



**OPTIMIZING FLIGHT SCHEDULES BY
AN AUTOMATED DECISION SUPPORT SYSTEM**

THESIS

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AFIT-ENS-14-M-04

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To my father who passed away while I was working on my research at AFIT, to my wife and daughter for their loving support, patience, and for understanding of the long hours I spent working and to my mother and brothers for their encouragement and love – Thank you all.

Abstract

In current air forces, due to different types of aircraft and missions, lots of flight schedules are published every day. All flying units make their flight schedules each of which contain decisions of the best pilot-mission-aircraft triplet according to unit's own constraints and rules.

In this study, main objective is to build a decision support system to assist the schedulers in fighter squadrons. Scheduling in fighter squadrons are complex and time consuming due to the combination of the large number of constraints and limited number of schedulers. Also, dynamic environment of the operation area that increases uncertainty level of the problem makes flight scheduling a difficult job. For this reason, building flight schedules without any supplementary tools takes a large amount of time. Thus, air forces are in need of automated decision support systems for flight scheduling.

The required Decision Support System is coded in Microsoft Excel Visual Basic to produce flight schedules which are now made manually. To generate feasible schedules, Greedy Randomized Adaptive Search Procedures is implemented and generated schedules are scored to attain best solution. Following that, performance of DSS and scoring method are evaluated to analyze solution technique.

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Ugur ERDEMIR

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OPTIMIZING FLIGHT SCHEDULES BY AUTOMATED DECISION SUPPORT SYSTEM

I. Introduction

Background

When we think about scheduling, we are faced with a definition which is broad. One of the reasons for this is that scheduling has extensive application areas in the world. If we try to make a simple definition of scheduling, we can summarize it as a process of matching some limited resources with some jobs /workers in an effective and feasible way. Here, the job, worker and resource terms can be different in each community. For instance, while scheduling may be deciding the shifts of workers in a production company, in a transportation company it may be selecting the shortest routes of buses which deliver some items. These examples demonstrate that scheduling is an activity which is inherent in its related organization.

Today, all agencies and institutes from the lowest to the highest level are interested in scheduling problems. When planning the fiscal year program in Congress, distribution of the budget expenses to the several units is considered as a political level scheduling problem. Also, determining the number of military weapons to purchase in a pre-specified planning horizon may be an example of a scheduling problem in a strategic level. In addition to these, allocation of the purchased weapon systems in the country to achieve the most reliable homeland security system can be shown as a tactical level scheduling problem.

However, scheduling problems generally do not have to be included in one of these higher orders. Most of the time decision makers encounter issues which are not as

crucial as political or tactical problems. As mentioned above, companies that deal with deliveries or production of some materials do not try to solve high level questions. They work mostly on potential daily scheduling crises. Therefore, in addition to being inherent in its own organization, scheduling has the characteristic of containing different levels.

Scheduling holds a large region in Operational Science's focus area and occupies a substantial position in Operational Research. Since stake-holders in civilian and military environment have come across scheduling adversities; it has been on the agenda of these people. Many researchers have been trying to bring up solutions for this problem. Decision makers in civilian society and the military have dealt with scheduling issues and attempted to detect the best approaches to various problems for many years.

To sum up, in any fields in which there are certain jobs that need to be performed by limited executives with limited resources, decision makers will face with a scheduling issue at some level and they will try to assign the best job-worker-resource triplet.

Problem Statement

If we narrow the scope of the above scheduling problems and direct our attention to both civilian and military aviation sectors, we notice that flying operations and their supporting sections (logistics, supply, and maintenance) hold innumerable scheduling activities. Although the job-worker-resource triplet for each section and their sub-sections vary depending on problem areas in the related field, they all have the same common allocation issues. For instance, since the maintenance usually deals with equipment replacement or repair, one of the most universal issues in the maintenance section is settling the triplet of replacement work, technician and material. Considering flight units,

this triplet can appear as transportation, airplane and personnel. Another important and common triplet can be the composition of mission, pilot, and aircraft which is our main point of interest in this study.

As a course of flying activities' nature, there is some amount of uncertainty in aviation world that is in non-negligible. To be able to accomplish the desired objective which is different for each organization, it is required that all units of the system should work faultless or perfect throughout the process. Here, depending on the features of the system, the objective can be transferring passengers to the destination point, extinguishing the forest fire as quick as possible, destroying a sensitive target in a given time window and so forth. In all these scenarios, overall success of the system depends on the success of all sub-units. If we investigate the airline industry, we can easily notice this link between success of the system and its sub-units. When a passenger boards to a destination, there are lots of events which should be followed correctly by the airline company to achieve the satisfaction of the customer. No delay should exist while boarding, the airplane should land at the destination point on time, and the customer should not experience any luggage problems, and so on. But unfortunately all things do not go well in real life. At a particular step of the process, any of the sub-units can fail. Weather may be adverse, the airplane may have certain technical issues, traffic in the air may cause some delay and occasionally the pilot may have some physical problems which compel the company to change the pilot. When these undesired events happen, decision makers have to take proper measures on the details and arrangement of the flights to preclude losing their customers. As everybody would appreciate, making proper changes in this dynamic environment is an extremely challenging and time-consuming

action. Due to the connection between the flights, any variation in the schedule leads to re-planning all the system every time. Moreover, when the number of necessary changes increases, if proper decisions are not made, the company can lose huge amounts of money. Therefore, nearly all airlines have a separate department that helps the decision makers to make proper changes to the schedule in a short time without spending much money.

Unlike commercial airlines, scheduling on the military side has unique properties. Flight schedules in military units are handled by one or two officers who have the responsibility of making the flight schedule and being an active pilot together. Also, the schedule officers are not excused to fly or participate in the duties of their daily unit life. Moreover, because of details of mission type, weapon load, time over target, and such critical information that is contained in the flight schedules, the schedule officer should hold enough knowledge of flight rules, maintenance procedures, possible weapon load, training programs, and similar data. For this reason, these officers are chosen from experienced pilots to make this difficult task easier.

Today, because of political, tactical or financial concerns, large numbers of countries have pilot shortage problem in their air forces. In these countries, the number of active-duty pilots is well below the required level which is a critical factor for the power of that air force. Although headquarters try to mitigate this undesired situation, this issue looks like a foregone conclusion on the account of having better working environment and conditions in commercial airlines after the cancelation of their contract with air force. Besides the impact of pilot shortage to the capabilities of the air force, it induces some important problems for the pilots who stay in the system. In spite of the shortage,

workload level and the amount of missions is not decreasing with the decreasing pilot level. Thus, while a pilot does his/her primary job (flying), he/she may have additional overwhelming responsibilities in his/her unit. Scheduling can be accepted as an example of these overwhelming responsibilities and may be accepted as the most difficult one. To understand why scheduling in military is so challenging, it is a good idea to look briefly at how the flight schedule is built and what are the points that make the schedule troublesome.

If we examine the flight scheduling process in several air forces, we see different procedures and policies. While some air forces totally make their schedules manually, some air forces use supporting tools to assist the schedulers. In both procedures, there are some steps that schedulers should follow.

In a routine day, before planning the following day's schedule, firstly, the scheduler should learn the number of available aircraft, list of the available pilots and their calendar. Secondly, the weather forecast should be examined for the following day. Also, the scheduler should get the details of mandatory operational flights, commander's concerns and similar information. After collecting essential data, the scheduler should specify the objectives for the schedule according to the attained information. Next, the group of pilots who need to fly should be determined. When deciding who to fly, the scheduler should think about a couple of things like the currency of pilots, mission capabilities and skills of them. Another important consideration is assigning a suitable flight position that is parallel to the proficiency of the pilots. For example, putting a pilot in two-ship leader position who is actually a four-ship leader without any reasonable explanation is not effective planning. Moreover, weather is a critical factor which can

force the scheduler to change all the planning. If the weather is unsteady during the block hours and the scheduler does not take this into account, this can cause dramatic results. These are just a few points which can help us to see the difficulty of this process. In real life, there are lot more things to think about for a flight scheduler. The flight scheduling process will be covered in later sections in details.

Currently, in most air forces, flight schedules in fighter squadrons are produced by the aid of certain software products which are nothing more than an application of error checking. These software products just prevent the scheduler from making mistakes like assigning a single pilot to multiple positions or setting shorter time aside for the pilot before the next flight. Thus, current supporting tools are not helping the schedulers in the context of decision making. The Scheduler should decide the pilots, missions, times and remaining information in the flight schedule.

To conclude, the dynamic environment of flight activities, the multiplicity of inputs, the great number of constraints and the limited amount of time reserved for schedulers oblige air forces to look for an automated scheduling tool to make flight schedules in a short time and practical way.

Scope of the Research

In this research, determination of the optimum pilot-mission-aircraft triplet is studied and it is applied for attaining the flight schedule of a simulated flight unit. Among all air force units, fighter squadrons have the most time-consuming scheduling process in that the automated tool is implemented to a fighter squadron. Regulations related to fighter aircraft and pilots are taken into consideration and used in the application. Even

though the tool is built for fighter squadrons it has common features by which all other flight units can benefit. Also, by means of the automated scheduling tool it makes a feasible flight schedule according to chosen objectives and given inputs. Since there isn't any computer program that assesses the dynamic situations better than human beings, some evaluations are allowed and/or required in particular steps of the tool for the best solution.

Research Question

Within the frame of this investigation, it is endeavored to answer the question:

How can an optimum pilot-mission-aircraft triplet be attained and used in a flight schedule by the aid of a decision support system?

Since the ultimate purpose of this study is to improve the construction phase of a flight schedule, it is required to look for a solution which represents the response of *which pilot should be assigned to fly what mission in which type of aircraft?* The decision support system is developed to answer these questions and to have a feasible flight schedule in a short span of time. Following the detection of the optimum match, it is intended to use this match in an appropriate position in the flight schedule.

Summary

In this chapter, general scheduling problems and their applications are discussed. Next, by limiting the scope of the problem, possible scheduling difficulties in civil and military aviation are stated. After that, the flight schedule procedure in most air forces is explained and possible reasons that make the schedule a challenging work are defined. Later, the research question is designated as how to detect optimum pilot-mission-aircraft

triplet and apply this data to a flight schedule by the aid of a decision support system. In Chapter 2, previous researches on flight scheduling problems are examined and background of scheduling problems is discussed. In Chapter 3, the solution technique and methodology of the problem is explained in detail. In Chapter 4, the analysis of solution technique is argued and performance of developed DSS is evaluated along with scoring method of schedules. In Chapter 5, the summary of the research, conclusion, and recommendations for future studies are mentioned.

II. Literature Review

Chapter Overview

The purpose of this chapter is to review previous research on flight scheduling in chronological order to learn how to implement similar applications to the flight schedule generation process. Since the GRASP heuristic method is applied in this research, general information about GRASP is covered following recent research on flight scheduling. The chapter ends with a description of Microsoft Visual Basic for Application to explain why it is used.

Recent Research on Flight Scheduling

Multiple studies on squadron flight schedules have been performed by many researchers. If we review these past works, we notice that while some of these studies focus on certain steps of scheduling and try to reveal meaningful solutions, some of them attempt to offer important information which can assist schedulers on pilot assignments to missions but leave all decisions to the scheduler. Furthermore, others make an effort to expedite the scheduling process by means of support tools. Here, one important point to consider in these studies is that most of this research concentrates on training units instead of fighter squadrons. Of course, there are lots of reasons to solve the scheduling problem in training squadrons rather than fighter squadrons. Most critical reason is the ease of scheduling in training squadrons compared to fighter squadrons. The motivations underline this can be described as:

- i. In Training squadrons, for each pilot there is a pre-specified syllabus that shows mission order and requirements. Schedulers must follow this order

for all student pilots. Thus, the next mission to be flown is known before hand by schedulers. For instance, in F-16 training squadrons, a student pilot is required to fly basic phase, air to air phase and air to ground phase. In each phase, there are several missions that a student pilot will fly in order. If he/she flew BFM-1(Basic Fighter Maneuvers-1) then he/she has to fly BFM-2 in the next sortie. For this reason, schedulers in such squadrons do not have to determine pilot-mission matches which may be a topic of another single thesis.

- ii. Most of the pilots in training squadrons are composed of instructors and student pilots. Instructor pilots can be assigned to all possible flight positions both in formation (number 1, 2, 3, 4) and aircraft (front-cockpit or back-cockpit). Besides, student pilots can only fly in wingman positions and/or in front-cockpit. Therefore, the time to make a feasible schedule is extremely shorter than fighter squadrons in this aspect.
- iii. Since most of the eligible pilots for ground duties such as SOF (Supervisor of Flight) and RSU (Runway Supervisor Unit) are instructors, the scheduler does not care about proficiency level-ground duty match. For example, while SOF duty can only be accomplish by four-ship leaders and instructors, two-ship leaders and wingmen are assigned to RSU duty as a mainstream in fighter squadrons. This constraint increases the difficulty of scheduling fighter squadrons.
- iv. Headquarters task several squadrons on different operational flights to maintain equal order distribution among air force units. While squadrons

are being tasked, current assignments given to squadron, workload of unit and a few similar criteria are taken into account. Thus, as a general rule, training squadrons are seldom tasked with operational flights not to affect training timeline negatively. On the other hand, nearly every week fighter squadrons are tasked with operational flights which the scheduler is obliged to use and put inputs that come from the ATO (Air Task Order) into the flight schedule.

As seen above, complexity and difficulty level of the problem in training squadrons is less than fighter squadrons.

Several articles have been presented about flight scheduling. To understand how recent research dealt with this problem, it is required to review similar applications and their solution methods.

Nguyen's research is one of the studies for training squadrons which assists schedulers by an Excel VBA tool with user friendly Graphical User Interfaces to attain initial feasible solution. Nguyen attempts to solve the scheduling problem in 87th Fighter Training Squadron and named his supporter tool as SSDT (Squadron Scheduling Decision Tool). This tool is designed to improve squadron's current system which is thought nonresponsive to the scheduling problems in efficient way. Nguyen's built up his tool by using framework of present application. Because of spreadsheet usage method in previous version of scheduling tool, instead of adding some kind of engine to produce schedules, Nguyen sticks to spreadsheet method (Nguyen, 2002).

Since his aim is to apply his study to a training squadron, Nguyen's main objective is to maximize sorties while meeting training requirements. To achieve this

goal, Belton and Elder's Visual Interactive Modeling approach is employed to generate robust feasible schedules. Belton and Elder's Visual Interactive Modeling (VIM) utilizes subject matter expert knowledge to guide the schedule generation process. (Nguyen, 2002) Figure-1 shows how Belton and Elder's VIM works in scheduling process. According to Belton and Elder, VIM utilizes an interface to some heuristic engine, with a built-in control mechanism, to influence heuristic search, preference, or performance criteria (Belton and Elder, 1996, p. 164).

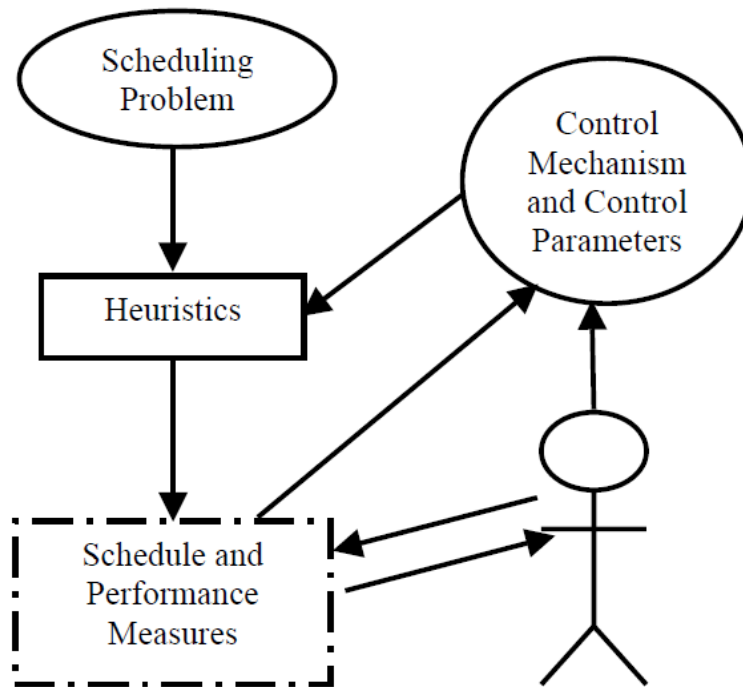


Figure 1-Belton and Elder's Visual Interactive Modeling (Belton and Elder, 1996)

When we look at Nguyen's research in detail, we see some important advantages of his implementation. First of all, if certain portions of schedule need to be changed,

scheduler has a chance to interact with generated schedules until satisfactory schedule is built. Secondly, as SSDST is a modified version of current scheduling tool, schedulers do not have to be trained for adaptation. Finally, scheduler can pick the scheduling rule by which initial feasible schedule is produced.

In Figure-2 implementation of Belton and Elder's VIM into 87th Fighter Squadron flight scheduling can be seen.

