

A Survey on Airline Schedule Development Approaches

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ABSTRACT: Air transportation for passengers and freight are provided by airline company. The greatest burden that an airline company faces is the operational cost and so the primary product of an airline company is the schedule. Several related problems have to be resolved based on the feasible schedule. Major challenge is dealing with huge data. With the help of a precise mathematical model; airline schedule management problem can be solved. As in real world a lot of factors are to be considered dynamically, the problem is to be modeled as a multi-objective optimization problem, allowing the airline to improve on more than one objective. Survey on various models and solution techniques are included in the paper.

KEYWORDS: Flight scheduling, fleet assignment, aircraft rotation, through flight selection

I. INTRODUCTION

Airlines have evolved over the years from simple contract mail carriers into sophisticated business and are a key component in the growth of tourism, now one of the world's major employment sectors. The prime challenge faced by an airline industry is the economic prosperity which purely depends on the business structure. Business structure can be divided into two sections: Planning and Operating (Figure 1). Planning section is the long term preparation of the activities to be executed which consists of fleet assignment, route selection, flight scheduling, aircraft routing and maintenance routing. Operating section is the short term arrangements for the successful execution of the planning that aims to manage the business[27]. It includes crew scheduling, gate assignment, airline irregular operations and other real time challenges. High priority is given to the planning section as the operating section completely rely on the efficiency of planning section.

Airline flight timetable can only be created by including all the planning decisions. Flight schedule is a list of flight legs created by the respective airline company satisfying the market demand. Each flight leg in the flight schedule is a non-stop flight from source to destination with specific departure and arrival time. Schedules for a fixed period are planned months ahead which includes source, destination, departure time, arrival time and flight number. Maximization of revenue can be performed by selecting ordered sequence of legs to form a route. While creating route several time disjoint legs sharing stations in common are selected. There should be sufficient time for the ground personnel to service the aircraft, transfer baggage before the plane leaves for its next leg, allow sufficient time for passengers to move out of the plane and allow time for the next group of passengers to move in.

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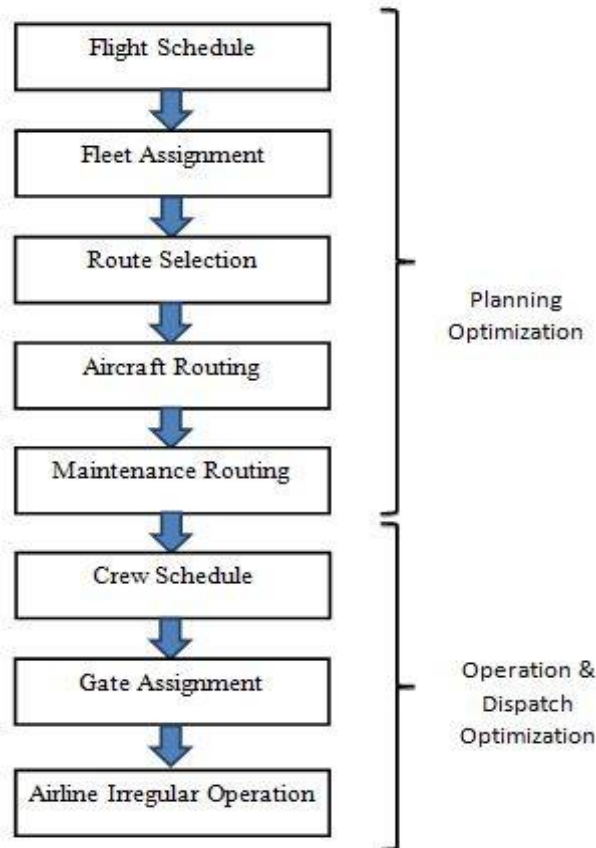


Figure 1: Airline Business Structure

Connection flights attract not only the passengers but also the airline company as the entire route can mostly be satisfied by a single aircraft. Before assigning aircraft for each route, fleet assignments have to be performed based on passenger demand, seat capacity, operational cost, demand for optimal revenue and availability of maintenance at the stations in the route. With the available set of aircrafts in a particulate fleet, airlines deal with the rotation problem through maximizing aircraft utilization before its maintenance. Once the route and the aircraft routing are complete airlines should solve the crew scheduling problem.

In general, the airline creates the flight schedule manually considering the experience and practical knowledge. Based on the schedule planner can chart connection flights which will be beneficial for an airlines. After fleet assignment, maintenance schedule for the aircraft is constructed satisfying the time slot of each aircraft. Staff scheduling, the process of building working timetables for manpower resources, helps the provider to serve their customers effectively. On completing the planning face by performing fleet routing and flight scheduling, the airline company has to complete operation phases. An airline has to deal with a set of interwoven complex problem. The problem has to be divided into sub-problems and solve the sub-problems independently. Solving the sub-problems sequentially helps the preceding sub-problem to deliver the data to the subsequent ones. Difficulties in developing a feasible network, availability and accuracy of data and strong relationship between market demands make the process of finding solution complex.

