OPTIMIZATION APPROACHES IN AIRCRAFT LANDING PROBLEMS

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ABSTRACT: *The Aircraft Landing Problem (ALP) is an important element in airport operations. It has been widely explored and a variety of approaches have been investigated and developed. ALP is an NP-hard problem that deals in assigning an arriving aircraft to an available runway and a landing time. The landing time for each aircraft must be within a time interval encompassing a target landing time. If the actual landing time deviates from the target landing time, an additional cost will be imposed that is determined by the amount of earliness and lateness of the actual landing time. The objective is to minimize the overall cost, i.e., the deviation from a preferred target time of each aircraft. This paper centers on reviewing optimization approaches as state-of-the-art algorithms proposed to ALP that are tested on OR-library datasets. These algorithms are analyzed in three categories, namely, exact, approximate and hybrid approaches. Finally, possible suggestions for future studies are obtained from this survey.*

Keywords: Aircraft landing, optimization approaches, OR-library dataset.

1. INTRODUCTION

The Aircraft Landing Problem (ALP) represents an important task for air traffic controllers in an airport. ALP involves assigning the landing sequence and landing time for the arrival of a set of aircraft inside the radar range, with respect to a set of constraints, such as the time window and separation time. The time window of each aircraft is the allowable landing time duration, which starts with an early landing time and ends with the latest landing time. The separation time is an interval time assignment between each pair of aircraft landing on the same runway, which is required for security matters. The multiple constraints imposed in ALP make the problem become an NP-hard problem [1].

ALP can be static or dynamic. The static type of the problem is when all the information on aircrafts are fixed and there is no change in information when the scheduling process commences. On the other hand, the dynamic version of the problem considers dynamic changes to the information that occurs during the scheduling process, where new aircraft may appear in the radar range. In the dynamic type of the problem, extra decision variables and constraints must be considered such as the appearance time of the new aircraft and the freezing time which indicates that the aircraft is too close to the runway and there is no rescheduling allowed for this aircraft.

The complexity of the ALP draws the attention of researchers from various research domains in order to generate a robust system to support air traffic controllers in making the lending decision. The simplest method widely used is the First Come First Save (FCFS) method that depends on the estimated arrival time of the aircraft in order to assign a landing time. Although FCFS is simple to implement, it is not efficient in generating the finest landing schedule. Thus, researchers are paying more attention in searching for alternative scheduling methods. Recently, different optimization techniques have been used to solve the ALS problem optimally such as by using exact methods [2]. Exact methods guaranty the discovery of optimal solutions for small size input data, which makes it inefficient for large size optimization problems. Therefore, metaheuristic algorithms represent the most suitable class of algorithm for ALP. Different metaheuristic algorithms used for solving ALP such as genetic algorithms [3], Scatter Search [4], Ant Colony algorithms [5] and so many others. Researchers in operational research face the problem of evaluating the algorithms they develop with other related works. Thus, there is a need to use standard test problems. In 1990, new test problem sets for various operational research problems was compiled by Beasley [6], which been named as OR-Library. In 1990, these test problems were collected or generated for the last 15 years of the work by Beasley [6] on operational research. The main idea behind the OR-Library system is the easier distribution of test problems for the researchers via email. The datasets used represents an important factor in formulating the ALP. There are two main dataset types reported in the literature. The first type consists of real datasets collected directly from the airports. The second type consists of the benchmark datasets generated by authors. In this paper, we review the work on ALP that used the OR-library dataset, which is the most widely used dataset in the literature. This dataset is publically available on the OR-library website [http://people.brunel.ac.uk/~mastjjb/jeb/orlib/airlandinfo.html]. The ALP dataset available in OR-Library includes datasets for both types of problems, static and dynamic, which includes 13 instances with aircraft numbers ranging from 10 to 500. Researchers in ALP in OR-Library dataset classified the ALP dataset into two classes according to the size of the instances [4, 7]. The instance from 1 to 8 with a maximum number of aircrafts not exceeding 50 aircrafts are considered as small size instances. Instances from 9 to 13 with a maximum number of aircrafts not exceeding 500 is considered as large size instances. The number of runways range from 1 to 5.