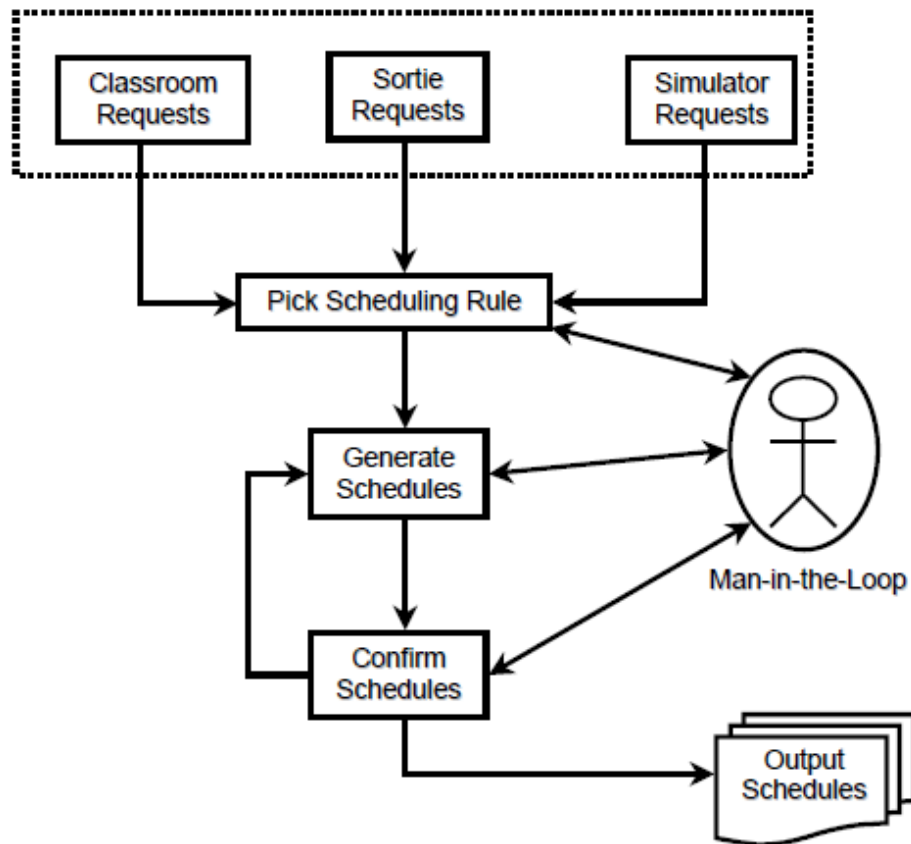


Figure 2-VIM Implementation in Scheduling Process (Nguyen, 2002)

In addition to the remarks above, the most powerful aspect of Nguyen's research is that scheduler can manually prioritize a specific flight over all flights. If a student pilot

needs to be re-scheduled due to non-effective mission or weather concern, scheduler is allowed to assign high priority to this flight to assure it is located in candidate schedule. Nguyen applies three different scheduling priorities in his study. These are described as Largest Number of Requests, Flight Behind the Training Schedule the Most, and Class Seniority. (Nguyen, 2002) The Table-1 which summarizes Nguyen's scheduling algorithm shown below.

Table 1-The Scheduling Algorithm (Nguyen, 2002)

<u>The Scheduling Algorithm</u>	
1.	Scheduler input flights' requests and special requirements.
2.	Scheduler selects appropriate flight priority (dispatch rule)
3.	Software prioritize flight requests based on selected priority (dispatch rule)
4.	Assigns flight request based on the priority to appropriate time-slots
a.	Assign sortie requests
b.	Assign simulator requests
5.	Scheduler modify schedule if necessary. Repeat step 2 if new prioritization is needed.
6.	Finalize schedules.

Another study on scheduling in training squadrons is Aslan's research which focused on an F-16 pilot training squadron. He developed a decision support system tool which proposes daily flight schedules using a heuristic approach. Aslan utilizes MOL (Mission Order List) described in squadron's syllabus and assigns missions to student pilots by the aid of this list. As in Nguyen's study, Aslan's decision support system begins with production of an initial feasible schedule and DSS generates final schedule

using the shifting bottleneck heuristic approach. Again, the scheduler can edit the schedule according to his/her desired inputs in particular steps of production (Aslan, 2003).

Aslan cites his tool as fighter training squadron scheduling support tool (FTSSST) which is mostly a spreadsheet based scheduling software. Objective of FTSSST is determined as maximizing number of pilot sorties, similar to Nguyen's study. Moreover, Aslan specifies that his research can be put into practice in training squadrons for generating weekly schedules and/or long-term planning purposes (Aslan, 2003).

Table 2-Feasible Initial Solution Construction Heuristic (Aslan, 2003)

1. Persons are assigned to duties
2. Scheduler selects the MOL
3. The missions are ordered according to the selected priority rule
4. If needed, "must-fly" student missions are prioritized in the MOL
5. Ties are broken according to the LFJ-LFM first rule
6. DFS is generated and if needed missions can be altered or a new mission can be inserted
7. Other resources for the mission are recorded on the DFS
8. Simulator schedule is produced (if required)
9. Course work is scheduled.

Additionally, Aslan underlines that daily flight schedule process investigates three different rules to prioritize candidate flights and puts them in order for further assignments. Following this step, shifting bottleneck heuristic is applied to candidate

flights to build a feasible schedule. Table-2 shows the phases of feasible initial solution construction heuristic and Figure-3 demonstrates Software Implementation of Aslan's research.

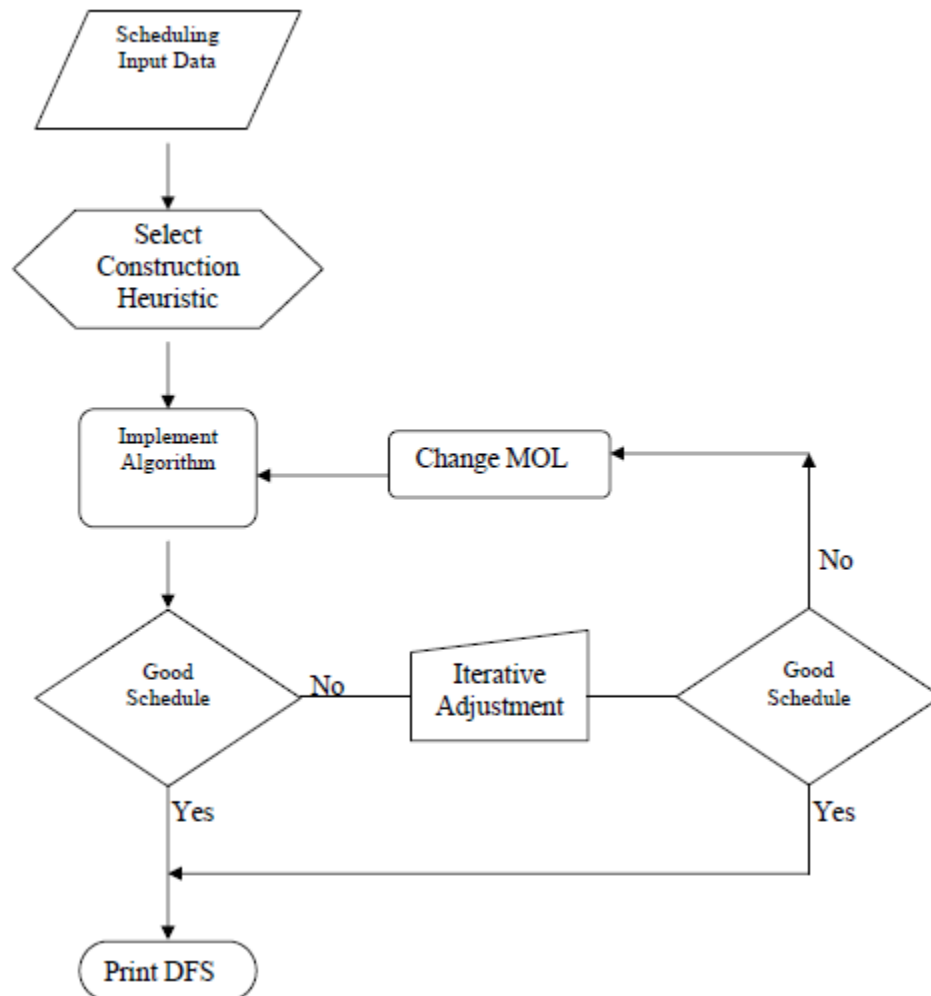


Figure 3-Software Implementation of Construction Heuristic (Aslan, 2003)

As seen in Figure-3, the scheduler can make some iterative adjustments until a good schedule is generated. The disadvantage of this method is that scheduler is not allowed to make any arrangements before or after the schedule is built. Besides, it is not

designed to put operational missions into flight schedule. On the other hand, considering ground duties such SOF and RSU, and figuring out scheduling problems for a small scale in short-time period are powerful points of Aslan's work (Yavuz, 2010).

Soon after Aslan's research, Boyd, Cunningham, Gray, and Parker put forth a network flow model (shown in Figure-4) to set up weekly flight schedule in fighter squadrons of Germany. However, their model is not applicable to real squadron schedules in USAF due to the necessity of additional study on the model. In their research, they emphasize that scheduling in fighter squadrons is very complex and heavily constrained process (Boyd et al., 2006).

The authors attempt to solve scheduling problem by splitting workday as AM and PM GOs. Because of wide AM and PM GO ranges, this technique decreases number of candidate pilots while actual number of available pilots is higher in reality. Since, this method is not accepted as adequate solution by the researchers, they suggest using more than two sections for a workday in future studies. Conversely, authors add that using more than two sections would increase number of variables dramatically and this dramatic increase would go beyond the limit of software which is Premium Solver Platform. In addition to workday splitting caveat, the model takes flight hours of past week instead of flight hours of each pilot as an input. This may lead model to assign possibly same pilots while they should not be assigned because of high flight hours. Finally, due to the structure of model, entering manual inputs to flight schedule is not allowed. In other words, scheduler cannot assign a requested pilot to specified mission manually (Boyd et al., 2006).

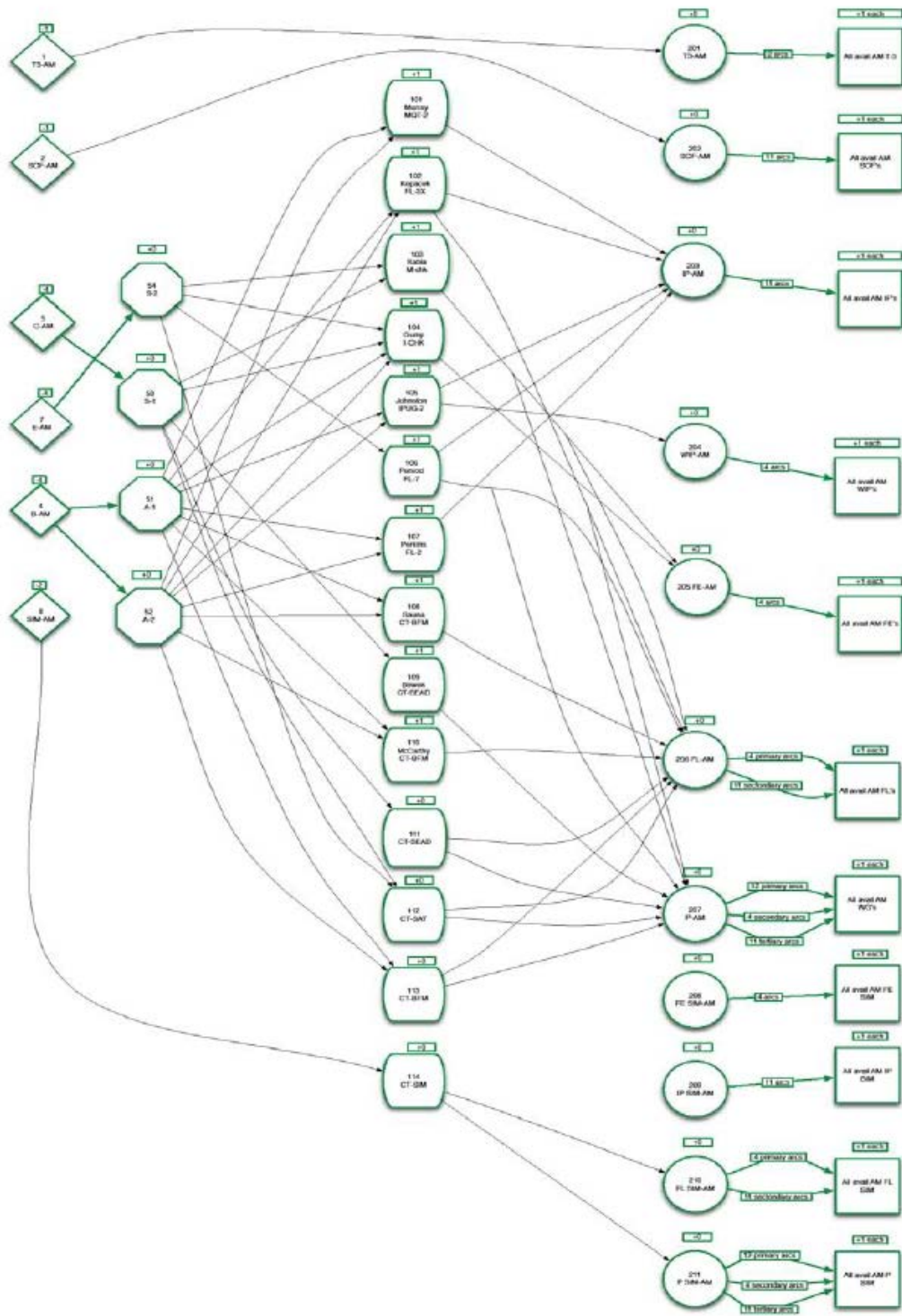


Figure 4-Network Flow Model (Boyd et al., 2006)

After the study of Boyd et al. (2006), Newlon makes a mathematical model of the scheduling process related to a fighter training squadron. Newlon follows the recommendations mentioned in Boyd et al.'s research. (2006) and establishes a model with Graphical User Interfaces by using Excel Visual Basic Applications. Hence, Newlon's research can be assumed as a upgraded model of Boyd et. al.'s research (2006)

Newlon starts from the points which Boyd et al. (2006) experienced difficulties to figure out. One of these difficulties was dividing the workday with two sections such AM and PM GOs. Since, Boyd et al. suggests dividing workday into hourly parts to overcome decreased available pilot count, Newlon partitions workday to hourly sections Monday through Friday in his model. He separates week into ten portions (he names these portions as sub-problems) and solves scheduling problem by taking these sub-problems as constraints of overall problem. Due to having less complex problem and relatively lower number of variables by dividing entire weekly schedule into ten sub-problems, an optimum solution can be found in Excel Solver Platform in this way. Solution steps start with solving sub-problem of Monday AM portion of the weekly schedule to optimality within given constraints. Next, Monday PM through Friday PM portions are solved in sequence (Newlon, 2007).

Newlon's model introduces two methods to achieve main objective of building a feasible schedule. First method is solving ten sub-problems by using results of the preceding one as inputs to next sub-problem, similar to chain reaction. The second method is assuming weekly schedule as one piece and solving it to optimality by utilizing conclusions of ten sub-problems (Newlon, 2007).

Similar to previous applications for training squadrons before Newlon, there are significant points to consider in his research, too. Firstly, while mathematical model attempts to find an optimum solution for each sub-problem, it may be required to fly an out-of-squadron pilot(s) in some scenarios. In real life, most of the time this suggestion might not be possible and results to have an infeasible schedule. Secondly, Newlon uses three different pilot availability levels (Available, unavailable, and DNIF). However, practically a pilot can be available or unavailable for just some portions of a workday. Thus, making hard definitions on availability might omit large region of optimal solutions. Finally, Newlon's research does not take into account manual inputs from Director of Operations. In a routine day, because of the squadron's nature, it is always possible that Director of Operations requests some pilots to be assigned directly to the schedule (Newlon, 2007).

Gokcen's research is another study on scheduling which generates robust flight schedules for fighter squadrons. Gokcen tries to develop weekly schedule by producing multiple schedules and comparing these generated schedules according to expected number of real-like updates that resemble to potential daily changes. Following comparison phase, candidate schedules are sorted with respect to number of updates and schedule with minimum number of updates is accepted as best schedule (Gokcen, 2008).

Gokcen's primary objective is developing a schedule which has smallest probability of being re-arranged or smallest probability of assigning alternate pilots. To achieve this goal, Gokcen mentions some assumptions to narrow down the scope of the problem. However, these assumptions might be seen a little far from daily squadron structure. For instance, the number of flown sorties is limited to six flights. Since Gokcen

divides workday into AM, PM, and Night GO sections, assuming to have maximum of six flights is not realistic for a fighter squadron. Furthermore, all of flight leads are assumed to be four-ship leaders and two-ship leaders are not included in Gokcen's model. In most of the fighter squadrons the number of four-ship leaders is almost the same as number of two-ship leaders. As a result of this, number of scheduled two-ship missions is high in the flight schedule. Moreover, Gokcen assumes that squadron does not have any D model (two-seated) aircraft. However, as he stated in this study, every squadron has two-seated aircraft to keep training level as high as possible and scheduling two-seated aircraft is the most difficult part of the schedule. If scheduler can decide two-seated aircraft assignments, remaining sections of the schedule does not take much time (Gokcen, 2008).

Two years after Gokcen, Yavuz works on automating weekly flight schedules for fighter squadrons especially in Turkish Air Force. Yavuz intends to generate a weekly schedule which facilitates scheduler's work by precluding non-current pilot existing for any missions and unequal distribution of pilot sortie counts in the squadron (Yavuz, 2010).

Yavuz's research answers the question of which pilots will be assigned to predetermined missions. Data of predetermined missions include take-off time, landing time, and pilots in which category will be assigned to mission. This means that pilot name slots of the flight scheduler should be filled by scheduler. Therefore, Yavuz focuses on pilot assignment portion of flight schedule (Yavuz, 2010).

