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A Genetic Algorithm Approach For Integrating Awacs Flight Training Programs Into Crew Schedules

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Abstract: Today, Air Force is the most effective element in defense and military organizations of the countries. In parallel with the technological developments in the defense industry, military combat aircraft and other air support elements contribute significantly to the success of the operations. The training of flying personnel using advanced technology and high capability weapons and equipment is getting more and more important every day. Individuals, who fly on high-cost platforms such as combat pilots and AWACS controllers are required to go through long and intensive training in order to achieve combat-ready status. Given the high costs of actual flights for training, a rigorous planning and scheduling activity is carried out to ensure that resources are used effectively and expenditures are minimized. In this paper, genetic algorithms were utilized for integrating AWACS flight training programs into crew schedules. The criteria which affect the scheduling were mathematically modeled and fitness function of the existing AWACS Crew Scheduling algorithm was revised. In order to measure the performance of the designed model, crew scheduling was carried out through a notional flight schedule of an artificial AWACS squadron similar to real-world examples. Genetic algorithms have been applied through a novel software developed as a test bed. As a result of the experiements, the algorithm was able to schedule all individuals based on the relevant criteria outlined in the guidelines, assigning students to flights with correct student-intructor pairings and complying with priorities selected by user while reaching the optimum solution in a reasonable time.

Keywords: AWACS, Crew scheduling, Genetic algorithms, Air force, Optimization, Flight training programs

Introduction

Air Forces generally has the largest share of military defense budgets. Thus, the training of personnel in the air force emerges as a costly process. The flying individuals such as pilots and AWACS controllers have actual training flights in addition to academic courses and simulator training in their training programs. This means that the resources spent on the trainings of these individuals are relatively higher than land force and navy.

One of the most effective ways to reduce the cost of flight training is proper fligt planning and scheduling. Optimal flight assignments and efficient scheduling can save a great deal on costs.

At present, significant amounts of manpower, resources and time are spent in scheduling activities performed manually at air bases and at the squadrons. The scheduling divisions of each base and each squadron continually work on long-range and short-range programs and strive to ensure that the training programs are carried out effectively by making changes to the schedule in line with the daily needs and disruptions in the program [1]. In order to integrate flight training programs into squadron flight schedules, there are a number of criteria outlined in relevant guidelines such as operational priorities, training requirements and crew constraints. At present, various solution methods have been developed for flight planning and crew scheduling, which are mostly carried out manually with classical methods.

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In addition to the routine exercises and daily training flights, operational flights can also be used for training purposes. Depending on the aircraft's capacity, more than one aircrew can be trained at the same flight, and the mutual coordination of the squadrons can help maximize the efficiency of training by using effective contracts.

The crew scheduling problem is defined as NP-Hard, since the problem space exponentially increases and the scheduling options can not be solved in polynomial time. Various studies have been published in the literature to prepare the most appropriate schedule in the dynamically changing conditions. With the advance of computer technology, analytical methods have been applied. And those methods are currently being replaced by *heuristics* and *metaheuristics*.

One of the best methods that can be used for the crew scheduling problem is the Genetic Algorithms due to its capability of yielding optimum results in a reasonably shorter times [2]. In this paper, a Genetic Algorithm-based approach is presented for integration of flight training programs into the crew Schedule of an AWACS Squadron. A mathematical model is proposed to assign the student-instructor pairs to the schedule in the most effective way, especially for basic training programs. The generated model was integrated into the fitness function of the existing genetic algorithm based solution [3].

AWACS Flight Training Programs

In an AWACS Squadron, there are basically two types of flight training programs. The initial training for an aircrew to become a combat-ready is called “Basic Qualification (BQ)” and/or “Combat Readiness Training (CRT)”. Once an aircrew gains combat-ready status, “Continuation Training – COT” is followed to maintain combat-readiness through flight career.