In this paper, we review the research articles that used the OR-library aircraft landing dataset by considering the optimization approaches used. Our review covered 22 papers collected from the literature starting from year 1990 to year 2017. The rest of the paper is organized as follows: in Section 2, the optimization approaches used are described, while in Section 3 the conclusion and future work are presented.

2. OPTIMIZATION APPROACHES APPLIED ON ALP BASED OR-LIBRARY DATASET

In this section, we discuss the optimization approaches used in solving ALP by considering the OR-Library dataset, according to papers we have reviewed i.e., exact, approximate and hybrid approaches.

2.1 Exact Approach

Exact approaches are optimization techniques that search the whole search space and is guaranteed to find the optimal solution. In ALP, different types of exact methods are used such as branch and bound and dynamic programming. In this subsection, we reviewed the papers that have used exact approaches in ALP.

According to Ernst, Krishnamoorthy, Sharaiha and Abramson [2], the specialized simplex algorithm, as well as branch and bound methods, were used for solving static ALP for single and multiple runways. The specialized simplex algorithm was used for finding the landing time for each aircraft and find the upper and the lower bound for the branch and bound algorithm. Next, the branch and bound algorithm were used to generate the solution in both the single and multiple runways problems. The experiments were conducted using 44 aircraft.

ALP was formulated as a mixed-integer zero–one program (MIP) and solved statically using tree search in [1]. Single runway formulation was used first and extended later to multiple runways. The formulation impact on solving the problem and the solution quality is discussed deeply. 50 aircrafts were used to evaluate the proposed algorithms.

Beasley [7] proposed a new method to solve ALP dynamically based on displacement. In dynamic ALP, the landing time of aircraft must be assigned by considering the time passed and the change in the environment. In Beasley [7], the ALP was solved as a displacement problem. In solving the displacement problem, new constraints or values may change over time and then a new decision must be made by considering the old decision. In dynamic ALP, new data is added to the problem, such as new aircraft appearing or a new aircraft which must land. The new schedule must have links that pack to the previous one. A tree search method was used to generate the solution for ALP with multiple runways dynamically. Small and large datasets were used in the experiment where large datasets consist of up to 500 aircrafts.

The work of Farah et al. [8] consists of two parts. In the first part, a new modelling method is used to represent the static single runway ALP based on a quadratic model. In the second part, an exact method based on branch and bound was used to solve the problem. In the modelling part, two types of variables were used. The first variable types are the binary variable which was used to show the first aircraft in the landing sequence while the second variable represents an integer variable that is used to represent the arrival time. The branch and bound algorithm used for the ALP consisted of three steps as follows: (i) initialization of the solution, (ii) apply the principles of the branch and bound method and (iii) obtain the best solution. In the experiment, 44 aircrafts were used, which indicates that only small size instances were explored in the work.

Another exact method used for single and multiple static ALP is described in Awasthi et al [9]. The proposed exact algorithm receives a feasible landing sequence on single or multiple runways and solves the landing time assignment part of the problem only. The author named the algorithm a "polynomial exact algorithm". In the proposed algorithm, the procedure of landing time initialization starts by assigning a landing time for all the aircraft in the sequence as late as possible by considering the safety constraints for all the successive pairs of aircrafts in the sequence. After completing the initialization step, the algorithm starts to reduce the landing time of the aircrafts in block form while maintaining the safety constraints. The author defined a mathematical procedure to continue reducing the assigned landing time unless one of the aircrafts in the block is scheduled for an early landing time or the safety constraint is violated. The experiment considers the single runway and multiple runways separately. Up to 500 aircrafts were used in this work and the runways range from 1 to 5 in the case of multiple runways. The results obtained in this work was compared with the work of Pinol and Beasley [4].