To designate pilots to pre-specified missions, Yavuz developed a grading technique for all possible pilot-mission matches. Remaining day count to be non-current for each mission, number of flown sorties in a month, pilot status, pilot category, and similar information for each pilot are considered while deciding grades of pilot-mission matches. Yavuz sums equations shown in Figure-5 and Figure-6 for each pilot-mission match to calculate grade (Yavuz, 2010).

$$\text{Grade1}_{ij} = 180 + [\text{Flight Date}_i - \text{Last Flight Date}_{\text{mission}(i),j}] - \text{Currency Limit}_{\text{mission}(i)} \quad (3.1)$$

Where;

i: Number of the pilot-mission match on the schedule, $i=1,2,\dots,285$

j: Number of pilot, $j=1,2,\dots$, number of pilots

mission(i): Number of the mission type (including other duties) of i^{th} match, mission type=1,2,...,24

Figure 5-Equation-1 of Grading Pilot-Mission Matches (Yavuz, 2010)

$$\text{Grade2}_{ij} = 500 * (20 - \text{nos}_j) / \text{remaining available days in the month} \quad (3.2)$$

Where;

i: Number of the pilot-mission match on the schedule, $i=1,2,\dots,285$

j: Number of pilot, $j=1,2,\dots$, number of pilots

nos(j): Number of sorties flown by the j^{th} pilot during this month

Figure 6-Equation-2 of Grading Pilot-Mission Matches (Yavuz, 2010)

After grading pilot-mission matches, Greedy Randomized Adaptive Search Procedures (GRASP) is implemented to decide which matches to put in flight schedule. In Yavuz's study, manual assignment of any match is allowed without considering low or high grade of match. Implementation of GRASP and overall process in Yavuz's research are shown in Figure-7 and Figure-8 (Yavuz, 2010).

```

Begin
Import the inputs
For i=1 to number_of_iterations
    Update the inputs according to the manual assignments
    While there exist a possible pilot-mission match
        While criteria  $\sim$  0
            Calculate the grades for each IP-mission match
            Calculate the criteria using Eq. (3.4)
            Find the matches whose grade  $\geq$  criteria and import them to the RCL
            Choose randomly one match from the RCL
            Assign the pilot to mission
            Update the inputs
        End
        While criteria  $\sim$  0
            Calculate the grades for each pilot-mission match
            Calculate the criteria using Eq. (3.4)
            Find the matches whose grade  $\geq$  criteria and import them to the RCL
            Choose randomly one match from the RCL
            Assign the pilot to mission
            Update the inputs
        End
        Reset all inputs to the previous week's values
        For j=1 to number of pilot-sorties in the schedule
            Calculate the benefit of the jth flight on the schedule
            Total Benefit = Total Benefit + the benefit of the jth flight
            Update the input based on first j flights
        End
    End
End

```

Figure 7-Implementation of GRASP (Yavuz, 2010)

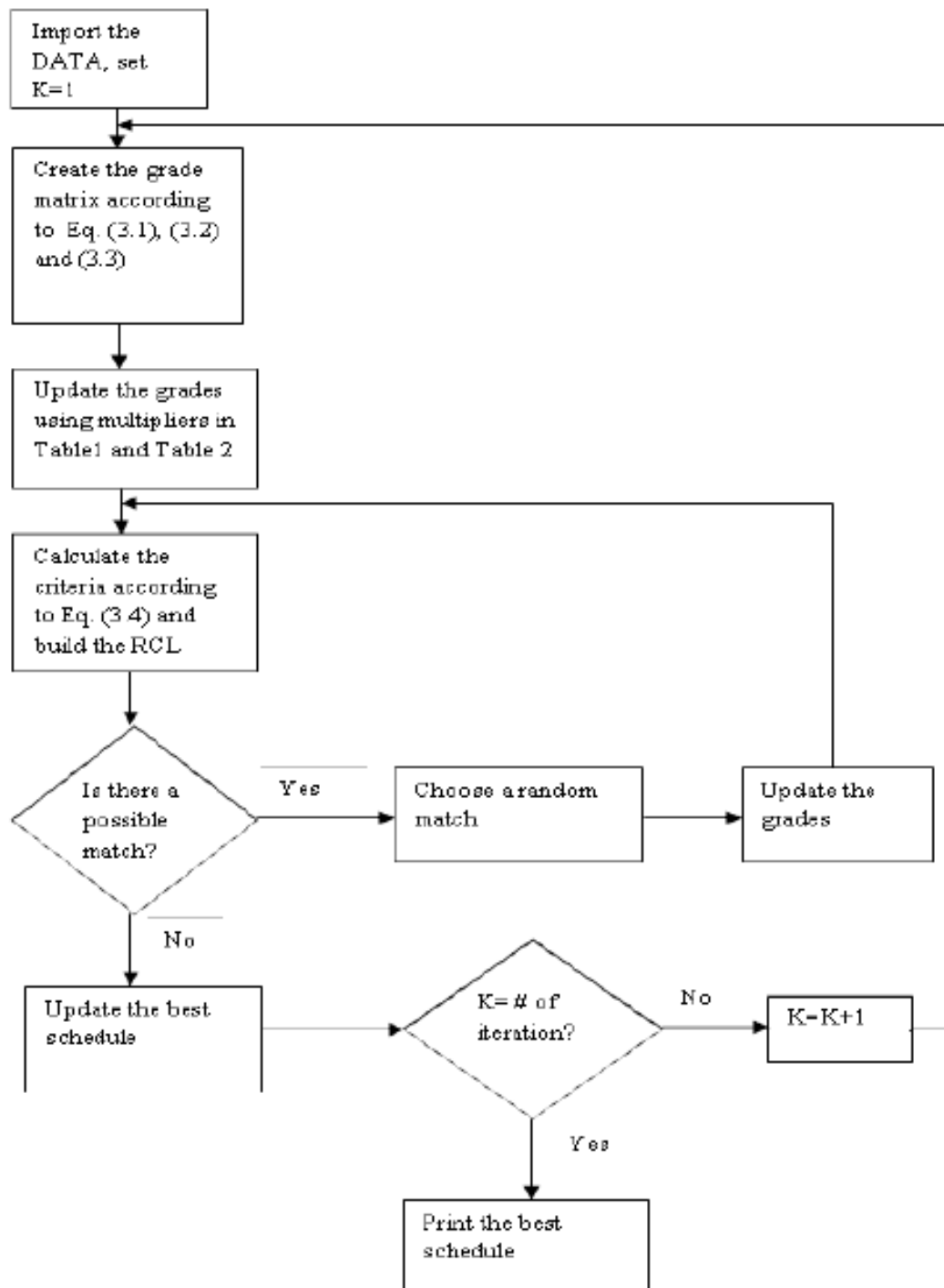


Figure 8-Overall Process (Yavuz, 2010)

Yavuz uses different programming language than researchers who focused on same topic before him. Despite studies till Yavuz utilizing VBA and Microsoft aided tools, Yavuz prefers to use MATLAB. However, important handicap of this preference is that schedulers in most of the squadrons like to use or are familiar to Microsoft Excel aided tools. So, fighter squadrons should purchase MATLAB to carry his model into effect (Yavuz, 2010).

Following Yavuz a research on establishing a decision analysis model which evaluates pilot-mission matches to assist decision makers on flight schedules is made by Durkan. He looks for a way to save time on flight scheduling and applies Value Focus Thinking approach to his model to sped up the flight scheduling process by the support of experienced schedulers and decision makers. Also, Durkan states that decision analysis model orders pilot-mission matches at the end of evaluation phase. Moreover, he assumes the evaluation of pilot-mission matches as multi-objective assignment problem and claims that decision analysis model in his research presents relatively new solution technique (Durkan, 2011).

Durkan's model helps scheduler in manually built flight schedules and focuses on specific time frame like a block or a day. Durkan summarizes the process of the model in three steps and sets his goal to achieve first two steps. These three steps are:

- i. Building an evaluation model using VFT (Defining objectives and values).
- ii. Using the evaluation model structure to aid the scheduler in manually building schedules (Decision Support System).
- iii. Automating the process of pilot-mission assignment with the help of defined values and objectives.

Durkan asks the question of “What is the value of pilot-mission match in a specific block of time?” to start his methodology. To determine value of particular pilot-mission match, Durkan carries out four major measures shown in Figure-9 (Durkan, 2011).

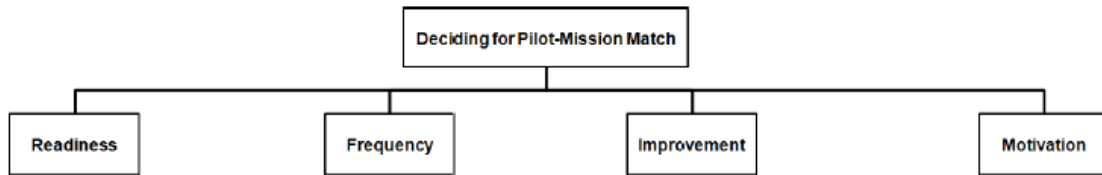


Figure 9-Four Major Values for Pilot-Mission Match (Durkan, 2011)

He cites measures for each major value branch and their value functions for evaluation. Preferences of decision makers and subject matter experts are considered to construct value functions to get results close to real life. In construction phase of value functions, Durkan uses a software tool (Hierarchy Builder 2.0, Weir, J. 2008) to built value hierarchy (Durkan, 2011).

Greedy Randomized Adaptive Search Procedures (GRASP)

Today, finding the optimum solution of current problems is regarded as a primary objective of most organizations. They spend considerable amount of money and build functional units that are dedicated to focus on optimization. They also task personnel to work on this issue. Although, how much money, time and/or personnel is devoted to get a feasible solution depends on the difficulty level of problem, most of the time decision makers have to decide among numerous alternatives. Especially, when we look at

problems waiting to be solved in military, we see that they might have countless solution combinations which result in different resources and costs.

One of the simplest ways to find an optimum solution is assessing all alternatives according to objectives of the respective organization and choosing the alternative which satisfies defined objectives most. Since this suggestion works perfect for limited number of alternatives, it can be accepted as reasonable when the number of alternatives is high. However, when the number of alternatives is extremely high, the assessment phase of all alternatives may not be possible because of the long-time period it takes. Therefore, some methodologies are developed to fix multi-alternative solutions (Feo and Resende, 1994).

Greedy Randomized Adaptive Search Procedures (GRASP) is an example of methods to fix multi-alternative solutions for large scaling problems either in air force or civil aviation. Since decision-makers do not have much time to look for a slow solution, they generally prefer to go forward with feasible but not necessarily optimal solutions. Crew scheduling, vehicle routing and transportation are some areas that we might come across several GRASP applications (Feo and Resende, 1994).

```
procedure grasp()  
1   InputInstance();  
2   for GRASP stopping criterion not satisfied →  
3       ConstructGreedyRandomizedSolution(Solution);  
4       LocalSearch(Solution);  
5       UpdateSolution(Solution,BestSolutionFound);  
6   rof;  
7   return(BestSolutionFound)  
end grasp;
```

Figure 10-GRASP Steps in Pseudo-Code (Feo and Resende, 1994)

GRASP is a multi-start procedure which consists of a construction and local search phase. Before starting GRASP construction phase, all necessary inputs are taken to be used later for producing a feasible solution list. Also, termination criteria to stop the iteration process should be determined before starting GRASP. Overall GRASP steps are shown in Figure-10 (Feo and Resende, 1994).

In the construction phase, the most efficient candidate is chosen from the feasible solution list. Of course, to pick the most efficient element, all the elements of the candidate list should be ordered by the aid of some functions. After selecting an element from the list, all remaining candidates are updated due to the impact of previous selections. For this reason, the “Adaptive” term is used in GRASP. Besides, there are not any limitations for the selection of the most efficient element of the candidate list. The chosen element might be a random one among best candidates. The “Randomly” part of GRASP comes from this logic. Construction portion of GRASP can be seen in Figure-11 (Feo and Resende, 1994).

```

procedure ConstructGreedyRandomizedSolution(Solution)
1   Solution = {};
2   for Solution construction not done →
3       MakeRCL(RCL);
4        $s = \text{SelectElementAtRandom}(\text{RCL});$ 
5       Solution = Solution  $\cup \{s\}$ ;
6       AdaptGreedyFunction( $s$ );
7   rof;
end ConstructGreedyRandomizedSolution;

```

Figure 11-Construction Phase of GRASP (Feo and Resende, 1994)

As mentioned above, solutions attained by selecting random or best elements of candidate list do not promise optimality. Therefore, if decision-makers desire the best course of action, local search phase is required. Local search phase is a substitution procedure that previous solution is switched with a new better solution when it is compared with its neighborhood. Here, how to decide which solution is more satisfactory than the others should be defined clearly to be able to apply local search in an effective manner. Local Search phase is shown in Figure-12 in details (Feo and Resende, 1994).

```
procedure local( $P, N(P), s$ )  
1   for  $s$  not locally optimal  $\rightarrow$   
2       Find a better solution  $t \in N(s)$ ;  
3       Let  $s = t$ ;  
4   rof;  
5   return( $s$  as local optimal for  $P$ )  
end local;
```

Figure 12-Local Search Phase of GRASP (Feo and Resende, 1994)

The common issue within both construction and local search phases of GRASP is the required time to apply these steps. How much time these phases take depends on how sufficient the initial solution they have. In addition to this, starting with well-designed algorithms is the key point to achieve adequate initial solution without spending much time. It is always easier and faster to have a good initial solution if powerful implementations are utilized (Feo and Resende, 1994).

Microsoft Visual Basic

In this research, Microsoft Visual Basic for Applications (VBA) is preferred to implement GRASP techniques. There are several underlying reasons to make this choice.

Seeing that this research addresses fighter squadron schedules and schedulers, it is needed to present some thoughts about the suitability of VBA to fighter squadron environment.

First of all, schedulers in fighter squadrons regard with disfavor models which require any certificate or training program to be able to use it. If it is considered that schedulers are already active pilots in the squadron and being a scheduler does not allow them to be exempt from their main responsibilities, it is not difficult to understand how busy the schedulers are. Thus, it is important to choose a programming language that schedulers are familiar with. In this view, Microsoft Visual Basic is more favored than any other language like Java or C++.

Secondly, purchase of new optimization software to run a scheduling model might not be accepted by most of the Squadron Commanders or Headquarters. Even though, it is worth it to purchase the software when all the effort on the scheduling issue is evaluated in entire air force, the command chain does not want to allocate money on that. Therefore, suggesting a solution by utilizing systems in hand is more valuable than purchase of a new software. Today, every computer in fighter squadrons has Microsoft Windows and its supplementary tools. Since VBA is a programming language which is embedded to Microsoft Office there is no need to install any other program to use it.

Finally, solution model should be capable of improvements, re-design and changes. Regulations and policies about flight operations are often updated key to air force needs and resources. For this reason, programs that work for flying activities are subject to change. As a result of this, constructing the solution model in a language which is easy to enhance is critical. VBA is a powerful language for easy and quick

improvements. By the aid of object-orientation and built-in functions, VBA can serve this purpose well.

Summary

This chapter has reviewed recent research about flight scheduling procedures to see how researchers dealt with similar problems. In addition to this, general information about Greedy Randomized Adaptive Procedures and Microsoft Visual Basic of Applications is given after recent research to show why they are used. In the following chapter, the applied solution methods, scheduling model and its algorithms will be covered in detail.

III. Methodology

Chapter Overview

The purpose of this chapter is to illustrate applied solution techniques for fighter squadron scheduling problem. This chapter begins with detailed description of Fighter Squadron Scheduling process to give better insight about the study. After that, elements which compose flight schedule are discussed along with their definitions. Following that, objectives and assumptions of flight schedule model are explained. Finally, decision support system is introduced to show how it is designed.

Fighter Squadron Scheduling Process

Flight schedules in most fighter squadrons are generally started to be built late afternoon hours. The reason behind this decision is on-going flight activities that might cause some important changes on following day's flight schedule. Any aircraft malfunctions, ineffective flight based upon pilot and/or weather concerns might result re-scheduling of all pre-constructed flights. Thus, schedulers opt to wait till most of current flight schedule is executed. In addition to this, when required amount of time for constructing a feasible flight schedule is considered, how long a flight schedule takes can be seen as well.

Before starting schedule, all required information should be collected from relevant units. Number of aircraft and pilots, calendar of each pilot, operational sortie requirements and similar data should be gathered to start schedule. However, this information gathering phase is a dynamic process which means that in any points of the

scheduling, possible updates on collected inputs might come out. In certain circumstances, an update might lead to start over entire flight schedule.

Flight Schedule production involves successive pilot-mission-aircraft assignment decisions. There is a cause and effect relation between current assignment and both its successor and predecessor. When a pilot-mission-aircraft triple is assigned to flight schedule, the population of remaining suitable triples will change according to the assigned triple. Therefore, remaining candidate triples will be formed by using previous entries. For example, if scheduler assigns a triple which consists of three pilots and two aircraft, total aircraft number decrease by two aircraft and total pilot number decreases by three pilots to be used in the rest of the flight schedule. If scheduler picks another triple instead of current one, then number of remaining aircraft and pilots differs. This chain reaction ends when the final flight schedule is attained. In this view, initial assignment decisions are much more critical than later assignments.