Airlines used a trial-and-error process for fleet routing and flight scheduling. They iteratively constructed and evaluated the schedule phases manually. Lack of optimization from a systemic perspective made it necessary for the airlines to check whether the schedules are manually acceptable. On failure, schedules are modified and the process is repeated until satisfactory results are obtained. The iterative construction and evaluation of the schedule will reduce the effectiveness and efficiency of the approach as the networks becomes larger, constrains becomes complicated or if its

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coordinated flight schedules. These strategies typically require a great deal of manual intervention by the schedule planner to remove inefficiencies and ensure the final schedule meets all operational constraints and adheres to aircraft count limitations. For these reasons, the process results in limited set of feasible solutions. The most efficient solution can be obtained by formulating an optimization model. The increasing complexity of decision making and increased competition along with environmental regulations forces airline companies to make optimum use of their resources. Due to the above reasons, rapid progresses have been made in the application of optimization techniques.

The paper is organized as follows: section two includes survey on various models and optimization techniques adopted by each sub problem in planning section. The third section discusses the solution approach performed on hybrid combination of sub problems and fourth section gives conclusion.

II. SCHEDULE PLANNING PARADIGMS**A. FLIGHT SCHEDULE DESIGN PROBLEM**

Flight schedule design is the problem of defining legs. It is the most important problem for an airline company as all the remaining problems depend on it. Issues related to network structure, sources, destinations, frequencies etc are addressed here. As it's a complex problem due to its inherent size and availability and accuracy of data, the process is done manually with limited optimizations[1]. Reviews of network design models[2] are done for analyzing the representation of the problem. Common approach used is incremental optimization where a base schedule is designed and additions or deletions are performed based on the improvements required for the objective function. Major challenges faced are the computational difficulties faced in the initial stage, steadiness of the network created and degree of consistency. From the base schedule, itinerary is created by connecting legs. Itineraries are finalized by eliminating unrealistic connections based on distance and node-based circuitry logic.

Setting of good flight schedules for airlines can not only enhance decision-making but also enhance airline operating performance. An earliest market share models employed a demand allocation methodology referred to as QSI model, developed by U. S. government in 1957. For a QSI model[3], preference weights are obtained using statistical model. Final QSI model for a given itinerary is usually expressed as a liner or multiplicative function of its service characteristics and preference weight. Because QSI models have a limited ability to capture the interactions or competitiveness among itinerates, other methodologies based on discrete choice models have emerged. Multinomial logit model (MNL) which is a discrete choice model describes how an alternative is chosen among a finite set of mutually exclusive alternatives[3]. The MNL forecasts were consistently superior to QIS model with reduced errors.

Mathematical models were extensively used for modeling airline scheduling problems. There are mainly three combinatorial optimization problems: set partitioning problem, multi-commodity network flow problem and Euler tour problem. Out of these first two are NP-hard problem while the third one is solvable in polynomial time. Exact methods for solving the set partitioning problem[4] are usually based on branch and bound algorithms, which need to repeatedly solve various linear programming (LP) relaxation problems. Integer programming solvers will be able to handle problem, when it is small. When it is large other technique like column generation is used. Network flow model used in airline schedule resolves time-space network. The problem of finding the cheapest assignment of aircraft or crew members to flights becomes that of finding the minimum-cost integral flows in the network. When multiple types of aircrafts are used, flows corresponding to these aircrafts having different suitability with regard to flight are considered. So, multi-commodity versions of the network flow problem[5] have to be used. As the problem becomes larger, special tools like Lagrangian relaxation, Dantzig-Wolfe decomposition etc have to be used for LP relaxations.

Several researches are done for the automatic creation of aircraft flight schedules, where the problem is a real world problem having constraints that are inter-twined in a complex manner. Nobue Adachi, et al.[6] used a genetic algorithm to achieve the optimization. Authors describe the problem setup and genetic algorithm configuration and verify the algorithm's effectiveness through experiments using real data. Significant reduction of the GA search space is achieved by setting the departure time and aircraft type of a flight as the minimum coding unit. Additional framework is constructed for improving the solution by assigning an aircraft from the specified aircraft type to each flight. Maintenance of the aircraft which is of high importance is not considered here. Traditional methods of developing flight schedules generally do not consider the disruptions that may arise during actual operations. L. H. Lee et al.[7] considered improvement in robustness and operational cost as main objectives and modeled a multi-objective programming problem by assuming that the aircraft rotation and crew pairing unchanged. Though the computation time

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is quite long, an efficient schedule was developed using genetic algorithm. W. Liang[8] research has proved that a global optimal flight sequence can be found using ant colony algorithm and they proved that the method reduces flight delay.