Faye [10] proposed an approximation of the separation time matrix and on time discretization approach to solving the ALP. In his approach, the separation time was approximated by a rank two matrix. The ALP is stated as 0-1 integer problem. When the separation time matrix is not a rank 2 matrix, an approximation is done. This provides lower bounds or upper bounds depending on the choice of the approximating matrix. These bounds are used in a constraint generation algorithm to, optimally or heuristically solve the problem. The results obtained by this exact method is compared to the result of in [4]. Based on the comparison result, the author reported that his approach outperformed the work in Pinol and Beasley [4] on some instances.

Ghoniem and Farhadi [11] investigated the computational tractability and the relative merits of a 0–1 MIP and a set partitioning formulation solved using the column generation approach for ALP. The proposed method used an objective function that is slightly different from other approaches, where the objective function is to minimizes the total weighted start-times. The dataset used in this work include aircraft numbers ranging from 10 to 500 aircrafts and 1 to 5 runways. The result of the proposed approach was compared with the result of the work Pinol and Beasley [4]. The comparison shows a clear improvement from Pinol and Beasley [4].

2.2 Approximate Approach

Moser and Hendtlass [12] proposed Extremal Optimization (EO) for a dynamic single runway ALP. The ALP was solved in two parts: the first, is to find the sequence of the aircrafts and the second, is to optimize the landing time for the aircrafts sequence. EO is an optimization technique that depends on the mutation operator for improving the solution. The landing sequence resulted from the EO solver is used as input to the algorithm used in the landing time assignment. The aircrafts numbers used in the experiment was up to 500 aircraft, with a single runway. The results obtained was compared against the results from Beasley [7].

Cellular Automaton (CA) model was introduced for modeling the ALP in Yu et al [13]. The work was organized in steps, where CA was used for generating the landing sequence and then Genetic Algorithms was used to optimize this landing sequence using a mutation operator. Also, a Relaxation Operator (RO) was used for generating landing times for the landing sequence obtained from CA. 13 instances of datasets with a single runway was used in the experiment. The result obtained was compared with the result of the work in Pinol and Beasley [4]. For the large size instances (instance Airland9-Airland13), the result of some instances was superior to the result of Pinol and Beasley [4].

New work based on Ant Colony Optimization was proposed to solve the ALP in Farah et al [14]. In this work, a static single runway problem is solved. The approach consists of modelling the problem based on the quadratic model and Ant Colony algorithm. The Ant Colony procedure was represented as a set of ants (solutions). Each solution has two vectors as the landing sequence and the landing time vectors. The objective function is to minimize the total delay of the arriving aircrafts. The total number of the aircrafts used in the work is up to 150 aircrafts (instance Airland1 to Airland10).

Multi Start Variable Neighborhood Search was used to solve the ALP with multiple runways Dhouib [15]. The author reported that he followed the work of Pinol and Beasley [4] in the solution representation of the procedure. For updating the solution improvements, three types of movements were used in this work. First, modifying the landing time of the aircrafts. Second, modifying the order of the aircrafts in the sequence on each runway. Third, modifying the runway allocation for the aircrafts. The objective function used is similar to the majority of other works as minimizing the total delay of the aircraft from its target landing time. In this work, multi-start techniques were used to overcome the problem of diversification in local search algorithms. Another improvement implemented on the proposed algorithm was by employing memory to forbid the algorithm from visiting the neighborhoods which were already visited with no improvements. The result obtained from this work was compared with Pinol and Beasley [4]. The average deviation from the best-known result taken from Pinol and Beasley [4] is 2.3% while it is (2.1%) and (1.7%) for Scatter Search and Bionomic Algorithm respectively.

Sabar and Kendall [16] proposed an Iterated Local Search (ILS) with multiple perturbation operators and time-varying perturbation strength to solve ALP. The success of the proposed algorithm largely depends on the local improvement. Local optima problem is a drawback for most local search algorithms. To solve this problem, the author in this work proposed four perturbation operators with time-varying perturbation strengths. Variable Neighborhood Decent (VND) algorithm is used for the local search procedure. In this work, the initial solution was generated using the Randomized Greedy (RG) heuristic. Then, four neighborhood structures were used for the local search improvements by considering swaps and moves. Afterwards, perturbation phase was invoked, which involves four different perturbation operators that include swap and moves. The dataset instances used in this work range from 10 to 500 aircrafts and 1 to 5 runways. The results of this work were compared in terms of the effectiveness of the perturbation operators on the performance of the proposed ILS, where the ILS was tested with each perturbation operator separately. In addition, the result was compared with different references from the state of the art, in terms of the gap, from the best-known values (BKV) taken from Pinol and Beasley [4]. The comparison approaches are taken from Pinol and Beasley [4] and Salehipour [17]. The author reported that his work achieved new best results in 16 instances overall 49 instances and matched all the remaining 33 instances.