While schedulers decide a pilot-mission-aircraft triple, there are lots of points to consider. Especially for the first assignment, these considerations can be a little overwhelming for the scheduler. Firstly, currency of each pilot should be taken into account at any time of the schedule. Since, loss of currency for a mission necessitates some number of compulsory sorties to become current again and it affects available number of pilots negatively for special missions, currency limits must be the very first criterion for scheduler. Secondly, training level of each pilot should be evaluated by the scheduler. Almost in every squadron, each pilot should fly some number of training flights to keep his/her skills in sufficient level. So, schedulers should track each pilots training level in detail. Moreover, total number of flight hours is assumed to be an

important indication of squadron's progress. Therefore, besides training level, the schedule should paid attention to the number of flown sorties for each pilot. Further, Headquarters might have some impacts on flight schedule. Nearly every week certain operational flight orders are delivered to squadrons and it is an obligation for scheduler to put those flights into schedule. Finally, schedulers should place emphasis on Squadron Commander's (SC) concerns about flight schedule. For instance, SC might request a particular pilot to be assigned or unassigned a mission. Hence, scheduler should take into account SC's concern. Otherwise, final schedule might not be approved by SC and it may cause the final schedule to be produced again.

Along with pilot-mission-aircraft triple decisions, schedulers are also responsible for ground duty assignments. Even the types of ground duties differ for each squadron, general duties in fighter squadrons are Supervisory of Flight (SOF) and Runway Supervisory Unit (RSU). In addition to these duties, Base Operation (Base Ops.) can be seen in some bases. These duties have their own requirements and durations which are essential criteria for assignment.

Another substantial point is that scheduler should cover pilots' demand as long as they are reasonable. For instance, if one pilot does not execute effective missions while flying with a specific pilot, schedulers do not prefer to assign these pilots together in same formation. Of course, this situation increases complexity of the scheduling problem but, in flight safety aspect it is not a negligible consideration.

To illustrate what scheduler does for producing a flight schedule, first it is required to present some definitions about fighter squadron schedules.

Definitions

Aircraft Types

Most of the fighter squadrons (except special role squadrons) consist of one type of fighter aircraft, such as F-16, F-22, or any other jet. Also, these squadrons usually have two different aircraft models as one-seated and two-seated. Two-seated (tandem) aircraft are required for training missions by which currency of the pilots is maintained, qualification sorties are flown, and training level is kept in desired level. If any pilot needs to execute training mission, he/she flies with an instructor pilot who sits in rear cockpit and controls front cockpit activities. In this research, one-seated and two-seated aircraft are called C and D Model aircraft, respectively. In Figure-13, D Model aircraft cockpit can be seen.

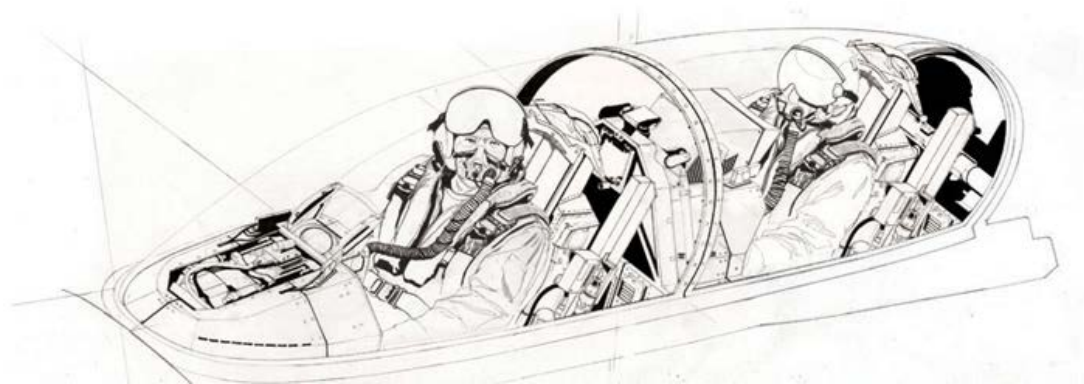


Figure 13-D Model Cockpit (Deviantart, 2010)

Formation

Formation is the composition of aircraft which executes a mission as a group. Formation is defined with the number of aircraft it includes. For example, if formation has 4 aircraft, it is called four-ship formation. The other formation types are three-ship,

two-ship, and one-ship formations. Here, which models of aircraft are included is not important to define formation. In addition to formation, it is required to mention about flight positions. Whenever a formation consists of more than one aircraft, there is always a leader in the air who is called as number-one. If formation is a two-ship formation then flight positions are number-one (leader) and number-two. In this research, highest formation is assumed as four-ship formation as shown in Figure-14.

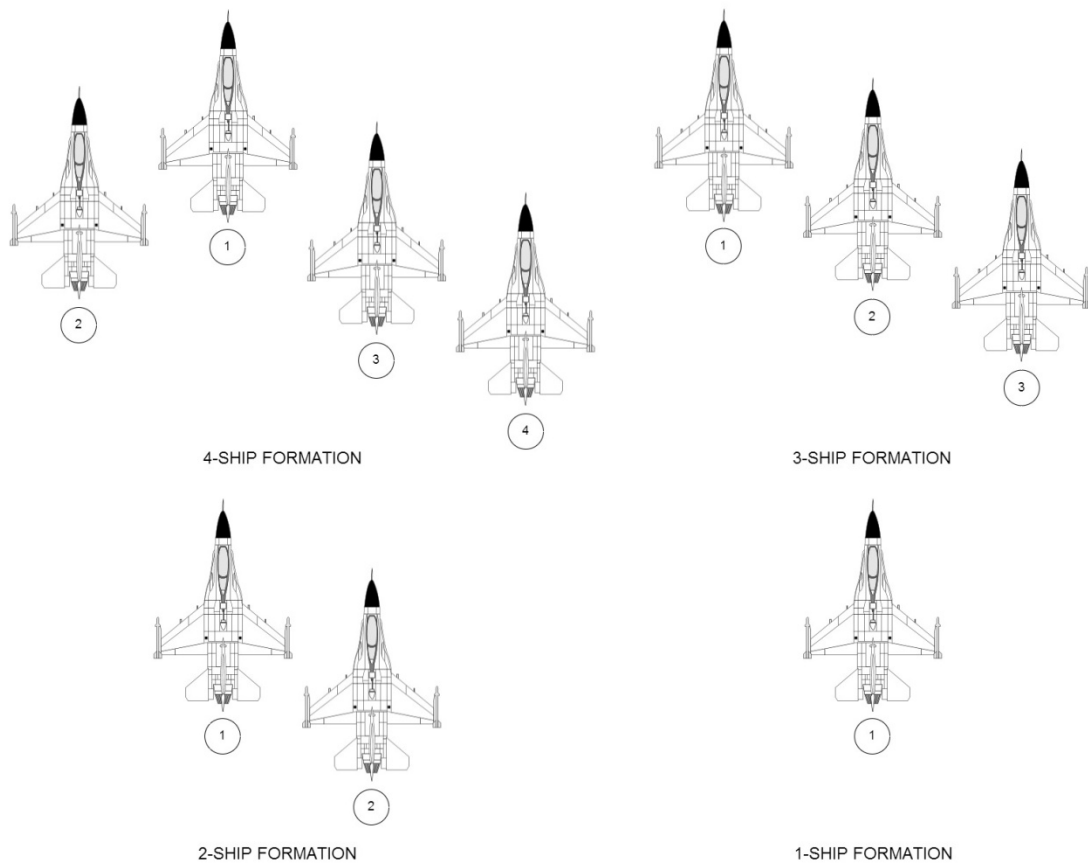


Figure 14-Formation Types

Pilot Status

In fighter squadrons, there are four main pilot statuses which are determined according to flight hours and pilot skills. From lowest to highest order, these are Wingman, Two-Ship Leader, Four-Ship Leader, and Instructor Pilot (Figure-15). Wingman is the lowest pilot status in which pilot does not fly in any leader position and follows the instructions of flight lead. Two-ship and Four-ship leaders are the pilots who are in charge of maximum two and four aircraft, respectively. The highest status is the instructor pilot who can fly in any flight position with any aircraft number. As a general rule, one pilot can fly in any lower pilot status than his/her own status. This means that four ship leaders can fly in leader position for three and two ship formations in addition to wingman positions of these formations.

INSTRUCTOR PILOTS	4-SHIP LEADER PILOTS	2-SHIP LEADER PILOTS	WINGMAN PILOTS
PILOT-A	PILOT-D	PILOT-H	PILOT-L
PILOT-B	PILOT-E	PILOT-I	PILOT-M
PILOT-C	PILOT-F	PILOT-J	PILOT-N
...	PILOT-G	PILOT-K	PILOT-O
	...	...	PILOT-P
			PILOT-Q
			PILOT-R
			...

Figure 15-Pilot Statuses

From scheduler's point of view, these statuses are utilized in Pilot-Aircraft portion of the assignment. In other words, each pilot status has a list of suitable cockpits in which that pilot can be assigned. List of suitable cockpits for each pilot status can be seen in

Table-3. As shown in Table-3, only instructor pilots are allowed to fly D Model back cockpits. Of course, in real life, lots of people like (maintenance or missile test personal) can fly in D back cockpit. However, those flights are out of the contents of scheduling problem and this research. Therefore, when scheduler tries to put a pilot to a cockpit, pilot-cockpit suitability should be considered.

Table 3-Pilot Category and Suitable Cockpits

PILOT STATUS	4-SHIP MISSIONS				3-SHIP MISSIONS			2-SHIP MISSIONS		1-SHIP MISSIONS	ALL MISSIONS
	NUMBER 1	NUMBER 2	NUMBER 3	NUMBER 4	NUMBER 1	NUMBER 2	NUMBER 3	NUMBER 1	NUMBER 2	FRONT SEAT	BACK SEAT
INSTRUCTOR	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
4-SHIP LEADER	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
2-SHIP LEADER	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES	NO
WINGMAN	NO	YES	NO	YES	NO	YES	NO	NO	YES	YES	NO

In fighter squadrons, total number of pilots often falls in the range of 25 to 40. When we look at the distribution of pilot status, we see that instructor pilots have the smallest percentage of total number. Generally there are three or four instructor pilots in a fighter squadron. On the other hand, number of Wingman pilots has the greatest percentage of total. In a 40-pilot squadron, number of wingmen can be as high as 15 pilots. Moreover, number of four and two-ship leaders are close to each other and there are nearly 10 pilots of each status. Although, these given numbers are subject to change in different squadrons, they can be accepted as reasonable numbers.

Missions

In general, there are two types of missions which are day-time and night-time missions. Sub-categories of day and night missions are Air to Air (AA) and Air to

Ground (AG) missions. Each mission has some restrictor features that scheduler must think of while making assignments. First of all, number of aircraft with which mission can be accomplished is one of these features. While some missions require four aircraft, some missions need three, two or one aircraft to be able to be flown. Mission and required number of aircraft is depicted in Table-4. Secondly, flight duration is another essential feature of missions. Flight durations change based on a few factors like onboard fuel, weapon load or flight characteristic of the mission. When scheduler produces a formation, assigned take-off and landing time should lie within the bounds of flight duration of relevant mission. Last feature of a mission is predefined currency limit that shows minimum number of days in which the mission should be flown to be current. While this number might be the same for all pilot statuses for a mission, it can also be different. For instance, while two-ship leaders must fly mission-x every 30 days, an instructor has to be assigned that mission every 90 days. If a pilot does not fly a mission within his/her currency limit, this yields extra sorties and cost to the squadron. Hence, scheduler must be very careful on currency issue and decide formations according to these limits.

Table 4-Mission-Aircraft Requirements

MISSION	AIRCRAFT REQUIREMENT			
	4-SHIP	3-SHIP	2-SHIP	1-SHIP
MISSION-A	YES	NO	NO	NO
MISSION-B	YES	NO	NO	NO
MISSION-C	YES	NO	NO	NO
MISSION-D	YES	NO	NO	NO
MISSION-E	NO	YES	NO	NO
MISSION-F	NO	NO	YES	NO
MISSION-G	YES	YES	YES	YES*
...	...	...	...	...

* 1-SHIP Mission can only be flown with two-seated aircrafts

Ground Duty

Ground duties are some kind of responsibilities that relevant pilot checks activities which may violate flight and/or ground safety. Thus, pilot on duty must assure that all activities inside his/her responsibility area are performed without any unsafe situation occurrence. The main duties are Supervisory of Flight (SOF), Runway Supervisory Unit (RSU), and Base Operation (Base Ops). Since, there is no need of RSU or Base Ops duty in certain bases, just SOF is the mandatory duty slot in flight schedule for some squadrons. Again, each ground duty has its own suitable pilot status and schedulers have to obey this rule. An example of duty-pilot status table is shown in Table-5.

Table 5-Ground Duty-Pilot Status

PILOT STATUS	GROUND DUTY			
	SOF	RSU	BO	SIM
INSTRUCTOR	YES	YES*	YES*	YES*
4-SHIP LEADER	YES	YES*	YES*	YES*
2-SHIP LEADER	NO	YES	YES	YES
WINGMAN	NO	YES	YES	YES

SOF : Supervisor of flight
RSU : Runway Supervisory Unit
BO : Base Operations
SIM : Simulator
YES* : Pilot can be assigned to duty but it is not preferable.

Block

Block time period is used to partition a day into segments in which several flights are executed. Although, blocks are preferred to be three or four hours time intervals, for

some specific reasons (operational, weather, etc.) they can be shorter. As in mission types, blocks can be day-block and night-blocks if there are night flights in the schedule. Schedulers should follow written policies while assigning a pilot into more than one block. These policies will be discussed in later sections.

Elements of Flight Schedule

Flight schedules consist of multiple sections and these sections are planned by different units. Flight schedule is not assumed as completed until all departments conclude their respective portion of the schedule and only after that schedule can be published. As seen in Figure-16 below, column titles of the schedule shows elements of a flight schedule which have to be filled by liable personnel. However, most of these elements other than the dashed region shown in Figure-16 can be completed in a short time period. The most important and time-consuming portion of the schedule is the region drawn with dashed line in Figure-16. This portion can be called as core schedule that answers a few critical questions like:

- i. Which pilots are flying?
- ii. Which missions are being flown?
- iii. How many blocks are there in a day?
- iv. What are the takeoff and land time of each mission?
- v. How many aircraft are used and which models they are?

After core schedule is finalized remaining sections are determined according to the information from core schedule. For instance, maintenance department decides which tail numbered aircraft will be assigned to pilots and from which shelter/parking lot they

will proceed to flight. Since, scheduler accounts for number of available aircraft and aircraft models while planning, allocation of tail numbers is just one to one pairing. Thus, this process takes extremely shorter time period than core schedule. In this research, it is aimed to build the section called as core schedule in as minimum as possible time period by a decision support system.

INDEX	CALL SIGN	COMM	BRIEFING TIME	TAIL NUMBER	SERIAL	SAR EQUIPMENT	PILOT CATEGORY	PILOTS		MISSION / DUTY	TAKE-OFF	LAND	AREA/ROUTE	LOAD
1	CS-1	C-1	XXXX	TAIL-1	S-1	SAR-1	CAT-X	PILOT-X		MISSION-X	XXXX	XXXX	AREA-X	LOAD-X
2				TAIL-2	S-2	SAR-2	CAT-X	PILOT-X	PILOT-X					LOAD-X
3				TAIL-3	S-3	SAR-3	CAT-X	PILOT-X						LOAD-X
4				TAIL-4	S-4	SAR-4	CAT-X	PILOT-X	PILOT-X					LOAD-X
5	CS-2	C-2	XXXX	TAIL-5	S-5	SAR-5	CAT-X	PILOT-X		MISSION-X	XXXX	XXXX	ROUTE-X	LOAD-X
6				TAIL-6	S-6	SAR-6	CAT-X	PILOT-X						LOAD-X
7				TAIL-7	S-7	SAR-7	CAT-X	PILOT-X						LOAD-X
8	CS-3	C-3	XXXX	TAIL-8	S-8	SAR-8	CAT-X	PILOT-X	PILOT-X	MISSION-X	XXXX	XXXX	AREA-X	LOAD-X
9				TAIL-9	S-9	SAR-9	CAT-X	PILOT-X						LOAD-X
10	CS-4	C-4	XXXX	TAIL-10	S-10	SAR-10	CAT-X	PILOT-X	PILOT-X	MISSION-X	XXXX	XXXX	AREA-X	LOAD-X
11	-	-	-	-	-	-	-	PILOT-X	-	DUTY-X	XXXX	XXXX	-	-
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 16-Example Schedule

Objectives of Flight Schedule

As all decision makers, flight schedulers have certain objectives in their minds while producing flight schedules. While some of these objectives are dictated by Headquarters, rest of them is determined by the schedulers and Squadron Commander. Although, these objectives might be different for each flight day, there are common objectives that are never changed for fighter squadrons. First of all, keeping all pilots in their currency limits for each mission is the primary objective of the schedule. Since, when a pilot falls behind his/her currency limits, he/she has to be assigned several

mandatory flights to become current again, schedulers pay utmost attention to currency limits. Second objective is to hold training and skill level of pilots as high as possible by assigning periodic training missions. Even though there is a predefined currency limit for each mission; schedulers want to fly pilots more than once in the currency limit of a mission. Also, they try to produce effective flight formations to improve mission effectiveness. Another objective is maximizing number of sorties or number of aircraft that are used in the schedule. For instance, if scheduler has 20 available aircraft and 15 of these aircraft are used for the schedule, scheduler might be criticized by Squadron Commander. Similarly, if there are available pilots on the ground who might be assigned to schedule without violating any constraint, this can leave scheduler in a difficult situation, too. In fact, overall objective of the schedule is construction a flight schedule that command chain would be satisfied with.

In this research, all the objectives mentioned above are covered as much as possible. Currency limits, desired manual assignments, maximizing number of sorties or number of aircraft are included in the model. Except these, minimizing the required time to build a feasible flight schedule is one of main objectives of this study.

