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AIRCRAFT MAINTENANCE ROUTING PROBLEM – A LITERATURE SURVEY

ABSTRACT

The airline industry has shown significant growth in the last decade according to some indicators such as annual average growth in global air traffic passenger demand and growth rate in the global air transport fleet. This inevitable progress makes the airline industry challenging and forces airline companies to produce a range of solutions that increase consumer loyalty to the brand. These solutions to reduce the high costs encountered in airline operations, prevent delays in planned departure times, improve service quality, or reduce environmental impacts can be diversified according to the need. Although one can refer to past surveys, it is not sufficient to cover the rich literature of airline scheduling, especially for the last decade. This study aims to fill this gap by reviewing the airline operations related papers published between 2009 and 2019, and focus on the ones especially in the aircraft maintenance routing area which seems a promising branch.

KEYWORDS

airline operations; airline scheduling; aircraft maintenance routing.

1. INTRODUCTION

The airline industry impacts the welfare level of countries with its numerous economic and social benefits. According to the Air Transport Action Group [1], this industry creates 65.5 million jobs worldwide and contributes approximately 2.7 trillion dollars a year to the world Gross Domestic Product. Additionally, developing social networks, creating new trade links, fast and reliable access to remote parts of the world, tourism, and environmental sustainability are some of the other benefits of this industry in which inevitable progress continues day by day. One of the indicators of this progress is that annual average growth in global air traffic passenger demand was 5.84% between 2006 and 2019 [2]. According to the second indicator, the growth rate of the global air transport fleet in the Middle East will be 5.6% by 2023 [3].

This progress in the airline industry forces companies to take a range of precautions to increase their market share in this sector. These precautions such as reducing costs, preventing delays, improving service quality, decreasing environmental impacts, etc. vary depending on airline operation type. Airline operations are classified as Flight Scheduling Problems (FSP), Fleet Assignment Problems (FAP), Maintenance-Repair-Overhaul (MRO) activities, and Crew Scheduling Problems (CSP). To expand the scope of this study, it would be useful to include schedule recovery operations, and Air Traffic Control Problems (ATCP) in the current classification. Although such operations have been studied for several years, the challenge still exists because of the increasing size of the industry and the high complexity of airline networks. In this context, the fact that the abovementioned reviews do not contain the rich literature of the last decade constitutes the basis of this study. For this reason, in this study, firstly the studies published on airline operations between the years 2009 and 2019 were examined to get an idea at a general level, and then the studies related to the Aircraft Maintenance Routing Problem (AMRP) were investigated in more depth due to the following reasons.

- Recently, aviation and airline maintenance providers are some of the most significant worldwide industries.
- MRO costs can vary between 10 and 45% depending on the aircraft type [4] and its age. This means that a lack of coordination and planning in MRO activities can cause monetary losses and also adversely affect the airlines brand.

Factors such as loss of life, reputation cost, monetary loss, etc. have caused the aviation industry to focus on maintenance operations lately. Otherwise, the increasing number of planes and passenger demand would probably have cause for greater catastrophes. Over the last 10 years, the airline industry has improved its overall safety performance by 54%. The accident rate in 2016 dropped to 1.61, compared to 3.53 accidents per million flights in 2007 [5]. Because of this situation, which shows the importance of MRO activities, the focus of this review has been determined to be the studies on Aircraft Maintenance Routing (AMR) operations. Based on this information, this paper is organised as follows: Section 2 outlines the methodology applied. Section 3 is devoted to some preliminary findings, while section 4 provides a detailed analysis of AMR studies. A discussion part is presented in section 5 and finally, conclusions are drawn in section 6.

2. SURVEY METHODOLOGY

Before searching the relevant studies in the literature, a schema was created. During the review, ScienceDirect, Springer, Institute of Electrical and Electronics Engineers (IEEE), Emerald, and Google Scholar databases were investigated and in the end, 117 papers which were published in international journals or conference proceedings during the 2009–2019 period were identified. Finally, these papers were analysed, classified, and recorded under the designed schema.

3. PRELIMINARY FINDINGS

The main purpose of this article is to conduct a literature review covering the last 10 years for a single type of airway operation. This section is therefore devoted to one thing: To determine the type of airline operation which is focused more in order to justify the next section's subject. Therefore, in this section, we tried to determine the areas on which the 117 studies are concentrated the most.