2.3 Hybrid Approach

According to Bencheikh [3], two population-based metaheuristic algorithms were combined to solve the ALP. The algorithms are the Ant Colony Optimization (ACO) algorithm and the Genetic Algorithm (GA). The ACO was used to generate the initial population and the GA is used for the improvement process. The purpose of using ACO is to generate high-quality initial population, because the GA performance strongly depends on the quality of the initial population. The author formulates the ALP as a job shop scheduling problem. A static ALP with multiple runways was solved. The result was evaluated using 50 aircrafts (instance Airland1 to Airland8). The obtained results were compared with optimal solution reported by earlier works.

Beincheikh [18] proposed a hybrid of two metaheuristic algorithms to solve the static ALP with multiple runways. The author reported that the best result for ALP were obtained by hybridizing algorithms and not by a single algorithm. Genetic Algorithms (GA) and the Tabu Search (TS) algorithm were used in the proposed work where TS was used to improve the solution obtained after the selection stage in GA. In addition, the crossover and mutation processes were utilized to improve the solutions. The data used in the experiment ranged from 10 to 500 aircrafts and 1 to 5 runways. The results obtained from the proposed approach were compared with the work in Pinol and Beasley [4].

In 2013, the mixed integer goal programming model is developed, which combined Simulated Annealing (SA) with Variable Neighborhood Descent (VND) and with Variable Neighborhood Search (VNS) as described by the work in Salehipour [17]. The developed model was solved using a CPLEX solver. Three different neighbourhood structures were used in order to improve the solution quality. First, swap aircrafts on the same runway. Second, swap the aircrafts on different runways. Third, remove an aircraft from one runway and insert it to another runway. Both the VND algorithm and VNS algorithm used with these neighborhoods were controlled by a SA framework in order to avoid trapping in local optima. The dataset used in this work ranged from 10 to 500 aircrafts and 1 to 5 runways. All the obtained results from the hybridization between SA and VND, and SA and VNS algorithms and the CPLEX result were compared with Scatter Search result from the work in [4]. The author reported that it is the first time that the optimal solution was obtained for 100 aircrafts, where the best results from previous studies obtained the optimal solution for 50 aircrafts only.

Another hybrid method was based on the Bat Algorithm with local search Xie, Zhou and Zheng [19]. The hybrid Bat Algorithm (HBA) consist of the population-based algorithm BA and two local search algorithms. In this work, the solution representation has an important role in the improvement process. The purpose of the local search is to improve the global best solution. One improvement procedure was implemented by selecting one runway from the solution randomly, next randomly selecting the aircraft on this runway, and then assigning the selected aircraft on a different runway. This was done by one local search. Another improvement procedure was implemented by mutating the current global best solution to ensure the diversity of the population. The process was iterated until the termination criterion was met. The dataset used in this work range from 10 to 500 aircrafts and 1 to 5 runways. The result obtained by HBA was compared with the result obtained by Pinol and Beasley [4] as well as to the result from Bencheikh, Boukachour and Alaoui [5].