Assumptions

To be able to build a robust scheduling model, it is required to make some assumptions on fighter squadrons which can speed up the process and decrease complexity of the problem. The reasons of some assumptions will be discussed in following sections. Assumptions in this study are:

- i. As stated above, number of active pilots in the squadrons generally ranges from 25 to 40 pilots. Thus, in this research number of pilots is limited to 40 pilots.
- ii. Although, there can be some additional pilot statuses (e.g. check pilots), it is assumed that there are four different pilot statuses. Since, those pilots (if there is any) in additional statuses are already instructors; they will be accepted under instructor category
- iii. Total number of aircraft is limited to 40, similar to number of pilots. Again, there is no restriction on number of C model or D model till total number of aircraft is not greater than 40.
- iv. There is no limitation on number of missions. User can add missions as much as he/she wants.
- v. Maximum number of blocks in a day is seven. Four of these blocks are reserved for day-time blocks and last three blocks are night blocks.
- vi. In addition to ground duties explained before (SOF, RSU, and Base Ops), Simulation is assumed as an additional ground duty. Squadron might be tasked with all four ground duties, or any one of them. For instance, SOF and RSU can be required to be filled in same block. Moreover, ground duty duration is all block period.
- vii. Each duty requires one pilot and each pilot can only perform one duty per block.
- viii. As in duty assignments, one pilot can be assigned to only one flight in a block.
- ix. Mission can be activated or de-activated by the scheduler according to weather forecast of actual flight day of schedule.

- x. Only instructor pilots can be assigned D model back seats. In real-life, all pilots can fly in back cockpit of D models while suitable pilot is in front seat. However, these assignments are not accepted as effective mission sortie for back seat pilot. Thus, they are out of context of this research.
- xi. For flight positions, it is assumed that the instructor can be leader of four-ship formation. Four-ship leaders are suitable for four-ship and three-ship lead positions. Two-ship leaders will fly in two-ship lead position.
- xii. C model aircraft cannot be assigned to one-ship formations.

Flight Schedule Model

Constructing Feasible Candidate Formations

Flight schedule is the combination of feasible formations which include much information. As seen in Figure-17 below, flight schedule is composed of feasible formations that are drawn with dash lines. Any one of these formations should not violate the feasibility of other formations to be able to attain a feasible schedule. In real-life, scheduler in the squadron first builds a feasible formation and looks for another possible one according to results of generated formation. This process continues until scheduler is satisfied with the schedule or there is no other remaining feasible formation. However, generation of these feasible formations is a difficult phase for the scheduler. Since there are lots of constraints and restrictions, scheduler has to follow many variables at the same time.

	PILOTS		MISSION / DUTY	TAKE-OFF	LAND
FORMATION 1	PILOT-X		MSN-X	XX:XX	XX:XX
	PILOT-X	PILOT-X			
	PILOT-X				
	PILOT-X	PILOT-X			
FORMATION 2	PILOT-X		MSN-X	XX:XX	XX:XX
	PILOT-X				
	PILOT-X				
FORMATION 3	PILOT-X	PILOT-X	MSN-X	XX:XX	XX:XX
	PILOT-X				
FORMATION 4	PILOT-X	PILOT-X	MSN-X	XX:XX	XX:XX
FORMATION 5	PILOT-X	-	DUTY-X	XX:XX	XX:XX

Figure 17-Feasible Formations

Scheduler must think about some points while constructing a feasible formation.

Some of these points can be summarized as:

- i. Selected mission and number of aircraft should match.
- ii. Pilots and currency limits should be taken into account.
- iii. Pilots should be assigned to cockpits in compliance with their status.
- iv. Mission of the formation should be available in predicted weather condition of the block.
- v. Availability of pilots should be checked before producing formation.
- vi. Scheduler should ensure that formation does not exceed number of available aircraft for each model.

As is also understood from the list above, even construction phase of feasible formations is a single problem apart from building flight schedule. For this reason, it is thought that automating this construction phase is required, firstly. After gathering all necessary information from the scheduler, scheduling model first generates all possible feasible formations. To do this, model utilizes a few tables that are populated by scheduler entries. In Figure-18, some of these tables can be seen. With the aid of the tables in Figure-18, the model creates a feasible triple list such that in each row is a feasible ***mission-block-C_D combination*** triple. C_D combination is an expression that shows which aircraft models are assigned to what flight position. For instance, C_C_C_C means that it is a 4-ship formation and all aircraft are C models. In this sense, 4 pilots must be assigned for this combination. C_D_C_C is another 4-ship formation but number two is D model and total of 5 pilots must be assigned for this formation. There are totally 29 different C_D combination types for four, three, two, and one ship formations. If formation is one-ship, as stated in assumptions, aircraft has to be D model.

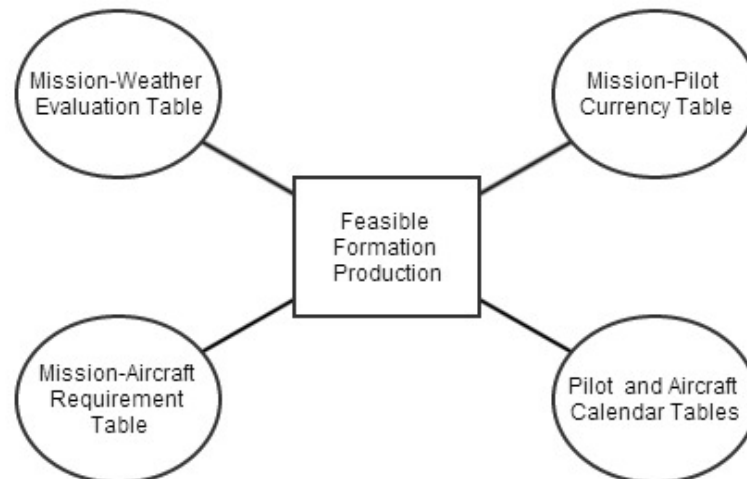


Figure 18-Required Tables for Feasible Formation Production

Creation phase of ***Mission-block-C_D combination*** triples is shown in Figure-19 as network diagram. Scheduling model, first checks if Mission-X can be flown in Block-X by using Mission-Weather Evaluation Table. Following this step, it is confirmed if Mission-X can be executed in C-D Combination-X. In the second step, scheduling model searches the data inside Mission-Aircraft Requirement Table and Aircraft Calendar to assure there are enough aircraft for this combination. Figure-20 presents flowchart of the ***Mission-block-C_D combination*** triples creation phase.

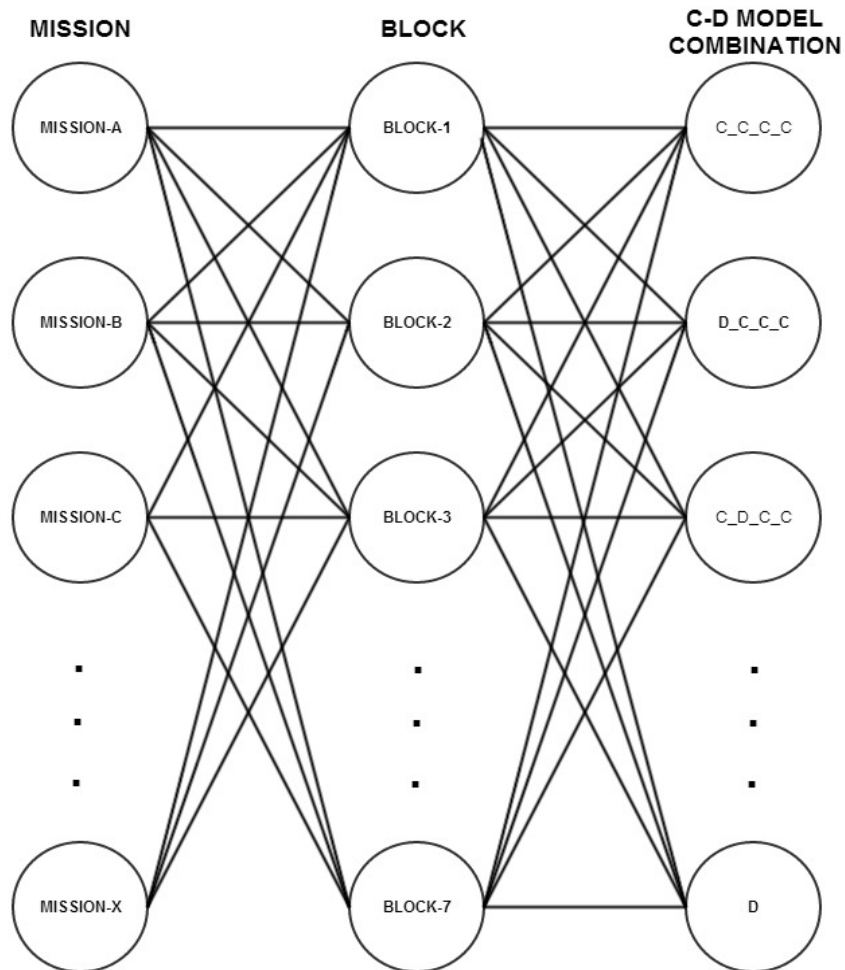


Figure 19-Feasible Mission-Block-C_D Combination Triple Search

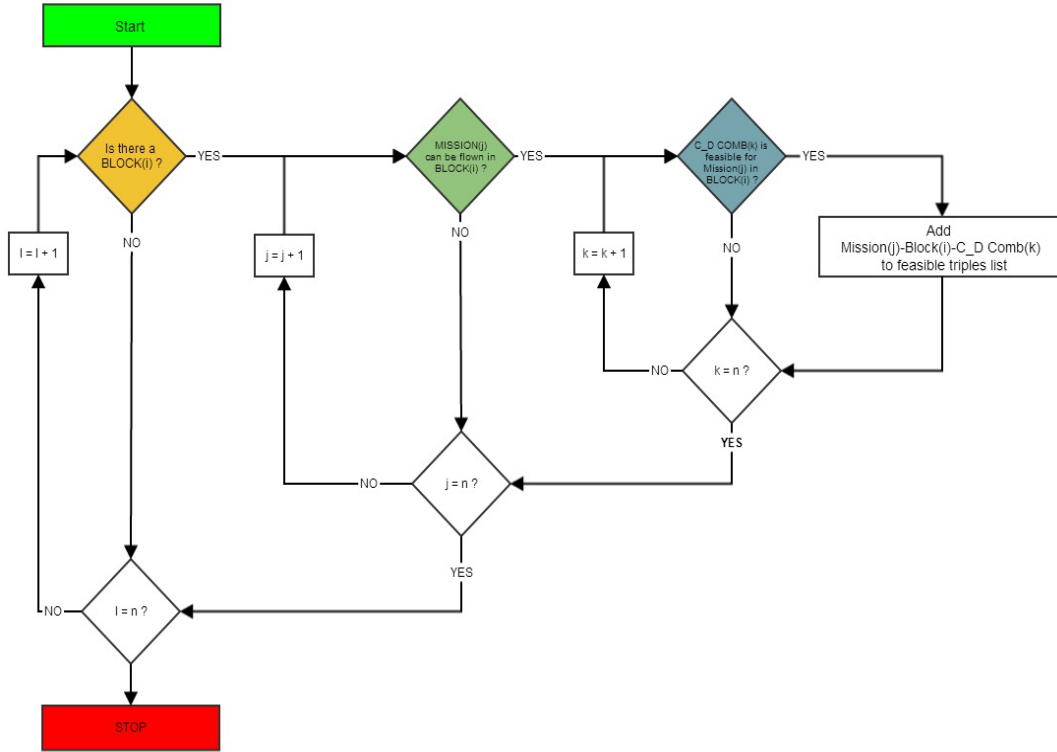


Figure 20-Flowchart of Mission-Block-C_D Combination Creation Phase

After populating *Mission-block-C_D combination* list, scheduling model assigns pilots to all triples in the list. For example, if one of the triples is *Mission-X, Block-1, D_C_C* then model, assigns a four-ship leader to number one, an instructor pilot to number one back-seat, a wingman to number two, and a two-ship leader to number three. Also, all these pilots should be available in Block-1 time period and their currency should allow them to fly Mission-X. Of course, this pilot assignment includes lots of different pilot assignments. Thus, many feasible formations might be produced at the end of this step. When pilots are assigned to triple, they are added to candidate formation list and pilot assignments for the next *Mission-block-C_D combination* triple starts. This process stops when there is no remaining triple. In Figure-21 Flowchart of pilot assignment is depicted.

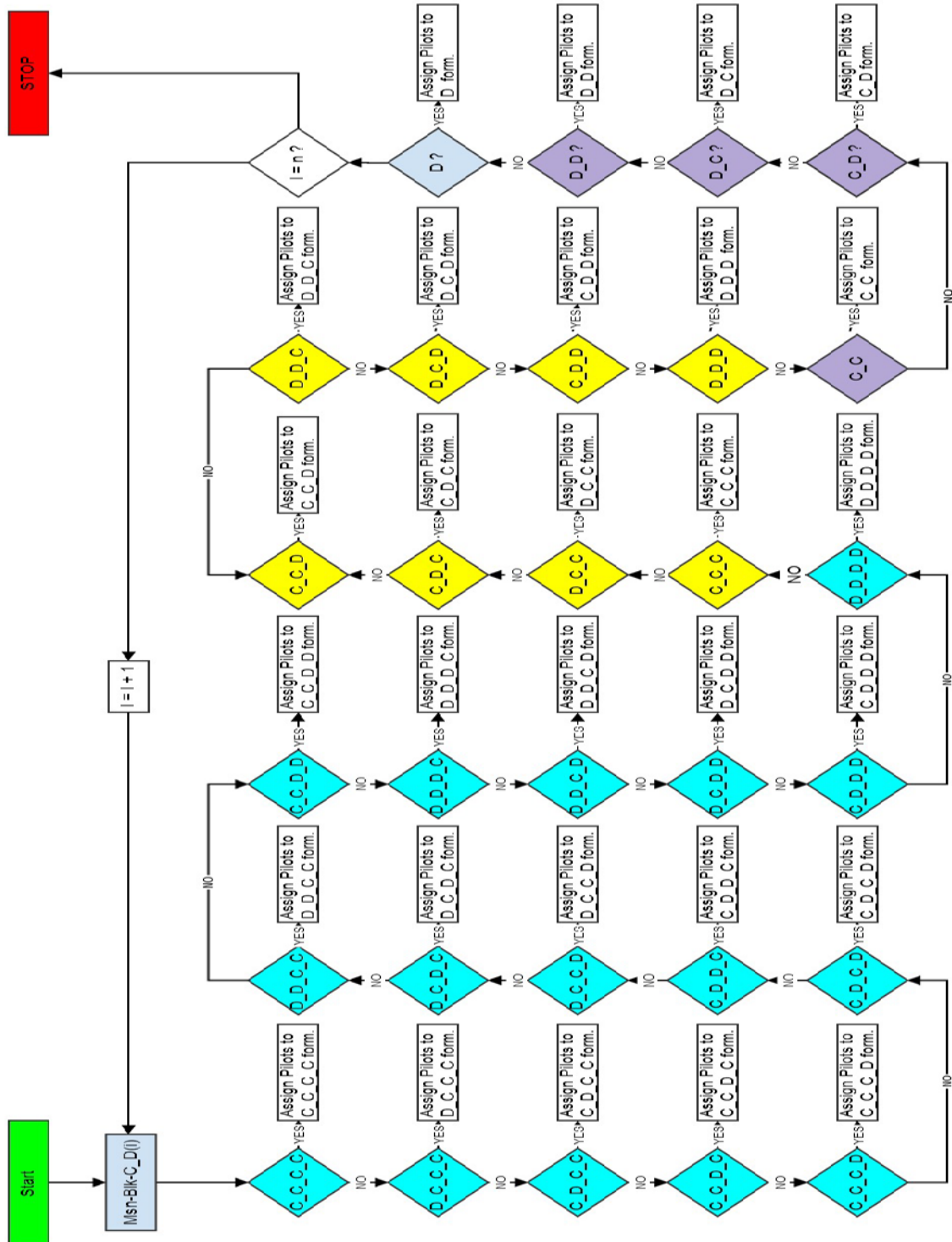


Figure 21-Pilot Assignment to Triples

At this point all feasible candidate formations are generated and stored in a list to be taken later and put into the flight schedule. However, to implement GRASP and optimize flight schedule, it is required to order this candidate formations according to some criteria and preferences. Since there is already a study in the literature (Durkan, 2011) which evaluates pilot-mission matches and gives a score to each match, this research does not focus on scoring formations. In addition to existence of a relevant study, each squadron may have special preferences on mission types and pilot assignment. For example, while a candidate formation is on top of the list in a squadron, same candidate might be at very bottom in another squadron (This fact can happen especially between Air to Air and Air to Ground Squadrons). Therefore, instead of scoring, a random number between 0 and 1 is designated for each candidate formation to ease scoring phase. This random number is assumed as currency score of the formation which is explained in Scoring of Generated Schedules section. Nevertheless, scheduling model is consistent to add a scoring function as in Durkan's research. If required, scores close to real-life scenarios can be attained by using Durkan's value functions or squadron's own scoring function in future.

Constructing Feasible Candidate Ground Duties

Ground duties are assumed as formations except they do not have information of aircraft or C_D combination. In the input entry part of the model, scheduler should select mandatory ground duties for each block and scheduling model uses this information afterwards when feasible candidate ground duties are created. As in construction of formations, model utilizes tables in Figure-22 to find feasible **Duty-Block** matches. After

that, eligible pilots are assigned to find feasible ***Duty-Block*** matches. In Figure-23, network diagram of feasible ***Duty-Block*** search can be seen.