3.1 Focused area(s)

In the previous sections, it was stated that the airline industry is a sector that is constantly developing due to its possible economic and social effects. This situation triggers the efforts of companies operating in this field to increase their market shares and therefore leads to the emergence of new solutions that increase customer satisfaction, reduce costs, and prevent delays as much as possible. These developments are a product of academic studies in different areas of the airline industry. *Table 1* displays the aforementioned studies conducted between 2009 and 2019, and the types of operations focused on in these studies.

The first judgment that can be drawn from *Table 1* is whether academics prefer to work in one field or more than one field at the same time. Airlines may choose to examine the selected problem areas step by step. Although this method simplifies the overall process, it causes a small reduction in costs. Most problem types in airline scheduling are known to belong to a class of problems called "Non-deterministic Polynomial-Time (NP)-Hard". In such problems, integrating a new problem into the calculation process causes the solution cost to increase exponentially and reduces the possibility of finding a fast method that can solve the final problem. In addition, even a small improvement in any of the airline scheduling problems will result in big gains. American Airlines reported a 5% revenue increase (about $1.4 billion over three years) in 1992 due to the introduction of a new yield management system [123]. In 1994, Delta Air Lines estimated that the use of a newly developed fleet assignment system would yield savings of up to $300 million over the following three years [124]. Therefore, it seems reasonable to approach each of the existing problems step by step. On the other hand, a major drawback of this sequential approach is that it ignores most of the interdependencies between the selected problems. In particular, it fails to build robust solutions that are resilient to unpredictable disruptions (like adverse weather, aircraft breakdowns, etc.) that translate into delayed and cancelled flights [15]. Hence, examining selected problems at the same time will make the process more complicated but result in further cost reduction. This is a trade-off that needs to be settled. This question has been answered in favour of studies conducted in a single

Table 1 - Focused areas in each study

Authors	FSP	FAP	CSP	SRP	ATCP	MRO Subjects					
						AMRP	MTIS	SI	MP	EA	Others
Chen et al. [6], Zhou and Zhang [7], Colbacchini et al. [8]							√				
Diaz-Ramirez et al. [9], Weide et al. [10], Dunbar et al. [11], Mohamed et al. [12], Parmentier and Meunier [13], Mohamed et al. [14], Ahmed et al. [15]			√			√					
Lacasse-Guay et al. [16], Papakostas et al. [17], Yang and Yang [18], Maher et al. [19], Liang et al. [20], Başdere and Bilge [21], Irvine et al. [22], Gopalan [23], Al-Thani et al. [24], Safaei and Jardine [25], Qin et al. [26], Sarhani et al. [27], Eltoukhy et al. [28], Orhan et al. [29], Aslamiah et al. [30], Afsar et al. [31], Kim et al. [32], Bulbul and Kasımbeylı [33], Zhong et al. [34], Afia and Sarhani [35], Zhang [36], Eltoukhy et al. [37], Cui et al. [38], Eltoukhya et al. [39]						√					
Vos et al. [40], Zhang et al. [41], Dožic et al. [42], Liu et al. [43], Hu et al. [44], Jufri et al. [45], Lin and Wang [46]					√						
Akartunalı et al. [47], Akartunalı et al. [48], Burke et al. [49], Chen et al. [50], Sun [51], Jiang and Barnhart [52], Abdelghany et al. [53], Sandamali et al. [54], Zhao et al. [55], Peng et al. [56], Chen et al. [57], Wang and Zhang [58], Ahmadian et al. [59]	√										
Azadeh et al. [60], Deng and Lin [61], Ionescu and Kliewer [62], Dück et al. [63], Saddoune et al. [64], Suraweera et al. [65], Bayliss et al. [66], Kasirzadeh et al. [67], Lijima and Nishi [68], Arayikanon and Chutima [69]			√								
Özdemir et al. [70], Pilla et al. [71], Kang et al. [72], Yang et al. [73], Ma et al. [74], Raudasoja [75], Boudia et al. [76], Liu et al. [77], Dozic et al. [78], Okafor et al. [79], Anzoom and Hasin [80], Silva and Poss [81], Su et al. [82], Dahel [83]		√									
Bruecker et al. [84], Qiang et al. [85], MacKenzie et al. [86], Datta et al. [87]									√		
Gürkan et al. [88]	√	√				√					
Dong et al. [89], Cadarso and Marin [90], Pita et al. [91], Cadarso and Marin [92], Kenan et al. [93], Mezentsev and Estraykh [94]	√	√									
Tsagkas et al. [95], Gerede [96], Gerede [97], Chang and Wang [98], Atak and Kingma [99], Quinlan et al. [100], Passenier et al. [101]								√			
Murça and Müller [102], Samà et al. [103], Samà et al. [104]					√						
Shanmugam and Robert [105], Yadav [106], Kasava et al. [107], Mofokeng and Marnewick [108]											√
Noweir and Zytoon [109], Irwin and Streilein [110]										√	
Babic et al. [111], Sandamali et al. [112], Lindner et al. [113]	√						√				
Jamili [114], Liu et al. [115]		√					√				
Özener et al. [116], Komijan and Tavakkoli-Moghaddam [117]		√	√								
Abdelrahman [118], Chan and Eltoukhy [119], Eltoukhya et al. [120], Eltoukhya et al. [121]							√			√	
Safaei [122]							√				√
Total	23	25	19	7	3	42	3	7	8	2	5