According to Sabar and Kendall [20], Hybrid Differential Evolution (DE) and Simple Descent (SD) algorithms are implemented to solve the ALP. The nature of the DE algorithm is for dealing with continuous optimization problems and thus, it is cannot be used directly for ALP. For solving this problem, the author proposed new representation methods for the decision variables of the ALP. The representation of the solution proposed in this work is done by having the integer part of the representation to the represents the runway number, and the fraction part to represent the aircraft order landing on this runway. In the first step of the solution representation using DE, the decision variables represent the runway numbers and the aircraft landed on these runways randomly. In the next step, the aircraft sequence on each runway was sorted in ascending order and given a landing time based on their targeted landing time. Commonly, DE improvements depend on the crossover and mutation and that may affect the quality of the solution in ALP negatively because of the nature of the ALP where small movements in the aircrafts order made big changes. Thus, SD was used to improve the solution after each time crossover and mutation was made using DE. The improvement in SD was implemented by examining the neighborhoods using move operators. From the combination of the proposed algorithms, it is clear to know that the DE explores the search space efficiently while SD exploits it. The proposed approach was tested using all the instances of the dataset in the 13 files with 500 aircrafts and 5 runways. The obtained results were compared in two aspects. In the first one, the DE result was compared with DE-SD. The second aspect of the comparison was made with the work in Salehipour [17] and Pinol and Beasley [4] vs the BKV result taken from Pinol and Beasley [4]. The author explained that his work obtained new best results in some instances.

Bencheikh, Baoukachour and Alaoui [21] proposed an Ant Colony Optimization (ACO) algorithm combined with local search for the dynamic multiple runways ALP. In the dynamic ALP, new aircrafts may appear as time passes. The proposed algorithm starts by initializing the ants constructively starting by aircraft selection, runway allocation and landing time assignment. The solution was represented by following the bi-level graph. The graph starts by dummy nodes representing the input and output of the graph. Instances used in the evaluation of the proposed algorithm ranged from 10 to 50 aircrafts and 1 to 4 runways (instances Airland1 to Airland8). The result of the proposed approach was compared with the result of the work Beasley et al [22].

Hybrid Particle Swarm Optimization (HPSO) algorithms with local search was proposed for static multiple runway ALP in Girish [23]. In the proposed algorithm, single runway and multiple runways were dealt separately in the construction of the initial solution and in the optimization process. The author also proposed a rolling horizon (RH) framework, which represents an online optimization strategy wherein, based on the currently available information of aircrafts, the problem is optimized for a fixed time horizon. For evaluation of the proposed approach, eight research papers from the literature were considered in the comparison which are Pinol and Beasley [4], Awasthi et al [9], Faye [10], Yu et al [13], Sabar and Kendall [16], Salehipour at al [17], Bencheikh et al [18], Xie et al [19]. The aircraft numbers used ranged from 10 to 500 and the runways ranged from 1 to 5 runways. The result of proposed HPSO reflected the efficiency of the approach.

3. CONCLUSION

Twenty-two reviewed literatures are categorized based exact, approximate and hybrid methods. Most of the papers used the exact methods solved the ALP with small size instances, while the large size instances were solved by using approximate or hybrid methods. From all the papers we had reviewed, only three papers solved the dynamic ALP while all the others solved the static ALP. Majority of the papers achieved good results on small size instances. The best result was achieved in Girish [23] in comparison with other approaches in the literature where the particle swarm optimization algorithm was used. We aim to investigate nature-inspired meta-heuristic algorithms for ALP to further improve the obtained best result in the literature. This is subject to future work.

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4. REFERENCES

[1] J. E. Beasley, M. Krishnamoorthy, Y. M. Sharaiha, and D. Abramson, "Scheduling Aircraft Landings — The Static Case," *Transportation science* , **34**:180–197, (2000).

[2] a T. Ernst, M. Krishnamoorthy, and R. H. Storer, "Heuristic and exact algorithms for scheduling aircraft landings," *Networks*, **34**: 229–241, (1999).

[3] G. Bencheikh and J. Boukachour, "Hybrid method for aircraft landing scheduling based on a Job Shop formulation," *" International Journal of Computer Science and Network Security* **9**: 78-88. (2009).

[4] H. Pinol and J. E. Beasley, "Scatter Search and Bionomic

Algorithms for the aircraft landing problem," *European Journal of Operational Research* **171**: 439-462 (2006).

[5] G. Bencheikh, J. Boukachour, and A. Alaoui, "Improved Ant Colony Algorithm to solve the aircraft landing problem," *Int. J. Comput. Theory Eng.*,**3:** 224–233, (2011).

