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Research Article

Optimization of Crew Assignment Problems in Aviation: A Mini Review Study

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Abstract – Planning and management of airline operations are of strategic importance for airline transportation. Problems such as fleet planning, crew search, flight scheduling and routing are among the basic elements of aviation operations and need to be managed in detail. Each problem has various constraints and with limited capacity, these processes need to be developed with maximum efficiency, minimum cost, minimum resource utilization and maximum customer satisfaction. In addition, these objectives are very difficult to achieve in the aviation industry where high safety and security are required. Many of these problems are classified as NP-Hard and have been intensively studied by researchers. Many optimization techniques are used to solve these problems. In this paper, a review of the crew assignment problem in aviation operations is presented and the problem is investigated in relation to flight assignment, fleet management and routing processes. The problems encountered in the processes and their solutions are presented to the researchers based on the studies in the literature. This article is based on studies conducted in 2020-2024. The application of optimization techniques is of great importance for the successful integration of these processes, timely and safe airline operations, competition and sustainable aviation. The study aims to raise awareness about the development and orientation of crew assignment problems in aviation and the characteristics of the applied methods.

Keywords – Optimization, Sustainable Aviation, Crew Assignment Problem, Fleet Management, Flight Scheduling.

I. INTRODUCTION

Crew Assignment Problem (CAP) is a strategic optimization problem encountered in complex systems where operations are carried out with limited resources. In land, sea, air and rail transportation, the assignment of crews to specific slots is of great importance in terms of time, cost, continuity and efficiency. In addition, CAP acts as a cornerstone in terms of increasing customer satisfaction, ensuring occupational health and safety criteria, maintaining and improving service quality. The problem involves many constraints such as time, cost, number of personnel, number of shifts, legal procedures and efficiency.

The aviation sector is a transportation sector with heavy traffic, where time is limited and competition is high. In this sector, assigning flight crew, cabin crew and maintenance crew to the right task at the right time is of strategic importance for flight safety, customer satisfaction and process efficiency. CAP covers a wide range of areas from technical requirements to legal obligations and is highly interrelated with many branches, especially flight scheduling, fleet assignment and ergonomics. Constraints such as pilots' and cabin crew's rest times, maintenance crew routing, number of shifts, personnel licenses and flight schedules increase the complexity of the problem. In addition, sudden changes such as delayed or canceled flights are factors that increase the uncertainty and dynamism in the CAP. Sustainable aviation objectives and the creation of flight schedules and crew assignments in this context make the CAP more difficult and take it to a different dimension.

In this paper, the problem of assignment of crew members serving in air transportation, the criteria considered in CAP and the techniques for solving the problem are discussed by considering the studies conducted in the literature in 2020-2024. In the next section, some of the studies on the subject in the relevant years are given.

II. LITERATURE

Zeighami et al. tried to solve the CAP based on the preferences of pilots and co-pilots and developed a hybrid algorithm consisting of Lagrange decomposition, column generation (CG) and dynamic constraint aggregation (DCA) methods. They applied the proposed approach on data obtained from a real-life airline [1].

Desaulniers et al. developed a hybrid method using (CG) and (DCA) techniques for the crew matching problem (CPP), where scheduling is done on a monthly basis. They considered the time window and tested the method on a real problem consisting of 46588 flight data. It was observed that the hybrid method is effective in problems where time window constraints are taken into account and improves the solution quality [2].

Chutima and Arayikanon considered the problem of scheduling cockpit crew working days and tried to optimize four different objectives. The objective function is formed by the outputs of cost minimization, pilot preferences, balanced distribution of workload among pilots and reduction of repetitive flight patterns. They solved the multi-objective problem with a hybrid approach integrating MOEA/D and HBMO methods and stated that the proposed method achieved optimal values in each objective [3].

Wen et al. considered the flight duration uncertainties in CPP in terms of time and number of flights and developed two different models for each. Each method utilizes a column generation algorithm. An application study using real flight data showed that the proposed approaches are effective in dynamic problems with flight delays [4].

Aggarwal et al. tried to solve the CPP with a CG-based modular software called AirCROP. They aimed to improve the solution quality, reduce the solution time and obtain information about the model parameters. In the application study, they considered 4200 flight data and 15 crews and tested the proposed method on this problem [5].

Beulen et al. solved the CAP problem using an artificial neural network algorithm and considering pilot preferences. A model based on linear programming was used in the method and a scenario-based study was carried out in an airline serving in Europe. The results of the analysis showed that, thanks to the method applied, more than 22% more demand was met with the same capacity of personnel. According to these results, both cost savings were achieved and staff satisfaction was increased [6].

Saemi et al. tried to find the optimum in a single model by integrating CAP and CPP in a single model. In the CPP, they took into account the intervals given due to personnel leave days, training periods and health checks. They used Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) metaheuristics and stated that PSO gives better results than GA in terms of solution quality and processing time [7].

Mallicka et al. considered the CAP for passenger buses and tried to solve it in line with the minimum cost and maximum profit objective and used the Hungarian Algorithm. As a result of the scenario study, they stated that the minimum waiting time is 33.30 hours [8].