Note: EA: Ergonomic Assessment; MP: Maintenance Personnel; MTIS: Maintenance Tracking Info Systems; SI: Safety Issues; SRP: Schedule Recovery Problem

field with 78% in the last 10 years. The ratio for the studies having multi-domain corresponds to only 22% of all studies.

The second conclusion that can be drawn from *Table 1* is the areas that the academics prefer to study the most. This is represented in *Figure 1*. *Figure 1* expresses that the number of articles on MRO is close to half of the current studies which shows the importance given to maintenance in airline scheduling. Besides, AMRP is the most frequently studied subject in the MRO related articles. On the other hand, when the four main operations were

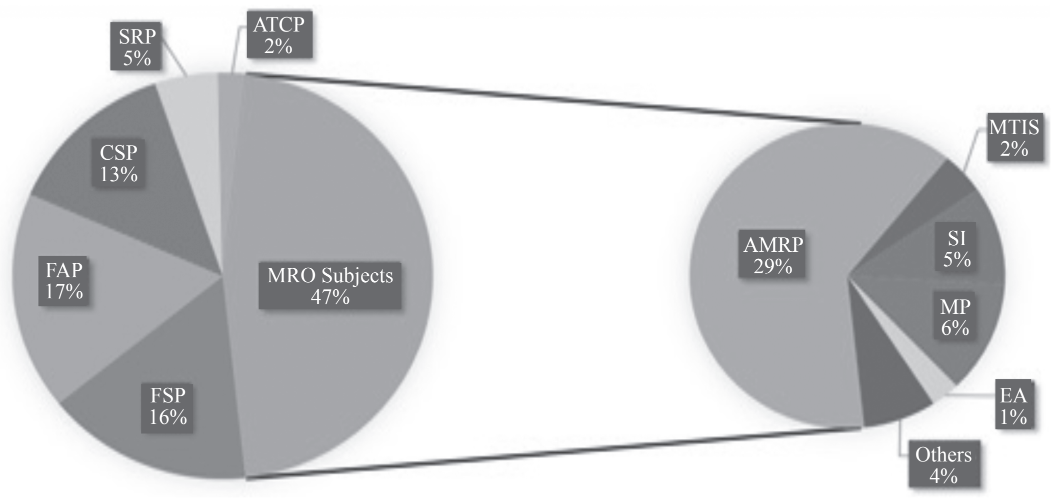

Figure 1 – Sub-problem distribution

compared, it was observed that the percentages of articles on FSP, FAP, and CSP were close to each other, while the percentage of articles related to AMRP was approximately twice of these.

3.2 Distribution of studies by publication year

The number of studies on airline scheduling tends to increase annually. The number of studies in the 2015–2019 period is approximately twice the studies published in the 2009–2014 period. In addition, when compared to other problems, AMRP, which is studied almost every year, is the most popular problem type in the 2009–2019 period.

4. AIRCRAFT MAINTENANCE ROUTING PROBLEM

The AMR process includes the determination of the sequence of flight legs to be flown by each individual aircraft so as to cover each flight exactly once while satisfying maintenance requirements [16, 24]. The general characteristics of the AMRP studies and a brief summary of the goals used thereof are presented in this section. *Table 2* summarises those features which will be examined in detail below.