The initial training starts with academic courses, followed by practical exercises in the simulator, and is finally reinforced by actual flights. All the training stages are carried out under supervision of an instructor with a combat-ready status. At the end of each phase, the next step is to be taken based on the targeted achievements and student performance. Inadequate performance or other factors such as meteorology or cancellation of a training event that takes place at a flight may enforce a complete flight to be repeated. This is directly reflected in the flight schedule and may cause the entire schedule to change.

There is a wide range of criteria assigning students to the relevant training flights in dynamically changing conditions. Operational requirements, training requirements of other aircrew in the squadron, aircraft availability, number of qualified instructors and aircrew limits specified in the relevant guidelines constitute the main criteria for assigning trainees to the schedule. The maximum flight and duty periods, as well as crew rest periods for combat-ready individuals also apply to students. In addition to the criteria listed above, each student must be distributed an equal basis for training opportunities, and the same amount of training flights for similar types of missions must be considered.

On the other hand, it is also aimed to optimize the schedule to reduce flight costs and save resources. For example, assigning an instructor to the schedule for a COT requirement while pairing with a student on the same flight is a good optimization. Similarly; choosing an instructor among other instructors, who has fewer flying hours, is another optimization.

For the cases illustrated above, scheduling and optimization by manual methods is inadequate, and an algorithm is needed that can evaluate all the criteria and can provide a solution in a reasonable time.

Related Work

There are several studies in the literature about crew scheduling and crew scheduling with heuristics and metaheuristics. Those, who focus on effective scheduling of training programs are listed below.

Aslan [4], in his master thesis at the American Air Force Technology Institute (AFIT), worked on a decision support system in the preparation of the daily flight schedules of the Turkish Air Force F-16 training squadron and presented iteration based and object based solution approach by using heuristic methods.

Dyer [5] developed an application by using visual programming and an heuristic database-assisted algorithm, aiming to facilitate daily and weekly schedules through automation with a user-friendly display.

Evans [6] presented a solution for the US Special Forces MC-130 aircraft, using integer linear programming model with a savings-based approach to keep higher combat-readiness status and achieve maximum gains from the trainings in parallel with the recent budget cuts.

Gökçen [7] performed a wide literature research in order to build a robust crew schedule for fighter squadrons in face of absenteeism and he utilized analytical methods for problem solution and effective rescheduling.

Durkan [8] in his master thesis at AFIT, considered crew scheduling as an assignment problem of Operations Research, and applied Value Focused Thinking method to build a decision analysis model to help decision makers in fighter squadrons evaluate the mission-pilot matches. In this way, he has provided an analytical decision support algorithm in order to enable decision makers to choose the best solution.

Erdemir [9] used Greedy Randomized Adaptive Search Procedure (GRASP) for schedules in fighter squadrons and prepared the decision support automation to facilitate schedulers with a visual interface.

Yavuz [10], in his Master Thesis at AFIT, he used the GRASP method to prepare the weekly schedules in the F-16 squadrons of the Turkish Air Force and aimed to speed up the scheduling process. He has described the constraints affecting the schedule such as crew rest times, etc. as well as instructional constraints and examined the results through a sample weekly program by using MATLAB.

Vestli [11] used Column Generation method to create the schedules that would enable pilots to refresh their tasks within the maximum duration of the Continuing Training in a fighter squadron.

Kawakami [12] used an integer programming-based algorithm to assign pilots to flights in the Japanese and US Air Force fighter squadrons, and the generic program was able to find resolutions to problems with 19 pilots, 477 constraints and 129 variables in a very short time.

Nguyen [13] presented a visually-interactive modeling approach for assigning students to flights in the fighter training squadrons in his master's thesis and aimed to generate optimum schedule while creating an attrition environment to simulate attrition probabilities of aircraft sortie training due to operations, maintenance, weather, and other cancellations.

Newlon [14] used a mathematical programming-based algorithm for efficient scheduling in fighter training squadrons, evaluating integer solutions of binary code variables for each input in the program, aiming to increase combat-readiness.

Van Brabant [15] in his master's thesis, he proposed an integer programming-based solution approach for preparing flight programs in the operational naval fleet of the US Navy, thus aiming to increase the level of readiness for flying.