Guimarães and Gualda minimized costs with a heuristic approach for airline recovery problems. In the problem, the networks for airplanes and passengers are considered and they tested the proposed method with real-life ROADEF data. The results show that the simultaneous consideration of the two networks balances the costs and results in lower costs [9].

Kiarashrad et al. applied the tabu search method to the airline fleet assignment problem by considering flight scheduling and ticket policy criteria and tried to maximize the airline's profit [10].

Chin used linear programming for CAP in the air force. In the fitness function of the model, they considered the maximization of training needs and minimization of over-qualification. In the study, the shortcomings of the currently used method were identified and tried to be eliminated [11].

Pereira solved a mix integer linear programming (MILP) problem of assigning aircraft based on the maintenance period of their components and the prediction of possible failures. In the problem, they considered aircraft fleets with more than one shareholder, uncertain situations and dynamically changing situations. As a result of the scenario-based studies, they found that taking into account the failure prediction positively affects the unscheduling process and reduces flight costs [12]

Zhou et al. considered both balanced distribution of workload and maximization of staff satisfaction within the CAP and used ant colony system (ACS) algorithm, multi-population and multi-objective ACS (MOACS) techniques. The application results show that the MOACS methodology outperforms traditional greedy heuristic algorithms and other population-based algorithms. [13].

Abdullahi et al. addressed the general assignment problem using the CPLEX method and aimed to minimize costs. They tested the proposed method in Kaduna metropolis[14].

Wen et al. used a column generation algorithm to solve the CAP and maximized the labor utilization while minimizing the costs of the objective function. They developed large-scale scenarios considering real flight information and showed that the proposed approach produces better results than traditional methods [15].

Pereira et al. considered CPP for the minimum flight cost objective using goal programming. They concluded that by improving branching strategies, better results can be obtained compared to greedy heuristics [16].

Dixit chose AIRINDIA airline company as an application study and addressed the problems in this company. The main scope of the problems were crew assignment, routing of airplanes and development of maintenance policies for airplanes. They used the methods of Vogel and Modi for the generation of routes and proposed a profit maximizing model for solving the CAP and used the Hungarian Algorithm. In addition, they proposed several strategies for the reduction of maintenance operations [17].

Yarong utilized the network flow model and column generation algorithm to solve the unit scheduling problem. They considered conditions such as legal requirements and passenger satisfaction in the problem [18].

Batelaan and Dollevoet used the set partition model, column generation and shortened branch-and-price algorithms to solve CAP. They utilized a clustering approach to solve the problem, which resulted in an improvement in computation time [19].

Glomb et al. used mixed integer mathematical modeling and a decomposition algorithm to optimize the assignment of aircraft to flights and return processes in terms of dynamic situations. They stated that thanks to the proposed model, optimal solutions are obtained in shorter times. In the study, they focused on the minimization of flight costs [20].

Ercsey and Kovács addressed the dynamic workforce assignment problem and modelled the problem with multicommodity network flow and mixed integer programming. In the problem, the criteria of equal distribution of the workload and the comfort of the employee are taken into account and it is determined how much time the personnel work in which time interval [21].

Helmrich et al., 2022, discussed the planning crisis experienced by Southwest Airlines, which resulted in the cancellation of 15000 flights. They stated that there were delays in flights due to bad weather conditions and the software that assigns the crew broke down. As a result of the analysis, they presented in their study that such problems can be overcome with dynamic software and solution strategies [22].

Wang et al. tried to solve CAP with a mathematical modeling approach using an annealing simulation algorithm and tried to minimize flight disruptions, staff shortages and the use of temporary qualifications [23].

Ahmed et al. developed the Column Penalty Method (CPM) and aimed to solve CPP and CAP in less time [24].

Zeren et al. solved CAP with a greedy heuristic and genetic algorithm and tested the methods on large-scale data from Turkish Airlines [25].

Lin et al. considered the fatigue level of pilots in MAP and solved the problem with MILP. They developed a three-step vigilance calculation formula to detect fatigue in pilots. The proposed mathematical model was tested on real airline data and the results proved the effectiveness of the proposed method [26].

Xu et al. conducted a survey study considering flight scheduling, fleet assignment and routing of aircraft within the fleet and MAP I and analyzed the sub-problems of these problems [27].

Pan et al. stated that MAP is a combinatorial optimization problem, computation time and costs increase as the size increases and traditional methods are insufficient. In the article, they prepared a review of the use of machine learning methods in MAP and the studies on this subject [28].

Thakkar and Palaniappan addressed the aircraft routing problem using dynamic programming and reinforcement learning (RL) techniques. They avoided delays by taking into account customer feedback and created routes accordingly [29].

Sciau et al. used a constraint programming approach to optimize maintenance processes in airline companies. They tried to minimize deviations in resource utilization and scheduled maintenance times in the objective function. They tested the approach on real data and concluded that the approach produces better results than existing solutions [30].