4.1 Maintenance consideration

Although there is no consistency in the used literature, Bergh et al. [125] provided a framework by using the most common maintenance definitions. Within this framework, the columns refer to the intensity of the workload, starting from short-term (frequent and light) to long-term (rare and heavy) maintenance. On the other hand, the rows refer to the uncertainty level showing whether the maintenance is planned or not.

In practice, each aircraft has many maintenance tasks, with over 50 different checks, which must be done on a regular basis during the life cycle [25]. These checks vary according to their scope, duration, and frequency. Additionally, the periodicity of these checks depends on the aircraft type and internal rules of the airlines [24]. The most common of these checks is A-check which must be performed every 65–125 flight hours. Other sources indicate that A-check is supposed to be issued once every 3–5 days [16, 29], or every week. An A-check which involves visual inspection of major systems lasts 8 hours at most. This duration is sufficient for aircraft to be maintained overnight. Papakostas et al. [17] considered the aforementioned short-term line maintenance activities in their approach. According to their approach, at any point of time when a set of maintenance tasks that can be deferred exist, a decision should be made. These decisions constitute a set of alternatives which are defined as the possible allocation of pending maintenance tasks to suitable resources either at the current or at successive airports. Maher et al. [19] presented an approach to find a single day aircraft routing plan. This solution is further protected from disruptions by applying the recoverable robustness framework whose primary concern is to achieve A-check maintenance feasibility while simultaneously improving the recoverability of the aircraft routing plan. Başdere and Bilge [21] developed a fast responsive methodology with the objective of minimizing the unused legal flying times within the fleet. In their study, a

Table 2 - Summary of literature on AMRP

Authors	Maintenance consideration							Time horizon			Shift period			Solution method				
	Short-term	Line	A-check	Heavy	Hangar	Sched-uled/ Routine	Unsched-uled/ Non-routine	1 day (daily)	4 days	7-days (weekly)	Morn-ing time	After-noon time	Night	Heu-ristic	Meta-heuristic	Exact method	Decom-position method	Simu-lation
Diaz-Ramirez et al. [9], Mohamed et al. [14]										√			√	√			√	
Weide et al. [10]													√	√				
Gürkan et al. [88]								√						√		√		
Papakostas et al. [17]	√	√																√
Dunbar et al. [11]														√		√	√	
Yang and Yang [18]															√			
Maher et al. [19]			√					√					√				√	
Liang et al. [20]														√			√	
Başdere and Bilge [21]	√		√							√				√				
Gopalan [23], Babic et al. [111]														√				
Mohamed et al. [12]										√				√	√	√		
Al-Thani et al. [24]										√					√			
Jamili [114]								√										
Parmentier and Meunier [13]										√				√				
Safaei and Jardine [25]		√								√						√		
Qin et al. [26]				√	√													
Liu et al. [115]								√								√		
Sarhani et al. [27]			√				√	√							√			
Eltoukhy et al. [28]			√						√					√				
Orhan et al. [29]	√							√										
Aslamiah et al. [30]								√						√				
Afsar et al. [31]										√				√	√			
Ahmed et al. [15]						√		√			√	√	√			√		√
Afia and Sarhani [35]							√	√							√			
Eltoukhy et al. [37]			√						√						√			
Safaei [122]										√								
Cui et al. [38]			√					√							√			
Eltoukhya et al. [121]			√						√		√	√	√		√			
Eltoukhya et al. [39]			√						√		√		√	√				
Total	3	2	9	1	1	1	2	10	4	9	3	2	12	16	9	7	5	2

branch-and-bound algorithm and a heuristic approach are used to solve the model they formulated. Furthermore, they presented a procedure to revise the existing routes while considering the maintenance decisions which are already made. Al-Thani et al. [24] used a graph reduction procedure to improve the solvability of the Operational Aircraft Maintenance Routing Problem (OAMRP) model. Eltoukhy et al. [28] and Orhan et al. [29] studied the OAMRP taking into account some operational constraints related to the daily maintenance process.