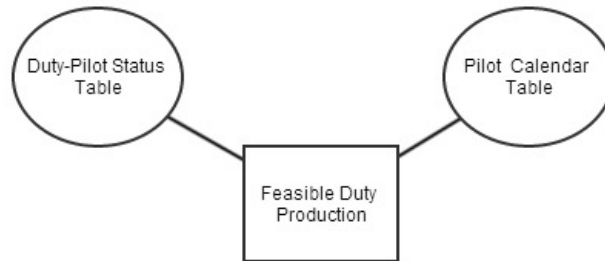


Figure 22-Required Tables for Ground Duty Candidates

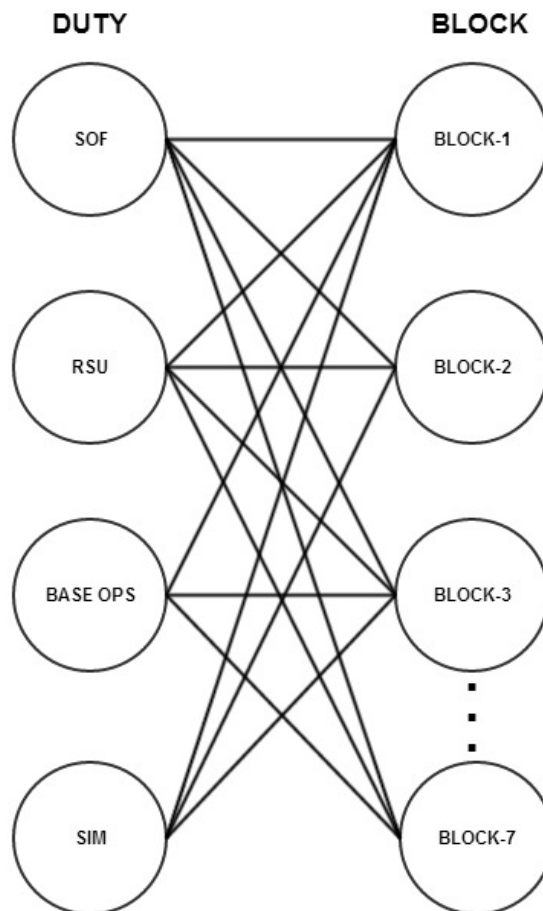


Figure 23-Feasible Duty-Block Match Search

When pilot assignment portion of candidate ground duty construction is ended, created duties are added to candidate formation list and ordered in the same way of formations. In other words, all candidates are kept together in one list.

CANDIDATE LIST										
MSN	BLK	C_D COMB	#1	#1 back	#2	#2 back	#3	#3 back	#4	#4 back
MSN-17	BLK-1	C_C	PILOT-A	-	PILOT-B	-	-	-	-	-
MSN-2	BLK-2	D_D_D	PILOT-B	PILOT-E	PILOT-F	PILOT-K	PILOT-I	PILOT-P	-	-
DUTY-1	BLK-1	-	PILOT-T	-	-	-	-	-	-	-
MSN-8	BLK-2	C_D	PILOT-A	-	PILOT-I	PILOT-K	-	-	-	-
*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*
MSN-11	BLK-1	D	PILOT-B	PILOT-P	-	-	-	-	-	-

Figure 24-Example Candidate List

Manual Assignments by Scheduler

In general, schedulers have an idea about the missions and/or pilots that he/she is mostly certain to put into flight schedule. Besides that sometimes squadron is tasked on operational flights which scheduler has to place into schedule. Thus, an effective scheduling model should be designed to allow scheduler to interact with the model on desired inputs. Scheduler should be able to add or remove any mission/duty/pilot while producing formations.

For the reasons above, developed model in this research is built in a way that scheduler is capable to assign or exclude any pilots, missions or duties in the candidate list. If scheduler decides to assign a particular pilot to a mission, the only thing to do is searching formations based on pilot and mission name. Model will show all matched formations to scheduler in the order of importance. Next, scheduler can go through search

results and assign or exclude any formations. If scheduler assigns a formation, this means that assigned formation(s) will be in all generated schedules. On the other hand, if scheduler excludes any formations, excluded one(s) will not be in generated schedules.

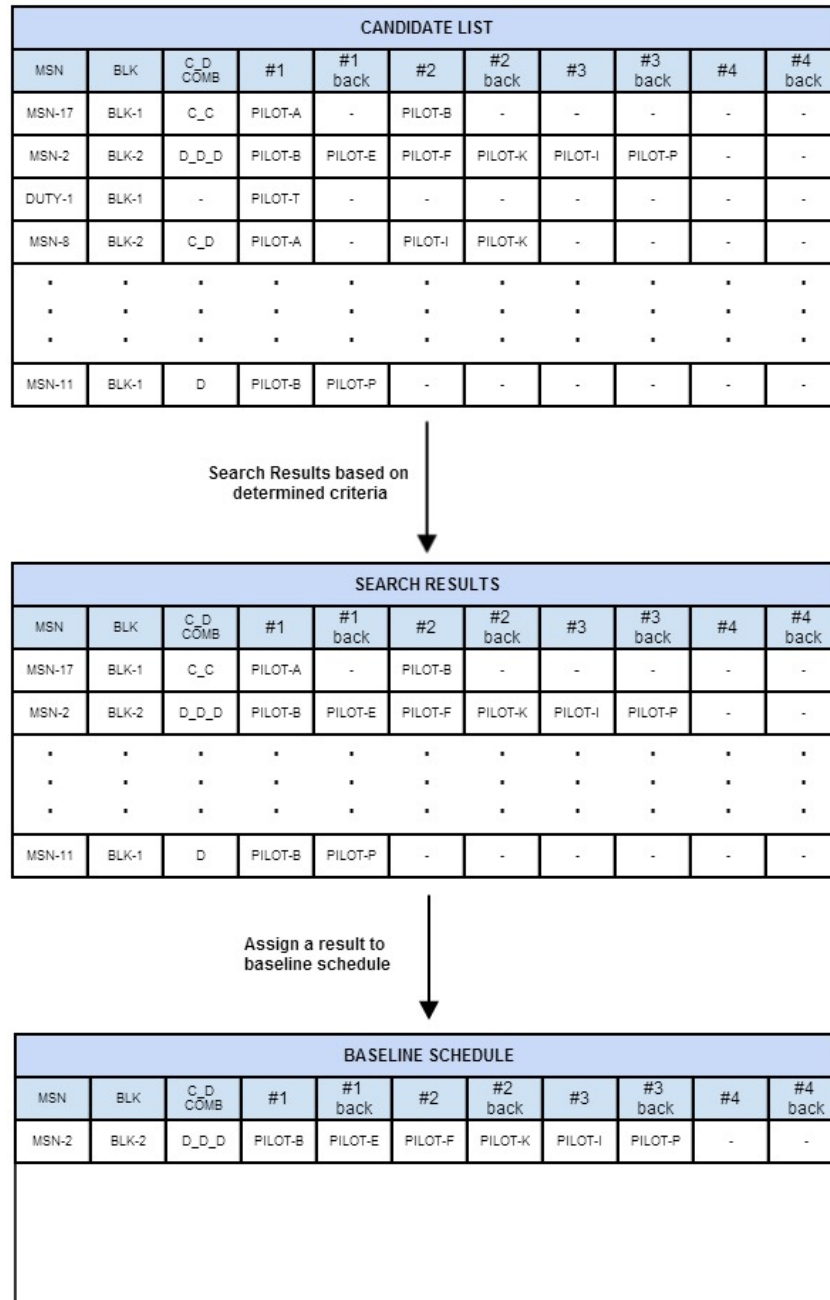


Figure 25-Manual assignments

Schedule Generation Process

After construction phase of feasible candidates is completed, schedule generation portion of model begins. Schedule generation phase is the step in which GRASP is applied to make a feasible and optimized schedule. In this phase, candidate formation with highest priority is taken from the candidate list and put into flight schedule. Following this assignment, candidate list is updated according to information of assigned formation. Next, candidate of highest priority in updated list is added to existing flight schedule. And then, another update is performed to candidate list. In each update of candidate list, the number of remaining candidates decreases quickly due to the constraints that are mentioned in assumptions. This process continues till there is no remaining formation in candidate list. When candidate list is empty, feasible schedule generation for first schedule is accomplished. Model stores generated schedule and starts over the process for a new schedule. The difference between first and second schedules is that model takes second candidate for the first assignment of the second schedule. However, for the remaining assignments, candidate with highest priority is used. When second schedule is finished, it is added to stored schedule list and model continues to work like this. In Figure-26 generation of first schedule is shown in detail.

The most important point to be able to produce feasible schedule is specifying pilots to required ground duties in the beginning of this phase. Since schedule is infeasible when required ground duties are left empty, schedule generation process should begin from this portion. Otherwise, schedule must be checked whether it is feasible or not at the end of generation phase. Of course, this results in extra work and causes model to run much longer and inefficiently. Therefore, model starts generation by

placing appropriate duty candidates to required slots. Due to the fact that duties are assumed as formations (except using one pilot and no-aircraft), the way model works is the same with the process shown in Figure-26 for ground duties.

Recall Table-5. Although, SOF duty can be executed by four-ship leaders and instructors, all pilots can be assigned to other ground duties. This shows that in a routine day, there can be many combinations of ground duty assignments. In addition to high number of duty combinations, tremendous number of schedules can be produced by using GRASP implementation in this way. Because of limited time schedulers have to make a flight schedule, the number of generated schedules is limited to five for each combination of duty assignments. In a manner, when model took fifth highest priority formation from candidate list for first assignment, this schedule will be the final one belonging to duty combination. For instance, assume that flight schedule has one SOF and one RSU duty, in block one and block two, respectively. In this situation, scheduling model will assign first available two pilots to SOF (Pilot-A) and RSU (Pilot-B) duties. After that, five different schedules will be generated and all five will have Pilot-A in SOF, Pilot-B in RSU. Next, model will try another combination like Pilot-A and Pilot-C, for SOF and RSU, respectively and produce additional five different schedules. When all possible combinations are tried, model stops generating schedules and begins giving scores to schedules. In Figure-27 and Figure-28 schedule generation process is shown as flowchart.