Based on the priority accorded for each requirement the approach of solving the problem will vary. The approaches considered for commercial airlines will not be sufficient for military aviation. Here various functions have to be considered along the trajectory for manned or unmanned vehicles separately. Dynamic Multiresolution route Optimization for Autonomous Aircraft [9] uses wavelet-like multiresolution representation allowing route optimization to be done at different scales for different portions of the trajectory. Using the evolutionary computing optimizer, more or less optimal solutions are provided depending on the number of iterations. Models are also needed to reinstate planned airline service following an unexpected perturbation in airline operations without changes to aircraft itineraries and crew rotations. An optimization model for a real-time flight scheduling problem [10] reoptimizes departure times and a new schedule is obtained by reducing flying, ground service, maintenance or passenger transfer time using time-based and dual formulations. By established traffic flow and capacity matching model based on traffic complexity, F. Sun et al.[11] developed a novel method for flight schedule plan using genetic algorithm. A multi-objective genetic algorithm is proposed to search Pareto solutions. The model is simple and realistic as the costs of time reductions, elements of the crew costs and passenger inconvenience are included in the objective function. A large number of researches are conducted with several types of objective functions and constraints.

B. FLEET ASSIGNMENT PROBLEM

Fleet planning is one of the most important strategic decisions that involve huge capital investment. It is assigning aircraft types to flight routes considering the factors like route length, passenger demand, seat capacity, operational costs, availability of maintenance time table etc. in order to maximize profit. Importance of fleet assignment lies in the fact that assigning too small aircraft to a particular flight results in spilling of passengers and assigning too large results in loss due to empty seats. Several aspects of fleet assignment were studied by Rexing et al.[12]. Output of fleet assignment becomes the input to aircraft routing; the output to aircraft routing is in turn the part of the input to crew planning. Barnhart et al.[13] proposed a string-based integrated model to simultaneously solve the fleet assignment and aircraft routing problems. Barnhart et al.[14] also proposed an itinerary based fleet assignment model which is an integrated model of fleet assignment and passenger. Many researchers have been done by combining the sub problems. Mou De-yi and Zhang Zong-xian[15] integrate the fleet assignment and aircraft routing stages in decision making process and guarantees feasible aircraft routings. They model the problem as a nonlinear programming problem. Studies are also made by fixing the fleet type to a particular type for finding optimal solution to the rest of the phases. Dr. Jenny designed the schedule with routing and maintenance of aircraft by fixing the fleet type[16].

C. AIRCRAFT ROUTING PROBLEM

Aircraft routing problem (ARP) is assigning of an aircraft to a route. Route consists of flight legs to be flown by individual aircraft. It can be single point route, from source to destination or multi-point route, from source to destination via few intermediate terminals. This is a special case of Vehicle Routing Problem (VRP) with maintenance as side constraint and so it is a NP-Hard problem. Several solution algorithms are developed based on linear programming, Lagrangian relaxations, two-phase heuristics and metaheuristics. ARP is usually solved for a given and fixed flight schedule and also the aircraft type (fleet) have to be determined. As the entire schedule is fixed the problem can be formulated as constrained Euler tour problem. L. Clarke et al.[17] approach was to dualize the constraint set to obtain Lagrangian relaxation. Chawalit Jeenanunta et al.[18] have performed aircraft routing for both international and domestic flights of Thai Airways. A multi-commodity network flow model for solving the problem is developed and aircraft routing and maintenance scheduling is generated for each instance and the solution to the problem found efficient after evaluation. Assigning aircrafts is always accompanied with maintenance scheduling.

D. MAINTENANCE SCHEDULING PROBLEM

Maintenance Scheduling Problem (MSP) is seen as a feasibility problem and it is typically considered after aircraft routing has been determined. Maintenance constraints need to be satisfied in MSP which vary depending on the airline, the aircraft, the maintenance program implemented etc. Talluri describes different types of maintenance for aircrafts[18]. Infrequent major overhauls to minor visual inspections are considered here. Frequent minor maintenances

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like cleaning, fueling, inspecting are performed during the turnaround time along with unloading and loading of passengers. Frequency of major maintenance operations depends on maximum number of flying hours, maximum number of landing, maximum number of calendar days etc., which is fixed based on the maintenance regulations established by FAA in US.