Other maintenance types such as B-check, C-check, and D-check take longer and are repeated at longer intervals. B-check is repeated every 300–600 hours of flying or once in a month and lasts around 1–3 days. This involves a more extensive visual inspection and also lubrication of all moving parts. C-check and D-check are repeated once every 1–4 years. These checks can only be completed in a month in specialised hangars. Although past AMRP studies have included many types of maintenance, these studies mostly considered the A-type maintenance instead of the long-term checks. This is because longer checks directly affect fleet capacity which is why such checks should be considered during FAP [21]. One of these rare studies is the Qin et al. [26] study, where hangar maintenance scheduling and parking layout planning problems were tackled together to minimise total maintenance delay.

The above maintenance is routine maintenance planned according to variables such as the number of landings or flight hours after the last inspection. On the other hand, checks with a high level of uncertainty are called unscheduled or non-routine maintenance. The unscheduled aircraft maintenance occurs anytime a component/unit has malfunctioned or is suspected of malfunctioning, and by definition, this maintenance is unforeseen. That is why it can be classified as either a corrective or predictive measure. Sarhani et al. [27] modelled the daily AMRP problem, whose aim is to minimise the planned and unplanned maintenance costs, and developed a new particle swarm optimization algorithm integrated with a population diversity-enhancing mutation operator to use as the solution of the problem. Afia and Sarhani [35], an advanced version of Sarhani et al. [27], is another study on unplanned maintenance checks.

4.2 Time horizon and shift period

Three types of time horizon, namely daily, 4 days, and weekly, are considered in the past studies. Weekly time horizon is the longest planning period in the past AMRP studies. There are two conflicting ideas in the literature regarding this time horizon. From one perspective, the weekly planning period is too optimistic for frequent disruptions in the airline industry. According to this view, the impact of stochastic events (severe weather changes, equipment failures, variable maintenance times, or even new regulations, etc.) having unknown occurrence time and frequency on the planning period is vital. Long planning periods in the airline industry can cause unnecessary repetition of similar processes and increase operational costs. In addition, in this approach, aircraft whose maintenance needs are not at critical levels should also be maintained. However, maintaining these aircraft earlier than necessary is contradictory to the goal of maximizing productivity because the scarce maintenance resources needed for the critical aircraft are consumed unnecessarily. On the other hand, the solution to a problem with a longer time horizon may indeed better utilise the remaining flying hours of the aircraft by delaying the maintenance of some critical aircraft beyond the current day but still within the legal limits [30]. A time horizon that works well on one data can prevent good solutions in another. For this reason, the process of determining the time horizon, which is similar to being on a knife edge, is perhaps one of the most important factors in solving AMRP problems.

Accepting that long time horizon gives better results, Afsar et al. [31] created a flight plan that takes into account the aircraft utilization and the long-term flight load of the aircraft. AMR and Maintenance Task Scheduling (MTS) activities were integrated on a weekly time horizon problem by Safaei [122]. In this study, routes are created in the first iterative cycle depending on the working hour criteria required for upcoming maintenance tasks, and then MTS is carried out in the second iterative cycle, considering the maintenance alternatives on the routes. If the set of tasks cannot be properly scheduled in the maintenance opportunities, a backtracking strategy is used by repeating the first iterative loop with additional maintenance constraints, referred to as “cuts”. Diaz-Ramirez et al. [9] have developed two different methods to solve AMRP and CSP both sequentially and integrated for airlines with a single fleet and a single maintenance and crew base. In the sequential approach, AMRP and CSP were solved by Greedy Heuristic and Column Generation Algorithm, respectively. In the integrated approach, the heuristic approach is used to check whether better solutions than those obtained in the sequential approach can be found. Parmentier and Meunier [13], Mohamed et al. [12], and Mohamed et al. [14] are other studies seeking integrated solutions to AMR and Crew Scheduling in problems with a weekly time horizon.

Contrary to the previous belief, according to Başdere and Bilge [21], the weekly time horizon is operationally quite long. Aslamiah et al. [30] support this view with the following statement: The time horizon may be even shorter than a day, as a new schedule will be required for the remainder of the flight leg network due to a disruption during the day. Gürkan et al. [88] presented a solution with a daily time horizon for the problem that deals with flight scheduling, fleet assignment, and aircraft routing together. They used a variable flight time strategy to expand the solution space. In this way, different alternatives have been created, in which whether an aircraft will be used or not and, if so, the flight order for that aircraft changes. Jamili [114] has developed a hybrid algorithm based on Simulated Annealing and Particle Swarm Optimization metaheuristics to solve the integrated aircraft scheduling, routing and fleet assignment model in which the planning period is one day. Liu et al. [115] used a combination of branch-and-price algorithm with column generation approach to solve the daily fleet assignment and aircraft routing problem. Ahmed et al. [15] and Cui et al. [38] are other studies seeking integrated solutions for the problems with a daily time horizon.