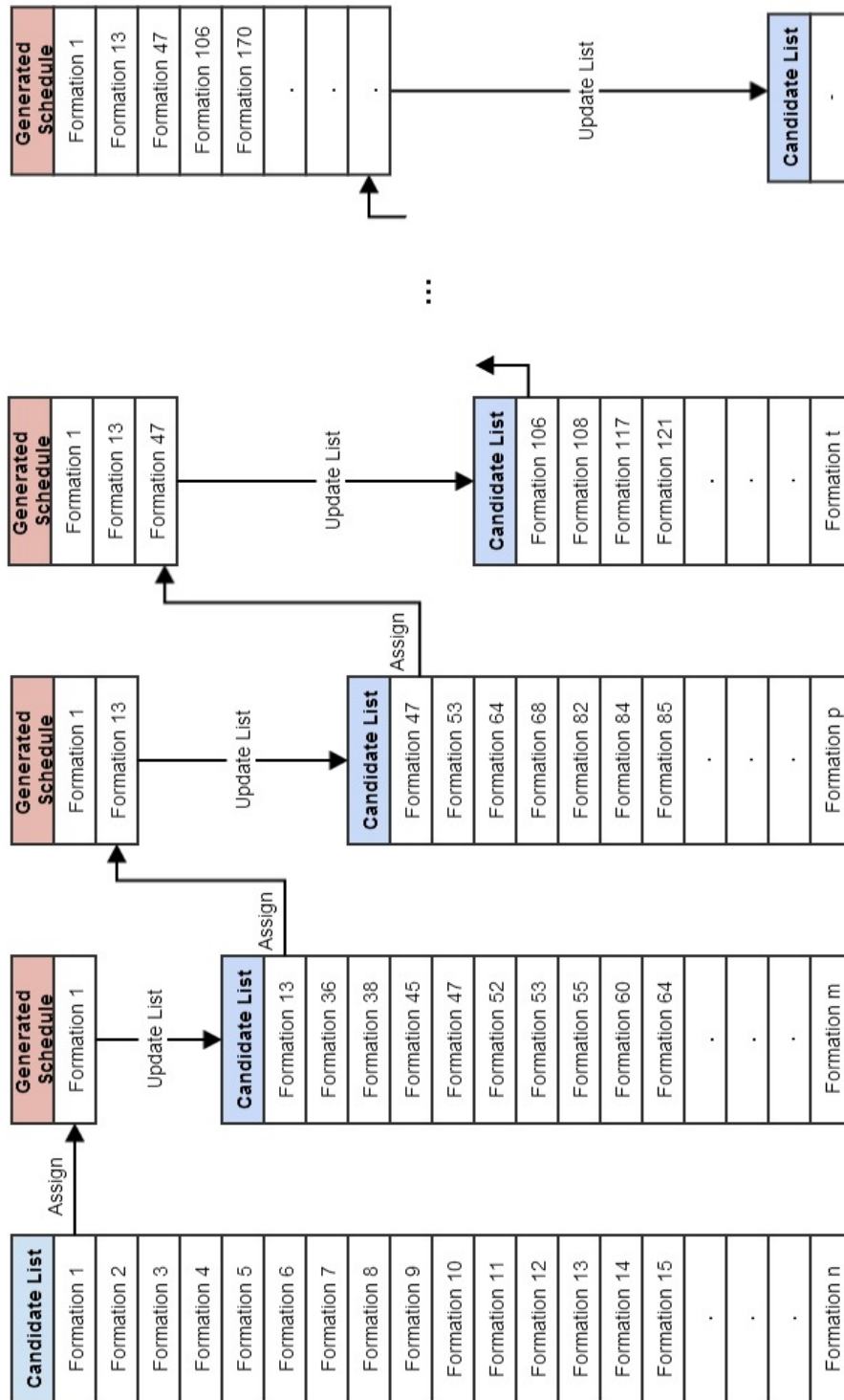


Figure 26-Generation of first schedule

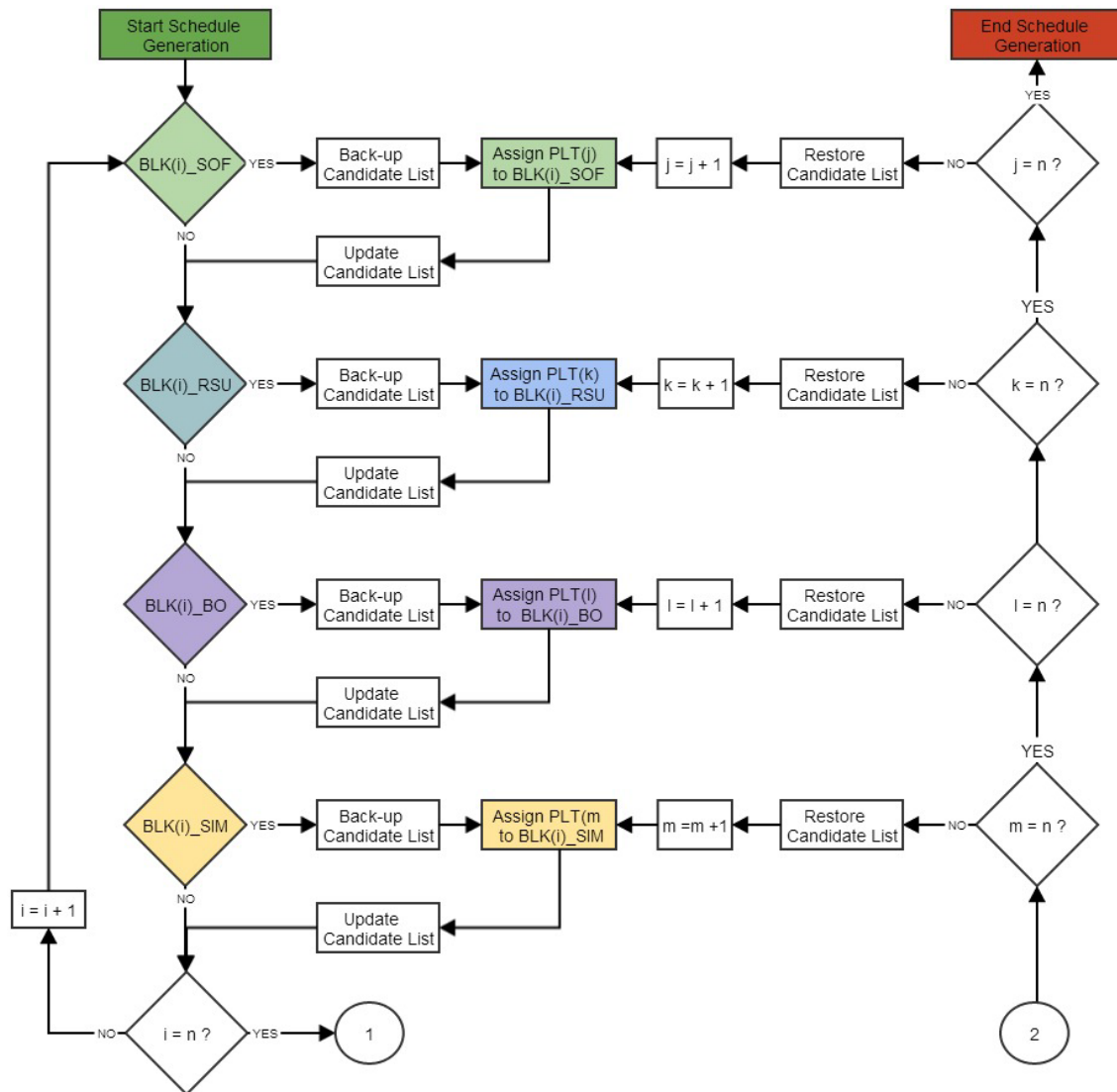


Figure 27-Pilot Assignment to Ground Duties

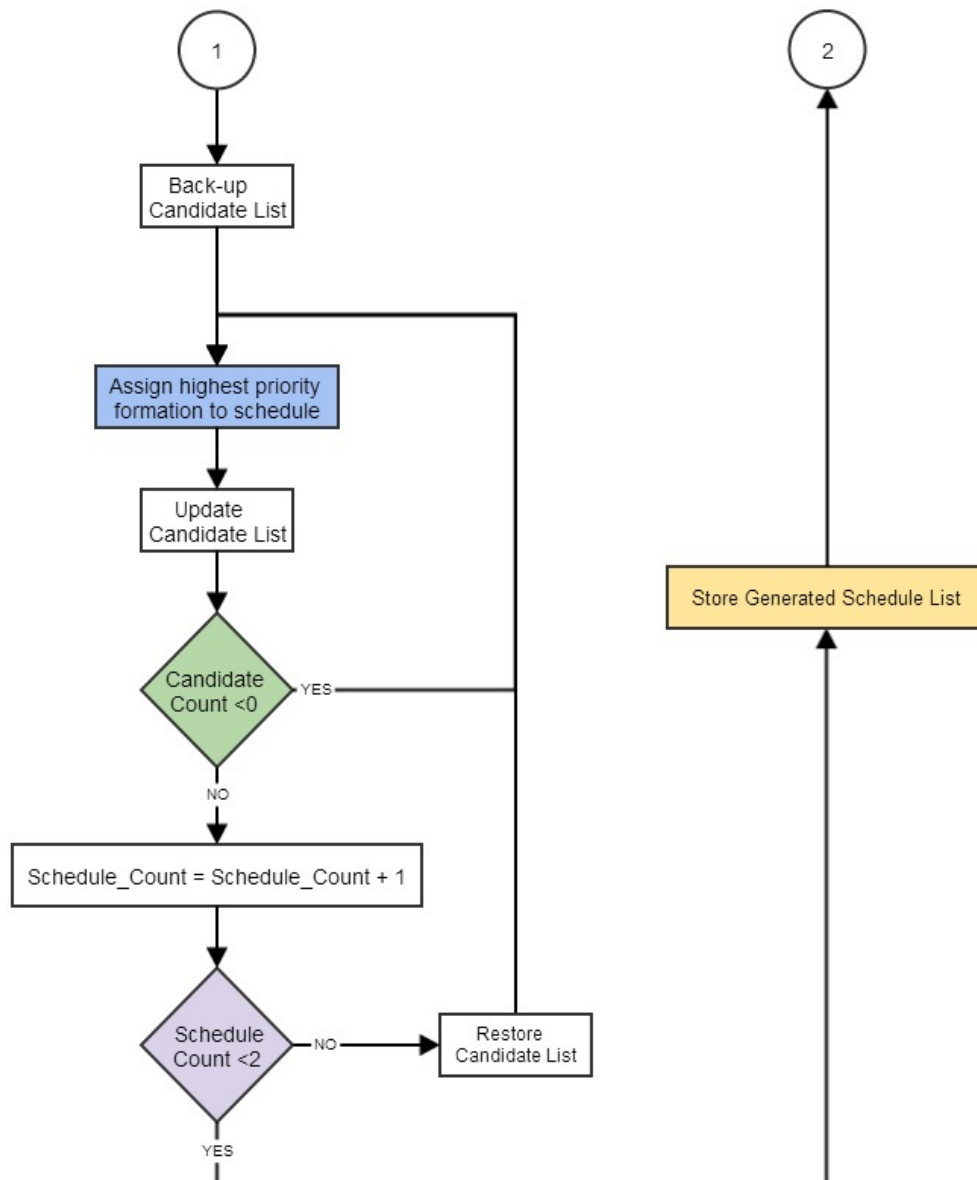


Figure 28-Flowchart of Schedule Generation

Scoring of Generated Schedules

When model finishes schedule generation phase, model will have generated many different schedules and score giving portion of the model will start. To give reasonable scores to a generated schedule, objectives and/or preferences of the squadron should be taken into account. As discussed before, although, daily objectives of the squadron may vary, general objectives are not subject to change in fighter squadrons. These objectives can be summarized as: keeping all pilots in their currency limits, maximizing pilot sorties, and maximizing aircraft usage.

To assume all of three objectives carry equal weight is not a realistic approach. For this reason, model assumes that each objective has a weighting value over the other objectives. Since the most important one is keeping all pilots in their currency limits, it has highest value and 50% of final score is given to this objective. Remaining 50% is divided equally by maximizing pilot sorties and maximizing aircraft usage objectives.

Calculation of currency objective's score differs from calculation of other two scores. Recall construction feasible formation candidate list. In this phase, model gives an individual score to each candidate and all candidates are ordered according to these scores at the end of construction. While model is calculating final score of currency objective, 50% of average pre-determined candidate score is accepted as final score. For instance, if a generated schedule has five formations, model takes the average score of five formations and 50% of this average is kept as final currency objective score.

Calculation of maximizing pilot sorties and aircraft usage scores works in similar way. To do this, model uses available pilot and aircraft numbers for each possible block. Percentage of used aircraft in each block is computed and 25% of average is assumed as

final score of maximizing aircraft usage objective. Similarly, percentage of assigned pilots in each block is calculated and 25% of average is accepted as final score of maximizing pilot sorties.

To attain generated schedule's score, final scores of all three objectives are added up and stored in generated schedules list to be used for ordering purpose in the next step. When scoring phase of generated schedules is finished, first ten schedules with highest schedule score is shown to scheduler to decide which schedule to be published.

Summary

In this chapter, description of fighter squadron scheduling process is given and elements of flight schedule are depicted along with their definitions. After that, objectives and assumptions of flight schedule are discussed. Finally, schedule generate phase introduced in details. In next chapter, analysis of the study will be explained.

IV. Analysis and Results

Chapter Overview

In this chapter, analysis of applied solution technique is discussed under three different headings. First, performance of the scheduling model is examined by several measures. Then, contribution of scheduling model to air force(s) is investigated from a labor aspect. Finally, scoring method of generated schedules is compared with other scoring techniques.

Performance of Scheduling Model

To be able to measure performance of scheduling model, it is required to define some criteria which show how sufficient the model is. One of these measures is the speed of scheduling model. It is important to develop a fast model since our main objective is to speed up flight scheduling process in fighter squadrons,

Scheduling model is run for 15 times with different scenarios to evaluate speed of the application. Number of pilots, aircraft, missions and blocks are changed to examine response time of the model in each scenario. As mentioned in Chapter 3, scheduling model consists of two generation steps which are candidate formation generation and schedule generation. Due to this fact, performance of the model is noted in terms of generation time and number of generated units, respectively. The results of runs are shown in Table-6.

The parameters of each run are determined after several interviews with schedulers in different fighter squadrons and it is attempted to choose as reasonable as

possible values to represent real-life scenarios. The reasons why parameters in Table-6 are picked is summarized as:

- i. As stated in Chapter 3, instructor pilots have the smallest percentage of total pilot number. Generally there are three or four instructor pilots in a fighter squadron. Thus, the number of instructor pilots is limited to three as maximum
- ii. Although, total number of pilots might be between 25 and 40, because of Temporary Duty (TDY), Duty to Not Include Flying (DNIF), and other given tasks, available pilots to be scheduled does not exceed 20. Therefore, total number of pilots is not chosen higher than 20 pilots in these runs.
- iii. Since only instructor pilots are allowed to fly in back-seat of D models, number of D aircraft is limited to three, similar to number of instructor pilots.
- iv. Even though there can be nearly 40 different missions; all of the missions cannot be assigned in a day. For this reason, maximum number of available missions is chosen as 9.
- v. Except long summer days, most of the time, there are two day-time blocks and one night block (if there is any night flights) in fighter squadrons. So, these numbers are used in the runs.

As seen in Table-6, when the parameters of each run are increased, number of generated candidates and generated schedules go up dramatically. Also, response time of the model gets longer because of increased number of units. For example, in 9th run,

squadron has 13 pilots, 8 C model aircraft, 3 D model aircraft, 8 different missions, 2 day-time blocks and 1 nigh-time block. On the other hand, in 12th run, there are 17 pilots, 9 C model aircraft, 3 D model aircraft, 9 different missions, 2 day-time blocks and 1 nigh-time block. When these two runs are compared, number of generated candidates in run 12 is nearly three times of 9th run's generation (174771 vs 63305). Similarly, in run 12th, 500 more schedules are created than run 9th.

Table 6-Model Performance Table

Run	# of Instr.	# of 4 L.	# of 2 L.	# of Wing.	# of Pilots	# of C Mod	# of D Mod	# of Msn	# of Blk	# of Gen. Can.	Time to Gen. Can.	# of Gen. Sch.	Time to Gen. Sch.
1	1	1	1	2	5	5	1	5	1	46	<1"	10	<1"
2	1	1	1	2	5	5	1	5	2	93	<1"	30	<1"
3	1	1	1	2	5	5	1	5	2+1	113	<1"	60	<1"
4	2	2	2	3	9	6	2	6	1	1486	2"	20	1"
5	2	2	2	3	9	6	2	6	2	2973	3"	100	2"
6	2	2	2	3	9	6	2	6	2+1	3619	7"	400	9"
7	3	3	3	5	13	8	3	6	1	23811	12"	30	5"
8	3	3	3	5	13	8	3	6	2	47624	21"	240	1' 30"
9	3	3	3	5	13	8	3	8	2+1	63305	32"	1440	12' 20"
10	3	3	4	7	17	9	3	7	1	65526	27"	30	13"
11	3	3	4	7	17	9	3	7	2	131057	51"	330	5' 40"
12	3	3	4	7	17	9	3	9	2+1	174771	1' 06"	1980	35'
13	3	5	5	7	20	10	3	7	1	145608	54"	40	53"
14	3	5	5	7	20	10	3	7	2	291220	1' 46"	480	31' 33"
15	3	5	5	7	20	10	3	9	2+1	376523	7' 04"	3840	2h 12' 17"

Instr	: Instructor	Msn	: Mission
4 L.	: 4-Ship Leader	Blk	: Block
2 L.	: 2-Ship Leader	Gen. Can.	: Generated Candidates
Wing.	: Wingman	Gen. Sch.	: Generated Schedules
Mod	: Model	2+1	: 2 Day-time + 1 Night-time Block

Furthermore, Table-6 displays that even the number of generated candidates and generated schedules are so high, generation of a feasible schedule takes less than two or three seconds in general. However, generation of a feasible schedule by human schedulers takes more than two hours on average according to interviewed schedulers. When time period of two hours is compared with model's schedule generation time, it is realized that scheduling model is more than a thousand times faster than human schedulers. Besides that, while schedulers make two or three possible flight schedules, scheduling model is capable to generate thousands of different schedules in same amount of time.

It is required to emphasize that none of the runs in Table-6 includes any manual inputs by the scheduler. In other words, scheduling model decides all formations and ground duties on its own. Nevertheless, this situation makes scheduling problem more complex and time-consuming. Because schedule generation phase starts with a high number of candidates which forces scheduling model to look through each candidate after any assignment. This means, after first assignment decision of 15th run, scheduling model checks 376522 candidates (except assigned one) to update candidate list. However, if scheduler enters a formation or ground duty manually before schedule generation phase, model may begin production with a lower number of candidates and it takes much shorter time to complete generation phase. There is not any rule on how much number of candidates reduces but it is clear that number of candidates decreases rapidly. For this reason, to illustrate impacts of manual inputs on schedule generation phase, model rerun for run-10 through run-15 with same parameters and one manual input. Results of these second runs are shown in Table-7, together with previous response times.

Table 7-Manual Input Impact on Response Time

Run	Time to Gen. Sch. without Manual Input	Time to Gen. Sch. after Manual Input
10	13"	1"
11	5' 40"	1' 12"
12	35'	11' 34"
13	53"	2"
14	31' 33"	4' 50"
15	2h 12' 17"	32' 30"

As seen in Table-7, the difference between schedule generation times is quite big for each run. When manual inputs are entered, scheduling model can build schedules almost four times faster than previous runs. If it is considered that SC or other personal request some points about flight schedule, this feature of scheduling model makes problem easier for schedulers.

Contribution of scheduling model to air force(s)

Today, there are lots of fighter squadrons in many different countries. Everyday nearly three people (SC included) work more than two or three hours on flight scheduling in these squadrons. In this view, it can be beneficial to calculate total labor hours on flight scheduling process to explain contribution of developed model for the entire air force.

Countries may have different number of squadrons and schedulers in relevant air forces. Besides, their scheduling environment might differ from each other. However, total labor hours on flight scheduling can be calculated for a sample air force by using arbitrary but sensible numbers.

Assume that there are 20 fighter squadrons in an air force and each squadron has two schedulers. If we suppose flight schedule takes two or three hours at best to establish on average, everyday between 80 and 120 labor hours are dedicated to flight scheduling in the entire air force. When we consider monthly and yearly totals, they range from 2240 to 3360 and 20800 to 31200 labor hours, respectively. Given a full time equivalent is 2000 hours a year, this means between 10 and 15 fulltime personnel are needed to fulfill the squadron scheduling. Briefly, flight scheduling is a very time-consuming activity in fighter squadrons.

As shown in previous analysis, while scheduling model achieves same objectives in very short time, the contribution of scheduling model is obvious in this aspect. Furthermore, by the aid of scheduling model, flight schedules can be completed by non-pilot personal instead of pilot schedulers. Thus, pilot schedulers can focus on their flight activities which are their primary responsibilities.

Finally, since scheduling model is capable to order candidate formations or ground duties according to defined functions which can take into account pilot currencies, monthly flight hours and similar data, generated schedules include most beneficial assignments for the squadron. As a result of this, instead of feasible but not best schedules, feasible and best schedules can be produced.

Evaluation of schedule scoring method

In Chapter 3, scoring method of generated schedules is discussed and weighting value of each objective is explained. Also, it is remarked that giving equal weights to all objectives is unrealistic. Therefore, weighting values are decided as .5, .25, and .25 for

maintaining currency limit, maximizing pilot sorties and maximizing aircraft usage, respectively. However, these weighting values should not be assumed as constant values. Because of dynamic environment of operation area, SC may request scheduler to use as many as possible aircraft or pilots. For this reason, it is required to test scheduling model with other possible weighting values to examine order of generated schedules.

Since there are three main objectives, model is tested for three different scenarios. In each scenario, one of the objectives is assumed to have highest weighting value and generated schedules are ordered according to their scores. After that, orders of first 10 schedules in each scenario are compared.

In scenario 1, it is assumed that objective of day is to maintain pilots within their currency limits as much as possible. Actually, this is already the objective that is used in scheduling model. Therefore, weighting values are not changed in this scenario and model is run with defined scoring function.

In scenario 2, 50% of final score is given to maximizing pilot sorties which is assumed as objective of the day. Remaining 50% is shared equally by maintaining pilots within their currency limits and maximizing aircraft usage objectives.

In scenario 3, while maximizing aircraft usage objective holds 50% of final score, 25% is given to maintaining pilots within their currency limits and maximizing pilot sorties objectives.

To evaluate impact of different weighting values on final score, sample of 80 generated schedules are taken. Following that, for each scenario, final scores of 80 schedules are calculated and schedules are ordered from high to low schedule scores. The results of this analysis are shown in Table-8.

Table 8-Schedule scores for different scenarios

Scenario 1			Scenario 2			Scenario 3		
Currency Highest			Pilot Sortie Highest			Aircraft Usage Highest		
Order	Schedule Score	Schedule Index	Order	Schedule Score	Schedule Index	Order	Schedule Score	Schedule Index
1	0.835	1	1	0.853	2	1	0.816	7
2	0.834	2	2	0.852	1	2	0.815	15
3	0.833	5	3	0.848	4	3	0.813	44
4	0.830	15	4	0.846	64	4	0.811	28
5	0.829	4	5	0.843	15	5	0.809	5
6	0.821	12	6	0.841	41	6	0.808	12
7	0.820	6	7	0.840	43	7	0.805	61
8	0.819	9	8	0.837	62	8	0.798	25
9	0.818	11	9	0.833	17	9	0.797	32
10	0.815	14	10	0.832	13	10	0.795	11

In Table-8, 10 highest scored schedules are shown similar to generated schedule display form of scheduling model. When we look at Table-8, it can be realized that order of first 10 schedules are different in each scenario. A scheduler might want to recommend a robust schedule such as 15 which is in fourth order in scenario 1, it is in fifth and second order in scenario 2 and 3 respectively and is the only schedule in the top ten for all scenarios. In addition to this, first schedules of each scenario are all different schedules with different score.

This analysis shows that if only one objective is accepted for all generated schedule scoring, scheduler model might miss some good schedules in terms of other

objectives. For instance, when we check fourth schedule in scenario 2 (Schedule index 64), this schedule is not in the list of scenario 1. Again, if model uses constant weighting values, it will not show scheduler Schedule 64 which is a good schedule as well. As a result, the model has a feature that allows scheduler to enter weighting value of objectives

Summary

In this chapter, performance of the scheduling model, contribution of scheduling model to air force(s), and scoring method of generated schedules are discussed. To examine performance of the model, response times of model are evaluated with different inputs. Next, contribution of model is explained from the point of labor. Finally, schedule scoring technique is assessed for three scenarios to decide whether weighting values might be changed or not. In final chapter, summary of the research, conclusions and future recommendations are provided.

