply with the union, the aviation authority regulation and the airline rules. The crew scheduling is prepared to consider the Turkish General Directorate of Civil Aviation and international aviation regulations. The basic rules of regulation considered within the scope of the study are as follows [34]:

- The preflight meeting (briefing) at the beginning of the flight duty period, where the flight details were shared and prepared, was taken as a minimum of 60 minutes.
- The debriefing at the end of the flight duty period was taken as a minimum of 30.
- The flight duty period was taken as 14 hours (840 minutes) for (1-4 landings) and 13 hours (780 minutes) for (5 landings).
- The maximum number of flight segments in duty is considered five, and the sitting time between two-flight segments is considered minimum ½ hours and maximum as 4 hours.
- Each pairing must start and end at the same crew base.
- For the maximum flight time, the restrictions in the flight crew flight duty, rest periods, and implementation principles instruction published by the General Directorate of Civil Aviation and shown in Table 1 were considered.

Table 1. Maximum flight time and flight duty period [34].

	Weekly (Hours)	Monthly (Hours)	Three Months (Hours)	Yearly (Hours)
Flight Duty Period	56	210	500	1800
Flight Time	36	110	300	1000

- Pass flight duty (deadheading) times were considered flight duty times. A deadheading crew member is a passenger who is not a member of the working crew and is being relocated by the airline as part of a workday or flight duty.
- The departure of a flight segment should occur after the arrival of the previous segments of the flight duty.

Table 2. The schedule for 42 flights

Flight Number	From	To	Departure Time	Arrival Time	Flight Number	From	To	Departure Time	Arrival Time
1	IST	ADA	16:55	18:10	22	GZT	IST	12:35	14:05
2	ADA	IST	18:40	20:00	23	IST	ADB	6:55	7:45
3	IST	ESB	9:55	10:45	24	IST	ADB	18:30	19:30
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
19	DIY	IST	17:40	19:25	40	ESB	IST	21:10	22:00
20	DIY	IST	17:00	18:45	41	IST	ESB	15:50	16:40
21	IST	GZT	10:40	12:05	42	ESB	IST	17:15	18:05

Table 3. The schedule for 76 flights

Flight Number	From	To	Departure Time	Arrival Time	Flight Number	From	To	Departure Time	Arrival Time
1	IST	ADA	06:30	08:00	39	GZT	IST	09:10	10:55
2	IST	ADA	15:15	16:45	40	GZT	IST	22:35	00:20
3	IST	ADA	20:20	21:50	41	ADB	IST	08:30	09:30
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
28	ADA	IST	17:40	19:10	66	ESB	IST	17:00	18:00
29	ADA	IST	22:30	23:55	67	ESB	IST	18:00	19:00
30	AYT	IST	08:30	09:30	68	ESB	IST	19:00	20:00
31	AYT	IST	12:35	13:45	69	ESB	IST	21:00	22:00
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
36	DIY	IST	09:25	11:10	74	DIY	ESB	11:30	12:45
37	DIY	IST	21:40	23:25	75	ESB	ADB	13:45	15:00
38	ERZ	IST	14:55	16:45	76	ADB	ESB	16:00	17:15

Flight data is the actual flight schedule published by two commercial airlines providing domestic flight services in Turkey. Although the starting-destination point, destination-starting point on a route in the program is the same, the flight time may differ. For example, in Table 3, IST-ADA takes 1h 30 min, ADA-IST takes 1h 25 min; similarly, AYT-IST takes 1h 00 min or 1h 10min according to departure time or arrival airport. Airlines assess the difference in taxi times based on the density at the arrival or departure airport, the air traffic density on the flight routes, and the impact of the wind from behind or from the opposite direction during the flight when determining the flight schedule. Table 2 and Table 3 present data sets for 42 and 76 flights, respectively, based on the IATA code of the airports. The flight schedules include flights to 10 and 16 domestic Turkish airports.

3. RESULTS and DISCUSSION

GAMS/CPLEX integer linear program solution software was used to solve the problems. The acquired experiment findings have been presented and interpreted.