Although studies involving a 4-day time horizon are not encountered very often, academicians who are looking for a safe harbour between the daily and weekly planning periods have increased their studies with this feature. Airlines tend to use the 4-day planning horizon in order to ease the requirement of satisfying 1 maintenance visit every 4 days for the aircraft, as mandated by the Federal Aviation Administration [39]. Additionally, the daily horizon assumes that the flight schedule is repeated every day of the week. On the other hand, 4-day or weekly horizons permit different flight schedules for each day of the week. Practically, daily horizon is not viable as airlines permit variations on the flight schedule for each day of the week to cope with the demand fluctuation of different flight legs (e.g. the demand on weekends is higher than other days). In light of this fact, the 4-day horizon is more practical in handling different flight schedules each day [126]. One of these studies, Eltoukhy et al. [28] used a heuristic model to solve OAMRP in a short computational time. Eltoukhya et al. [121] formulated the coordinated configuration of OAMRP and the Maintenance Staffing Problem as Leader-Follower Stackelberg Game; Eltoukhya et al. [39], unlike the existing OAMRP studies, included operational maintenance constraints such as restrictions on the total cumulative flying time, restrictions on the total number of take-offs, the workforce capacity and the working hours of the maintenance stations in the modelling process. Eltoukhy et al. [37] proposed a new robustness approach called the Turn-Around Time Reduction approach to be used in the AMR problem, which includes all maintenance requirements at the same time.

Another important feature in AMRP is the shift period. The shift time of major airlines varies according to the type of maintenance to be performed. Since light maintenance does not take much time, they carry out the service at any time by keeping their technicians at suitable airports or receiving support from other companies. Likewise, these airlines prefer to do their activities when the aircraft is idle or when there is a backup aircraft to complete the heavy maintenance as soon as possible. The exception to this situation is small airlines that operate a limited number of flights with a relatively smaller fleet. These airlines which are called charters prefer to perform the maintenance at night because it is prohibited to land and depart from 23.00/24.00 until 05.00 in some airports. Consequently, depending on the size of the airline, maintenance activities can be performed at any time during the day or overnight.

4.3 Solution methods

Stochastic events frequently encountered in the airline industry may affect the status of the aircraft in the fleet, causing infeasibility or increased operational costs in the existing route assignments. So, AMRP is required to be solved very frequently to respond to such changes; which is why developing a fast and responsive solution method is essential [21]. However AMRP is an NP-hard problem [24] for which exact methods are not likely to find effective solutions in a reasonable computational time for large-scale instances. Therefore, in most cases, (meta)heuristic approaches are used to handle this difficulty. *Table 2* summarises the solution methods used in some AMRP studies. The general approach in these studies is to use the exact methods that will provide the solution in a short time for small-scale problems prevailing in charter companies. However, these methods cannot solve real life problems in a reasonable time. An AMR problem with a daily time horizon should often be solved in 1–1.5 hours. This period will sometimes be shorter due to possible disruptions during the day. Considering today's airlines, which have an incredible number of daily flights and destinations, it cannot be expected from the exact solution methods to yield reasonable results in the specified period. For this reason, studies in which heuristic approaches are used in the solution of such large-scale problems are frequently encountered in the literature. Some of those approaches are Genetic Algorithm in Yang and Yang [18]; Particle Swarm Optimization in Mohamed et al. [12], Sarhani et al. [27], Afia and Sarhani [35]; Variable Neighbourhood Search in Al-Thani et al. [24], Cui et al. [38]; Ant Colony Optimization in Eltoukhy et al. [37] and Simulated Annealing in Afsar et al. [31].

4.4 Common AMR objectives

There are many types of objective functions considered in studies in the field of AMRP. While some objectives are directly related to profit and cost, it is seen that some of them have indirect effects. For example, in 2010, 65.000 U.S. airline flights could not take off due to improper MRO, resulting in $28.2 million as a penalty cost against 25 U.S. airlines [127]. All airlines aiming to increase their market share in the airline industry must consider multiple factors simultaneously and make a trade-off between them. However, it has been determined that the studies on AMR mostly have a single objective and the existing multi-objective models generally include some of the operational cost items such as crew pairing cost, idle time cost, carbon dioxide (CO_2) emission cost, fuel consumption cost, spill cost, daily aircraft usage cost, delay propagation cost, ferry flights cost, maintenance cost, maintenance misalignment cost, maintenance request decline cost, weighted cost of recovery, connection change cost, additive routing cost, etc.