Shirley Jr. [16] used a rule-based heuristics to solve the United States Inter-Continental Ballistic Missile Battalion Crew Scheduling Problem, and he obtained schedules that were close to optimum in a short time with his algorithm.

O'Connor [17] developed an automation program to assist in scheduling responsibilities in the preparation of the program, emphasizing the necessity of a good scheduling activity for mission performance and high motivation in the fighter squadron.

Brown [18] used a mixed integer programming approach based on equality principle in training requirements and task distribution for the crew scheduling problem in the US Marine Corps Aviation Squadrons.

Mathematical Model

In modeling the proposed AWACS Crew Scheduling Problem [3], the criterion forming the schedule is defined as part of the objective function. The criteria that must have an absolute value to obtain a *valid* schedule are called hard constraints. The criteria used to optimize the schedule are soft constraints. For example, assignment of an individual to a unique mission is a "hard constraint". Because an aircrew can not perform two tasks at the same time. On the other hand, the assignment of an individual with a lower flight hour to the schedule constitutes a soft constraint.

In the mathematical model of the AWACS crew scheduling problem, it is desired to minimize the functions of hard and soft constraints by the "cost" principle. Each gene that does not meet the desired criteria adds some cost to the function in varying amounts. The cost of whole chromosome is obtained by summing up all these costs.

The fitness function used in the AWACS Crew Scheduling Problem is expressed in the following form.

$$\min T_{ijk} = \min \sum_{l=0}^{n} \left(\Delta te_{ijk} + \Delta c_{ij} + \Delta q_{ij} + \Delta \mu_{ij} + \Delta h_{i} \right) \tag{1}$$

T_{ijk}	:	Total cost of fitness function,
Δte_{ijk}	:	Training event readiness function for flight, Simulator and ground training
Δc_{ij}	:	Cost of time confliction,
Δq_{ij}	:	Duty equity cost,
$\Delta \mu_{ij}$	:	Cost for equal distribution of tasks
Δh_{i}	:	Equity of flying hours cost
i	:	0....n; flying individual in crew
j	:	0....n; tasks
k	:	0....n;training events

The Δc_{ij} variable here emerges as a hard constraint. An aircrew assigned to the schedule must comply with the criterion outlined in the guidelines while being scheduled to a unique slot. In other words, an individual must be available, having no other assignments such as administrative duties or other duties not including flying. The time conflict cost of an individual can be described as follows;

$$v = \begin{cases} 0, no\ conflict \\ \geq 1, conflict \end{cases}$$

Where;

v : multiplier of time conflict.

The other variables forming the fitness function, such as training requirements, duty equity costs, cost for equal distribution of tasks and general equity cost represents “soft constraints” and should be optimized to maximum extent.

Integration of Algorithm

The fitness function presented above may not satisfy squadron requirements when students and combat-ready aircrew are to be assigned to the same schedule. Since the BQ and CRT has different structures from COT Programs, an algorithm that can evaluate all training requirements together is needed. It is practically impossible to solve this NP-Hard problem by analytical methods where solution space is infinite.

In order to solve the problem described above, the following genetic algorithm solution is revised in crew scheduling and the following integration is performed.

Chromosome Structure: Students who are subject to initial training programs (BQ or CRT) do not enforce any changes in chromosome structure. Because the layout in the aircraft where seat assignments and crew positions of relevant functions are the same. The seat required by the crew position is used by the student and is assigned to the same scheduling slot.

The change that must be made in the programming of the algorithm is a pseudo modification for each chromosome cell (gene). If the student assignment is made, the instructor is to be paired with the assigned student. Whether or not a student assignment is made is indicated by a boolean variable. The aircraft capacity and the maximum number of aircrew for each position are also to be calculated.

Generating the Initial Population: The algorithm is expected to form the first population by random assignment method. If a student is assigned randomly, a random instructor should be assigned from the instructor pool and registered in the connected cell. The necessary update is made in the aircraft capacity and the next step is continued.