[6] J. E. Beasley, "OR-Library: distributing test problems by electronic mail." *Journal of the operational research society* 1069-1072. (1990).

[7] J. E. Beasley, J. E., M. Krishnamoorthy, Y. M. Sharaiha, and D. Abramson. "Displacement problem and dynamically scheduling aircraft landings." *Journal of the operational research society* **55**: 54-64 (2004).

[8] I. Farah, Ihsen, Ali Kansou, Adnan Yassine, and Thierry Galinho. "New modelling and exact method for aircraft Arrival Sequencing and Scheduling." In *Logistics (LOGISTIQUA), 2011 4th International Conference on*, pp. 44-49. IEEE,(2011).

[9] A. Awasthi, Abhishek, Oliver Kramer, and Jorg Lassig. "Aircraft landing problem: An efficient algorithm for a given landing sequence." In Computational Science and Engineering (CSE), 2013 IEEE 16th International Conference on, pp. 20-27. IEEE, (2013).

[10] A. Faye, "Solving the aircraft landing problem with time discretization approach." *European Journal of Operational Research* **242**: 1028-1038 (2015).

[11] Ghoniem Ahmed, and Farbod Farhadi. "A column generation approach for aircraft sequencing problems: a computational study." *Journal of the Operational Research Society* **66**,: 1717-1729 (2015).

[12] I. Moser and T. Hendtlass, "Solving dynamic single-runway aircraft landing problems with extremal optimization," in *Proceedings of the 2007 IEEE Symposium on Computational Intelligence in Scheduling, CI-Sched 2007*, , 206–211 (2007).

[13] S. Yu, X. Cao, M. Hu, W. Du, and J. Zhang, "A real-time schedule method for aircraft landing scheduling problem based on cellular automaton," *Applied Soft Computing*, **11**:3485–3493(2009).

[14] I. Farah, A. Kansou, A. Yassine, and T. Galinho, "Ant colony optimization for aircraft landings," in *2011 4th International Conference on Logistics, LOGISTIQUA'2011*, 235–240 (2011).

[15] S. Dhouib, "A multi start adaptive variable neighborhood search metaheuristic for the aircraft landing problem," in *2011 4th International Conference on Logistics, LOGISTIQUA'2011* 197–200 (2011).

[16] N. R. Sabar and G. Kendall, "An iterated local search with multiple perturbation operators and time varying perturbation strength for the aircraft landing problem," *Omega (United Kingdom)*, **56**: 88–98 (2015).

[17] A. Salehipour, M. Modarres, and L. Moslemi Naeni, "An efficient hybrid meta-heuristic for aircraft landing problem," *Computers & Operations Research* **40**, 207–213(2013).

[18] G. Bencheikh, F. El Khoukhi, M. Baccouche, D. Boudebous, A. Belkadi, and A. A. Ouahman, "Hybrid algorithms for the multiple runway aircraft landing problem," *Int. J. Comput. Sci. Appl.* **10** 53–71, (2013).

[19] J. Xie, Y. Zhou, and H. Zheng, "A hybrid metaheuristic for multiple runways aircraft landing problem based on bat algorithm," *Journal of Applied Mathematics* , vol. **2013**, (2013).

[20] N. R. Sabar and G. Kendall, "Aircraft landing problem using hybrid differential evolution and simple descent algorithm," in *Proceedings of the 2014 IEEE Congress on Evolutionary Computation, CEC 2014* 520–527 (2014).

[21] G. Bencheikh, J. Boukachour, and A. El Hilali Alaoui, "A memetic algorithm to solve the dynamic multiple runway aircraft landing problem," *Journal of King Saud University-Computer and Information Sciences*, **28**: 98–109 (2016).

[22] J. E. Beasley *et al.*, "Displacement problem and dynamically scheduling aircraft landings," *Journal of the operational research society*, **55**: 54–64,(2004).

[23] B. S. Girish, "An efficient hybrid particle swarm optimization algorithm in a rolling horizon framework for the aircraft landing problem," *Applied Soft Computing.*,**44**: 200–221 (2016).