The legal pairings have been created according to the Turkish Directorate General of Civil Aviation regulations. The number of flight segments in duty is allowed to be 2, 3, 4 and 5. The cost of each pairing is also calculated according to the equation of (1). The minimum number of crew pairing is found using the first mathematical model. After adding the minimum number of crew pairing to the second model as a constraint, the crew pairing cost is minimized. The model results have been compared according to the number of crew pairing, deadheading and cost. Models were run on a computer with Intel Xeon 3.50 GHz, 16 GB Ram 64-bit processor. The solution times of the models are 3.76 minutes and 67.8 minutes for 42 and 76 flights, respectively.

Two data sets were examined within the scope of the study. In the first data set consisting of 42 flights, first of all, the legal crew pairings were determined as 144 using GAMS. Using the first mathematical model, the minimum number of crew pairings required to complete the flights in the flight schedule was determined as 12. In this model, the crew pairing costs were assumed to be equal to each other as one. However, considering the cost of each crew pairing according to the crew pairing generator, the crew pairing cost of the first model emerges as 3,714.55 minutes. When the second mathematical model was run by adding the minimum number of crew pairing required to perform the flights as a constraint to the model and considering the real cost of each pairing, the total crew pairing cost was determined as 3,282.84 minute. When the first and second models were compared in terms of the total cost, 11.62% savings are achieved with the bi-objective model. Both mathematical models determined the number of crew required to complete the flights as 12. When compared with the number of deadheading flights to be performed by the crews, the first model produced a solution that included 6 deadheading flights and the second model 2 deadheading flights. Table 4 shows the optimal crew pairings for 42 flights, in which each flight leg is covered exactly by one crew.

Table 4. The optimal crew pairings for 42 flights

No	The flight assigned to the crew pairings			
1	28	30	-	-
2	35	36	-	-
3	1	2	15	16
4	3	31	32	42
5	11	13	4	38
6	12	14	7	9
7	17	19	8	10
8	18	20	39	40
9	23	25	21	22
10	37	5	27	29
11	37	6	24	26
12	41	33	34	40

The second dataset consists of 76 flights. When the first model was run to determine the minimum number of the crew with the same cost, the required number of crew pairing was found to be 20. Adding the minimum number of crew pairing determined in the first model as a constraint and considering the actual costs of the crew pairings, the second model was run, and the total crew cost was determined as 5,871.18 minutes. When the two models were compared, 4.54% savings were achieved with the bi-objective model. When both models were compared in terms of deadheading flight, both models suggested the same number of crew pairing. However, the crew pairings model with real crew cost was run without the constraints of minimum number of crew pairing, the number of crew increased by 10% to 22. As a result, the bi-objective model offers successful results in terms of the number of crew and crew costs. The optimal crew pairings in which each flight leg is covered exactly by one crew for 76 flight is given in Table 5.

Table 5. The optimal crew pairings for 76 flights

No	The flight assigned to the crew pairings				
1	25	51	-	-	-
2	26	52	-	-	-
3	1	27	23	49	-
4	2	28	20	46	-
5	4	30	12	38	-
6	6	32	3	29	-
7	8	34	18	44	-
8	9	35	60	69	-
9	10	36	24	50	-
10	13	39	56	65	-
11	15	41	16	42	-
12	19	45	21	47	-
13	53	61	55	64	-
14	53	62	5	31	-
15	55	63	22	48	-
16	57	66	11	37	-
17	58	67	14	40	-
18	59	68	7	33	-
19	17	76	71	72	70
20	54	73	74	75	43

4. CONCLUSION

The aviation industry is a sector with very low-profit margins, and airlines that can optimally solve scheduling problems can gain advantages over rival airlines. The crew costs have a significant share in the operation costs. The small proportion of the cost savings can have vital importance for the airline.

A mathematical-model-driven method to minimizing airline crew pairing costs is presented in this paper. The results showed that airlines could significantly reduce both the number of crew and crew costs, and achieve significant savings. It has been shown with the proposed approach that 4.54% and 11.62% savings can be achieved in terms of cost in problem sets consisting of 42 and 76 flights within the scope of the study. According to the analyzed problem sets, it has been revealed that when the bi-objective model is used, savings that will also provide advantages to the airlines in the number of crew and deadheading flight flights can be achieved. As a result, airlines can carry out their operations with less crew and allocate the aircraft seat to the passenger, where they can generate income from the passenger by reducing the number of deadheading flights.

The proposed approach is an integer models, the number of decision variables and constraints, depending on the model size is exceeded a certain optimization method known means may be insufficient. When the problem size grows, the decomposition, parallel optimization and metaheuristic methods should be considered.

CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

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