Evaluating Fitness: To evaluate fitness, the cells where students are assigned are to be calculated differently. As a prerequisite, the user opts for a priority for each student as "Low, Medium or High". Based on squadron needs, students may have different priorities. For each priority, a constant multiplier is determined and adapted to training requirements variable of fitness function. The original function for calculating training requirements cost is described below;

$$te_{ijk} = \min \frac{d_{ijk}}{P_{k\max}} \qquad (2)$$

Where;

d_{ijk}	:	days remaining to currency of aircrew i,for task j and training event k
$P_{k\max}$	:	maximum currency period for training event k
te_{ijk}	:	training event cost of fitness function

The above equation is to be revised to include students in the schedule as;

$$te_{ijk} = \min \frac{\omega_{ijk}}{P_{k\max}} \qquad (3)$$

Where;

ω_{ijk} : Priority constant for student i.

The value of ω_{ijk} is to be lower when a higher priority is selected and vice versa. Since the genetic algorithm aims to reduce cost in every generation, the students who need to be assigned with high priority will reduce the total cost of the chromosome.

Crossover: The difference of the crossover operation from the classical method is the distinction between the combat-ready individuals and the students. When the crossover is performed, the parent chromosomes must be carefully examined. A task that is full in capacity can take students from the other parent. This may cause the chromosome to become an invalid chromosome. Also, the instructors paired with the students are to have no conflict cost.

This is the most difficult step in the manual scheduling process and is one of the critical steps that demonstrate the ability of genetic algorithms to achieve rapid solving.

Mutation: A similar strategy is used for the mutation operation as in the crossover process. If there are students assigned in the genes to be mutated, correction is necessary to adapt to the new situation. The aim of this correction is the chromosomal placement of the student-instructor pair that optimizes the computational complexity.

Experiments and Computational Results

Experiments were carried out to study solutions obtained by applying the integration process to the algorithm described above. For this purpose, a sample weekly crew schedule for an imaginary AWACS squadron has been created. The squadron has 77 combat-ready aircrew and 11 students. The schedule is comprised of 20 tasks from various categories and 131 scheduling slots. The results obtained from the experiments are depicted in Table 1.

Table 1. Experiments and Results

Experiment#	Student# Assigned to Schedule	Rate of assigned Students	Instructor# properly assigned	Instructor Rate properly assigned	Solution Performance	Time elapsed (sec)
1	9	%82	8	%89	%96	4800
2	10	%91	10	%100	%99	5000
3	10	%91	9	%90	%97	4900
4	9	%82	8	%89	%95	5000
5	8	%73	8	%100	%90	4700

Source: Author's own calculations

Conclusion and Discussion

In this paper, a genetic algorithm-based approach is presented for integrating AWACS Flight Training Programs into the crew schedules. For this purpose, a mathematical model is proposed and integrated into existing fitness function of AWACS Crew Scheduling Problem [3].

Particularly for an AWACS squadron, where operations and training flights are conducted together, it is a difficult and cumbersome task to assign students to the schedule. Optimization of the product is aimed at to save resources where training flights constitute high costs to defense budgets. The student-instructor matches must be performed carefully and all training programs must be run in harmony. In addition, the criteria outlined in the relevant guidelines must be complied where crew rest limits and general flight rules must not be violated.

Since the solution space of the problem is exponentially increasing for even a few tasks, it is practically impossible to solve it with analytical methods. There are various studies in the literature regarding such problems defined as NP-Hard, among which Genetic Algorithms are the foreground. Genetic algorithms are based on the principle of constantly improving on the basis of natural inspiration and are able to capture near-ideal results for acceptable optimization problems that can not be solved by analytical methods.

In this study, the existing genetic algorithm fitness function was revised to integrate the students subject to the initial training programs into the crew schedules and unique strategies have been proposed for crossover and mutation.

Experiments were performed on a notional AWACS Squadron Crew Schedule to measure the performance of the updated algorithm and it was observed that the revised algorithm performed the optimum student assignments and optimum instructor pairings up to 100% success while satisfying all criteria with no loss of solution performance.

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