5. DISCUSSION

In this article, 117 studies published between 2009 and 2019 are considered to determine the trends in studies on airline operations. As a result of this research, it was determined that the problem of AMR is extremely important in the airline scheduling literature and is studied more than other problems. This finding has led to a more in-depth review of those related to the AMR problem among the 117 articles in question. As a result of examining the AMRP studies, the following findings were obtained.

- The number of short-term maintenance studies is much higher than long-term maintenance, and the number of scheduled maintenance studies is much higher than unscheduled maintenance.
- Although the number of studies with daily and weekly time horizons is close to each other, the number of studies using a 4-day period is quite low compared to these.
- Although maintenance can be performed at any time, it is a common situation to maintain aircraft at night.
- Due to the NP-hard nature of AMRP, heuristic and metaheuristic approaches are generally preferred to solve these problems.

This study revealed that the issues presented below should be taken into account for future studies.

- Besides monetary issues, the academics should deal with many other factors such as delay, flight efficiency and operational risk within their studies. Additionally, academics should pay more attention to the Maintenance Base Location (MBL) Problem which has a direct impact on AMRP results.
- The transportation sector is one of the sources of many problems such as global warming, environmental degradation, and greenhouse gas emission. Air transportation, the second most preferred type of transportation, has a great effect on this problem. Although this situation requires increasing scientific contributions to reduce the negative environmental impact, this goal was studied only in Gürkan et al. [88].
- Special solution procedures integrating AMRP with Artificial Intelligence (AI) have to be developed to obtain better results in terms of solution time and quality.
- Solution approaches including algorithms to repeat the problem-specific parameter fitting process in each new AMRP problem are required to be designed.

6. CONCLUSIONS

The airline industry has shown significant growth in the last decade. This inevitable progress makes the airline industry challenging and forces airline companies to advance in distinct airline operations.

However, although such operations have been studied for several years, the literature review on airline scheduling is still missing for the last decade. This study aims to fill this gap by reviewing the airline operations related papers published between 2009 and 2019, and focus on the ones especially dealing with the AMR area which seems a promising branch.

Hence, 117 studies published between 2009 and 2019 are first considered to determine the trends in studies on airline operations, and later the papers related to the AMRP are studied in more depth in terms of mostly considered maintenance types, applied time horizon and ship period, and finally the used solution methods and objectives. At the end of the review, not only some general ideas are proposed but also future remarks are given in order to enable progress of future studies.

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UÇAK BAKIM ROTALAMA PROBLEMI: BIR LITERATÜR ARAŞTIRMASI

ÖZET

Küresel hava trafiği yolcu talebindeki yıllık ortalama büyüme ve küresel hava taşımacılığı filosundaki büyüme oranı gibi bazı göstergelere göre, havayolu sektörü son on yılda önemli bir büyüme göstermiştir. Bu kaçınılmaz ilerleme, havayolu endüstrisini zorlu hale getirmekte ve havayolu şirketlerini tüketicinin markaya olan bağlılığını artıran bir dizi çözüm üretmeye zorlamaktadır. Havayolu operasyonlarında karşılaşılan yüksek maliyetleri azaltmak, planlanan kalkış saatlerinde gecikmeleri önlemek, hizmet kalitesini iyileştirmek veya çevresel etkileri azaltmak amacını güden bu çözümler ihtiyaca göre çeşitlendirilebilir. Bu konuda geçmişte yapılan araştırmalar özellikle son on yılda havayolu çizelgelemesine ilişkin zengin literatürü kapsamamaktadır. Bu çalışma, 2009-2019 yılları arasında yayınlanan havayolu operasyonları ile ilgili makaleleri gözden geçirerek bu boşluğu doldurmayı ve özellikle gelecek vaat eden bir dal gibi görünen uçak bakım rotalama alanında olanlara odaklanmayı amaçlamaktadır.

ANAHTAR KELIMELER

havayolu operasyonları; havayolu çizelgeleme; uçak bakım rotalama.

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