Maintenance activity can or cannot be performed during a maintenance opportunity, which is the minimum maintenance time an aircraft deadhead at a maintenance station. Based on the scope, duration and frequency different maintenance checks like Type A, B, C and D, are classified by Clarke et al.[17]. Based on this classification, C. Sriram and A. Haghani[19] present an innovative mathematical formulation and an effective methodology to solve the aircraft maintenance-scheduling problem. Solution to this large scale integer programming problem is produced by heuristic approach which is a combination of depth first search and random search. Chawalit[20] have classified the above maintenance types as two; light maintenance and line maintenance. Based on this, multi-commodity network flow model is developed and the solution is tested in three instances to prove its efficiency. Dr. Jerry[16] has formulated ARP and MSP as a longest path problem with maintenance side constraint and solved the problem with a heuristic algorithm.

H. M. Afsar et al.[21] have proposed a method that maximizes the aircraft utilization before maintenance interventions and smooths the flight load of the aircrafts so that maintenance checks are regular for all the flight. The method proved that the aircraft need not be provided with a maintenance opportunity on every certain number of days. Formulating the problem as mixed integer linear programming model, over or under maintenance aircrafts are identified and a better maintenance schedule is developed. Mathematical model for determining the best schedule for maintenance of aircraft is presented by N. S. Fard[22]. He developed an inspection schedule for critical paths of an airplane to minimize expected total cost of maintenance and failure per time unit. Sequential approach of ARP and MSP make the instances to have no feasible solutions and if a solution exists then it can be found in a range of several hours of computational time. Maintenance policies dependent on the states of the aircraft are obtained by Ville and Kai[23] by formulating maintenance scheduling as two problems. In the first, the average availability of aircraft is maximized by choosing when to start the maintenance of each aircraft and in the second formulation, the availability of aircraft is preserved above a specific target level by choosing to either perform or not perform each maintenance activity. Maintenance of fighter planes is considered here.

E. HYBRID APPROACH

Along with solving the problem of scheduling, airline company have to solve several related primary problems like fleet assignment, aircraft and maintenance routing etc and secondary problems like traffic forecasting and allocation, run way optimization, gate scheduling etc. As we have to explore several objective spaces and identify promising regions, optimization techniques must cater to multi-objective problems. E. K. Burke et al.[24] present an approach for multi-objective improvement of features in airline schedules. The approach is applied to investigate simultaneous improvement of reliability and flexibility in real world schedule by improving flight retiming and aircraft rerouting, subject to fixed fleet assignment. The search methodology is based on hybridization of genetic algorithms with local search. C. H. Chen et al.[25] studies a multi-objective evolutionary approach to solve the highly complex integrated airline scheduling problem which involves an optimization process assigning flight legs to both aircrafts and crews simultaneously under several real-world constraints. They successfully demonstrate an approach that uses NSGA-II method to solve the problem including routing and pairing sub-problem. Kalyanmoy Deb[26], proposed an evaluated preference genetic algorithm where selection, crossover and mutation are not particularly specified. The multi-objective optimization approach dynamically revises the original schedule and selects a new revised schedule with minimum negative impact of the disruption.

Genetic algorithm has become more important for researches as they can provide feasible solutions in limited time. Ming-Wen Tsai et al.[28] has proposed an effective two dimensional genetic algorithm which uses two-dimensional encoding scheme and appropriate two dimensional crossover and mutation operators to solve aircraft scheduling problem. The proposed two-dimensional crossover operator generates offspring chromosomes either by horizontal or by vertical approach. A repair mechanism for adjusting infeasible chromosomes to feasible ones is also proposed. Genetic algorithm is also used solve large-scale airline network planning problem. Katrin Kolker and Klaus Lutjens[29] present an assessable formulation and approach to integrate network planning and scheduling. They also integrate minor effects of aircraft rotation and passenger demand using genetic algorithm. Understanding of final profit

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composition is enhanced by including costs of ownership and revenue along with the operating cost in the objective function.

III. CONCLUSION

With high-speed development of aviation sector and the need for safe and profitable operation, dynamic flight scheduling has been one of the most important strategies of an airline company. In the survey highly sensitive planning problems faced by an airline company are addressed. Different methods for analyzing the problem by shifting the objectives and constraints are identified. Several related works varying in model and solution techniques are studied. Analysis states that the efficiency varies based on the objective function and constraints. It is found that traditionally, airline scheduling problems are solved by Operation Research techniques, which always require a precise mathematical model. But in real-world airline operation environment, there are too many factors to be considered dynamically, and it is very difficult to define a precise mathematical model in time. Mathematical models help us to solve the problem in polynomial time with a specific set of solution where as using evolutionary algorithms provide with optimal as well as suboptimal solutions. Recent trends in airline scheduling focus on integrated scheduling models and new approaches to build more robust schedules. As the design problem is multi-objective, these objectives have to be combined in order to yield a feasible solution. Evolutionary multi-objective optimization approach can handle several objective functions simultaneously, which is extremely useful for the scenario.

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