III. SOLUTION METHODOGIES AND PROBLEM SPESIFICATIONS

In this section, the approaches used to solve the problem are systematized and shown in Table 1. In this section, the approaches used to solve the problem are systematized and shown in Table 1. According to the table, it is seen that artificial intelligence algorithms, metaheuristic algorithms, linear programming, mathematical modelling and operations research techniques are used to solve the problem. Especially column generation algorithm and mixed integer programming were found to be frequently used in solving the problem. The reason for this is attributed to the success of the column generation algorithm in large size problems.

Table 1. Methods used in solving the CAP between 2020-2024

		Solution Methodology																									
Article	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
[1]	2020	X	X	X											X												
[2]	2020		X	X											X												
[3]	2020				X	X									X												
[4]	2020		X																								
[5]	2020		X																								
[6]	2020						X	X																			
[7]	2021									X	X																
[8]	2021											X															
[9]	2021												X														
[10]	2021													X													
[11]	2021							X																			
[12]	2021								X																		
[13]	2020												X			X	X										
[14]	2024																	X									
[15]	2022																										
[16]	2022												X						X	X							
[17]	2022											X															
[18]	2022		X																		X						
[19]	2023		X																	X							
[20]	2023								X													X					
[21]	2024								X																		
[22]	2023																										
[23]	2024								X														X				
[24]	2024																							X			
[25]	2024									X			X														
[26]	2024								X																		
[27]	2024																										
[28]	2024																										
[29]	2024																								X	X	

In addition to the above methods, it has been determined that Hybrid Algorithms are frequently used in solving MAP and give effective results. It has been determined that Artificial Intelligence and Machine Learning algorithms are rarely used in solving the problem and researchers should work on this issue.

Table 2. Index description of the columns in Table-1

Index	Methodologies	Abbreviation	Index	Methodologies	Abbreviation
1	Lagrange Approach	LA	14	Hybrid Algorithm	HA
2	Column Generation	CG	15	Ant Colony System	ACS
3	Dynamic constraint aggregation	DCA	16	Multi-objective ACS	MOACS
4	Multi-objective evolutionary algorithms based decomposition	MOEA/D	17	CPLEX	CPLEX
5	Honeybee Mating Optimisation	HBMO	18	Goal Programming	GOAL
6	Artificial Neural Network	ANN	19	Branch and Bound	BB
7	Linear Programming	LP	20	Network Flow Model	NFM
8	Mix Integer Linear Programming	MILP	21	Decomposition Algorithm	DA
9	Genetic Algorithm	GA	22	Simulated Annealing	SA
10	Particle Swarm Optimization	PSO	23	Column Penalty Method	CPM
11	Hungarian Method	HM	24	Dynamic Programming	DP
12	Heuristic Algorithm	HEA	25	Reinforcement Learning	RL
13	Tabu Search	TS	26	Constraint Programming	COP
14	Hybrid Algorithm	HA			

Table 3 summarizes the objectives considered in the studies conducted in relation to MAP between 2020 and 2024. According to the table, minimization of time and cost has been the most considered objective in the studies. Balanced distribution of workload and delays in flights or different indicators were another objective that received high priority. Balanced distribution of workload among the personnel and cockpit crew preferences were another high priority objective considered in the MAP.

Table 3. The features considered in the CAP for 2020-2024

	Specification													
Article Index	Pilot preferences/ fatigued state	Balanced distribution of workload	Cost /Time minimization	Monthly scheduling	Delays	Vacation days, training	Maximum Profit	Airline Rescue	Maximization of training requirements	Maximum Profitability	Satisfaction maximization	Maximum Capacity	Minimization of total pairing	Survey
[1]	X													
[2]				X										
[3]	X	X	X	X										
[4]					X									
[5]			X											
[6]	X													
[7]						X								
[8]			X				X							
[9]														
[10]							X							
[11]									X					
[12]			X							X				
[13]		X									X			
[14]			X									X		
[15]			X											
[16]			X											
[17]										X				
[18]		X	X								X			
[19]													X	
[20]			X											
[21]		X									X			
[22]														
[23]					X							X		
[24]														
[25]														
[26]														
[27]														X
[28]														X
[29]					X									
[30]			X		X									

IV. LITERATURE

In this paper, a mini-survey for MAP is conducted and the evolution of the problem between 2020 and 2024 is analyzed. In the survey, the scope of the researches is defined and the methods used and the objectives considered in these researches are expressed in tables. As a result of the survey, it was found that the column generation algorithm and mixed integer programming were used extensively in solving the MAP problem, while the objective function focused on cost minimization, workload balancing and pilot preferences. The MAP problem is a high-risk, costly and time-consuming process for the aviation industry. Solving the problem quickly in a short time and obtaining optimal results is of great importance for aviation. With the advances in technology and artificial intelligence, it is foreseen that different constraints and objectives will be taken into account in MAP. In addition, it is predicted that better quality and faster solutions will be obtained by using machine learning and artificial intelligence techniques in solving the problem and hybridizing them with metaheuristic algorithms.

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