V. Conclusions and Recommendations

Chapter Overview

The final chapter presents a brief summary of the research and attained conclusions by the aid of research. Also, it introduces recommendations for future studies on flight scheduling.

Summary of Research

In the beginning of the research general scheduling problems and their applications in civil/military aviation are discussed. After that, reasons that make flight scheduling a challenging work are explained. Next, the research question is determined as how to detect optimum pilot-mission-aircraft triplet and apply this data to a flight schedule by the aid of a decision support system.

Previous research on flight scheduling is reviewed to learn potential solution techniques that can be exploited in this research. Also, general information about GRASP and description of VBA are covered.

The study proceeds with illustration of applied solution technique and methodology of fighter squadron scheduling problem. Besides that, fighter squadron scheduling process and elements of flight schedule are described to provide better insight of the study. Moreover, objectives and assumptions of flight schedule model are introduced.

In analysis of research, applied solution technique is assessed to examine performance of the scheduling model. In addition to that contribution of scheduling

model to air force(s) is investigated from laboring aspect. Analysis of the study is ended with the discussion of generated schedules' scoring method.

Conclusions of Research

This study has shown several findings about fighter squadron scheduling problem and its applied solution method. Most of these findings suggest that this research or implemented technique can be put into practice in any air force after specific adjustments.

One of the most significant findings is that GRASP might be an efficient and quick heuristic method to solve flight scheduling problem in fighter squadrons. As seen in the analysis of study, sufficient schedules can be generated by GRASP implementation.

The second major finding is that a lot of feasible flight schedules can be generated in very short time period by developed DSS. Tables that show response time of the scheduling model for different scenarios confirm this fact. In addition to this, flight schedules which are oriented to objective of squadron can be generated by DSS.

Another finding is that choosing VBA as programming language to automate flight scheduling and develop required DSS is a proper decision. The tests on performance of DSS show that VBA satisfies the needs for building required user friendly tool.

Last but not least, due to the dynamic environment of operation areas, DSS should allow scheduler to pick current objective of day instead of one general objective not to miss generated good schedules.

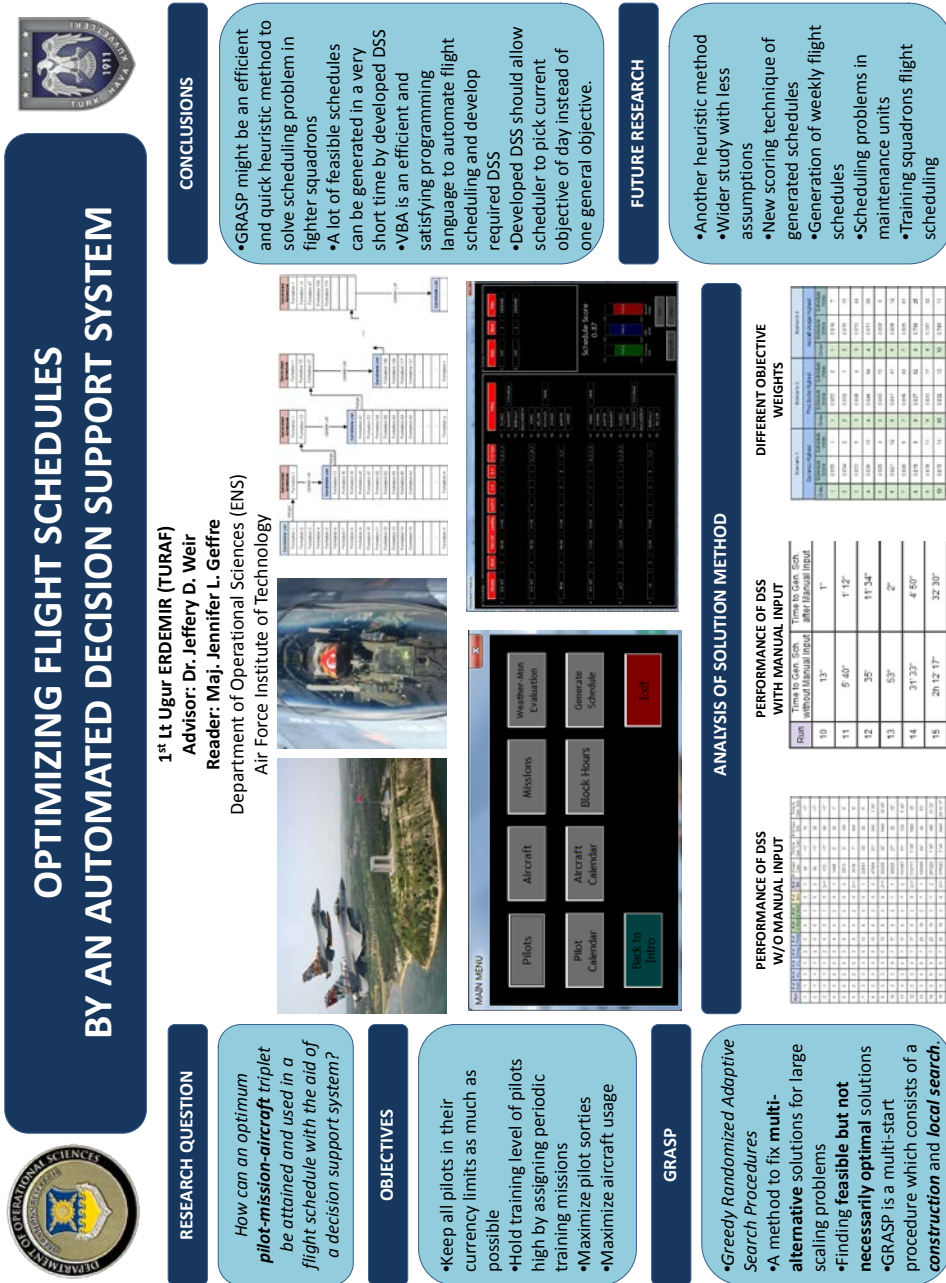
Recommendations for Future Research

Further studies in fighter squadron flight scheduling might investigate another heuristic method instead of using GRASP. Since, there are several heuristic methods in literature; another approach can be applied to similar problem. Also, after reducing the number of assumed points in this research, a study with wider scope might be executed in the future. In addition these points, another research might focus on scoring technique of generated schedules.

As next step of daily flight scheduling, generation of weekly flight schedules might be investigated with same solution techniques of this research. Moreover, similar scheduling problems in maintenance units can be figured out with similar techniques. Finally, flight schedule problems in training squadrons might be answered with developed DSS after some adjustments.

Appendix A

Quad Chart



Appendix B

DSS Userforms

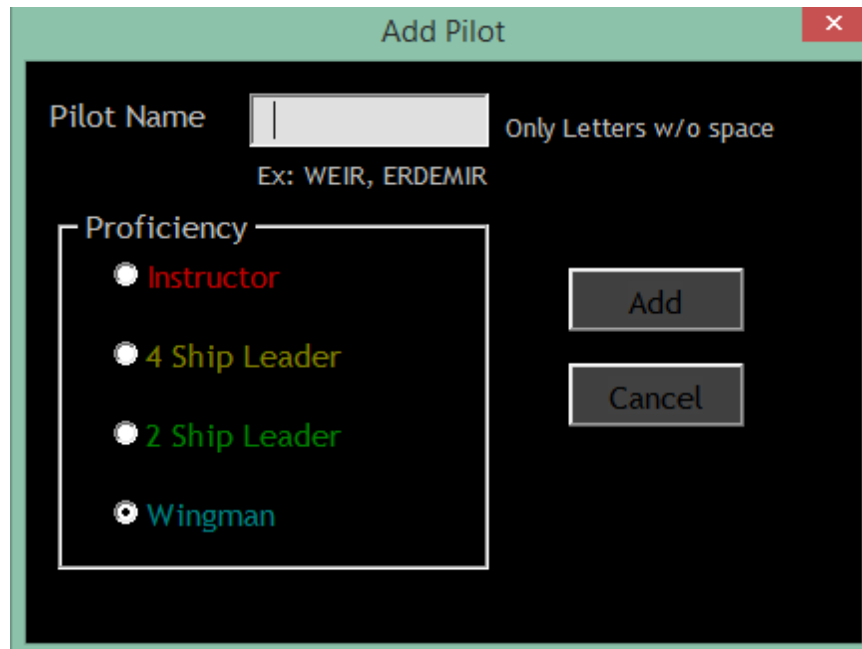
In this section userforms of DSS will be shown.

The screenshot displays the 'Pilot List' userform. It features a sidebar on the left with a close button (X) and the title 'Pilot List'. The main area is divided into four categories of pilots, each with a list of names in a box:

- Instructor** (red text): COCHRAN, MILLER, WEIR
- 4 Ship Leader** (yellow text): ERDEMIR, FLORES, JONES, UMAR
- 2 Ship Leader** (green text): FRAWLEY, KENEALLY, MARTIN, WALES, WARD
- Wingman** (blue text): BANGERT, COUSINS, GAREE, GUTIERREZ, HARDEN, LIU, MACANDREW, NELSON, POWER, TURNER, WHITE

At the bottom of the sidebar, there are four buttons: 'Add Pilot', 'Delete Pilot', 'Edit Pilot', and 'Main Menu'.

Figure 29-Pilot List Userform



The 'Add Pilot' userform has a title bar with a close button. It contains a 'Pilot Name' label, a text input field, and a note 'Only Letters w/o space' with an example 'Ex: WEIR, ERDEMIR'. Below this is a 'Proficiency' section with four radio button options: 'Instructor' (red), '4 Ship Leader' (yellow), '2 Ship Leader' (green), and 'Wingman' (blue, which is selected). To the right of the proficiency list are 'Add' and 'Cancel' buttons.

Add Pilot

Pilot Name Only Letters w/o space
Ex: WEIR, ERDEMIR

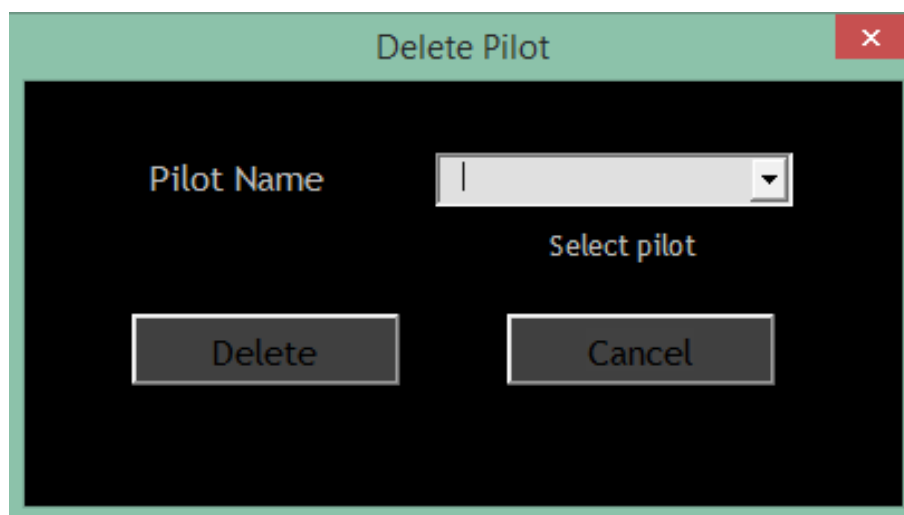
Proficiency

- ☐ Instructor
- ☐ 4 Ship Leader
- ☐ 2 Ship Leader
- ☒ Wingman

Add

Cancel

Figure 30-Add Pilot Userform



The 'Delete Pilot' userform has a title bar with a close button. It contains a 'Pilot Name' label, a dropdown menu, and the text 'Select pilot'. At the bottom are 'Delete' and 'Cancel' buttons.

Delete Pilot

Pilot Name Select pilot

Delete

Cancel

Figure 31-Delete Pilot Userform

Pilot Calendar

AVAILABILITY

BANGERT	☒ All Day Available	☐ All Day Off	☐ Specific Events
COCHRAN	☒ All Day Available	☐ All Day Off	☐ Specific Events
COUSINS	☒ All Day Available	☐ All Day Off	☐ Specific Events
ERDEMIR	☒ All Day Available	☐ All Day Off	☐ Specific Events
FLORES	☒ All Day Available	☐ All Day Off	☐ Specific Events
FRAWLEY	☒ All Day Available	☐ All Day Off	☐ Specific Events
GAREE	☒ All Day Available	☐ All Day Off	☐ Specific Events
GUTIERREZ	☒ All Day Available	☐ All Day Off	☐ Specific Events
HARDEN	☒ All Day Available	☐ All Day Off	☐ Specific Events
JONES	☒ All Day Available	☐ All Day Off	☐ Specific Events
KENEALLY	☒ All Day Available	☐ All Day Off	☐ Specific Events
LIU	☒ All Day Available	☐ All Day Off	☐ Specific Events
MACANDRE	☒ All Day Available	☐ All Day Off	☐ Specific Events
MARTIN	☒ All Day Available	☐ All Day Off	☐ Specific Events
MILLER	☒ All Day Available	☐ All Day Off	☐ Specific Events
NELSON	☒ All Day Available	☐ All Day Off	☐ Specific Events
POWER	☒ All Day Available	☐ All Day Off	☐ Specific Events
TURNER	☒ All Day Available	☐ All Day Off	☐ Specific Events
UMAR	☒ All Day Available	☐ All Day Off	☐ Specific Events
WALES	☒ All Day Available	☐ All Day Off	☐ Specific Events

Cancel

Save

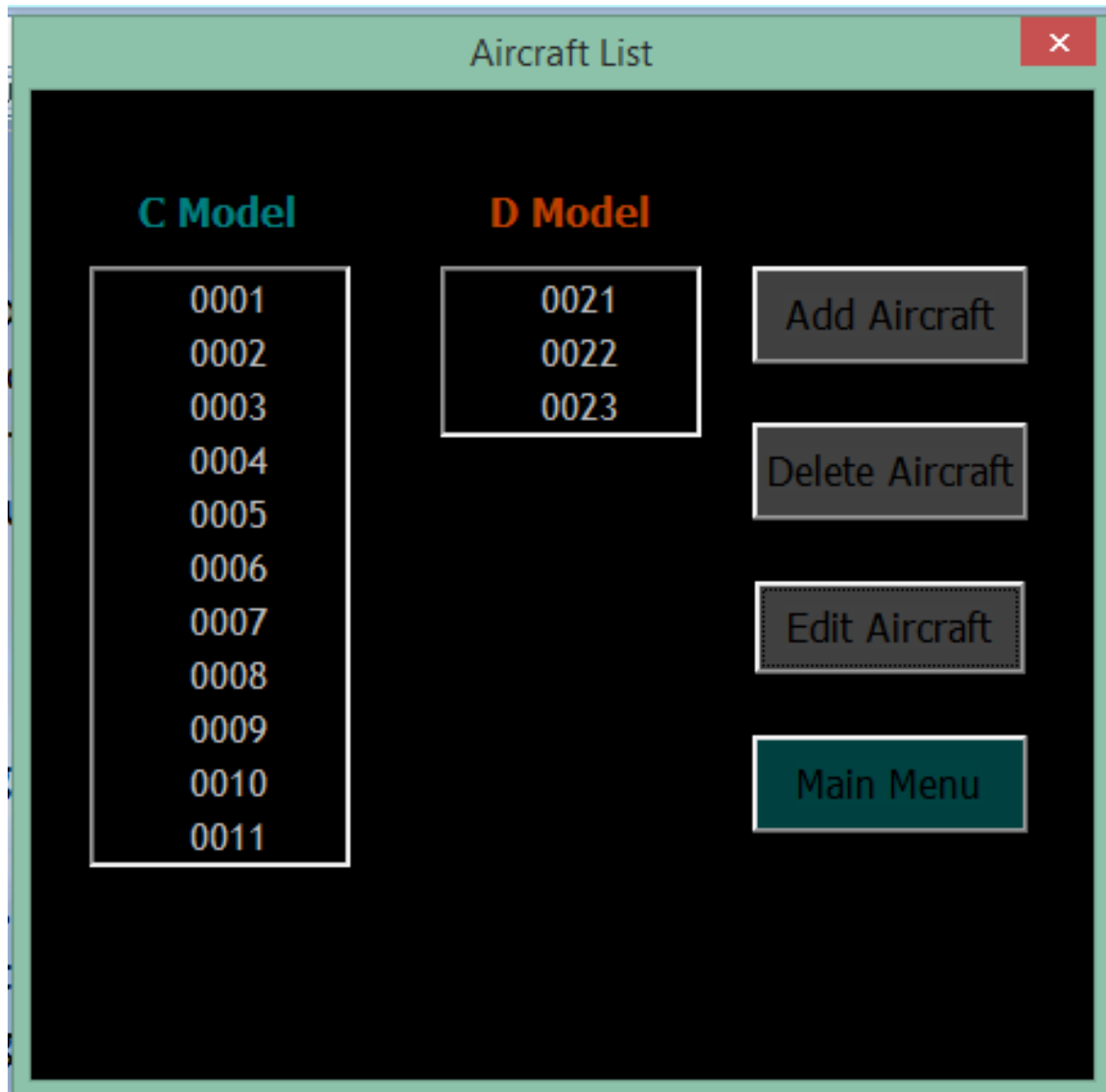
Instructor

4-Ship Lead.

2-Ship Lead.

Wingman

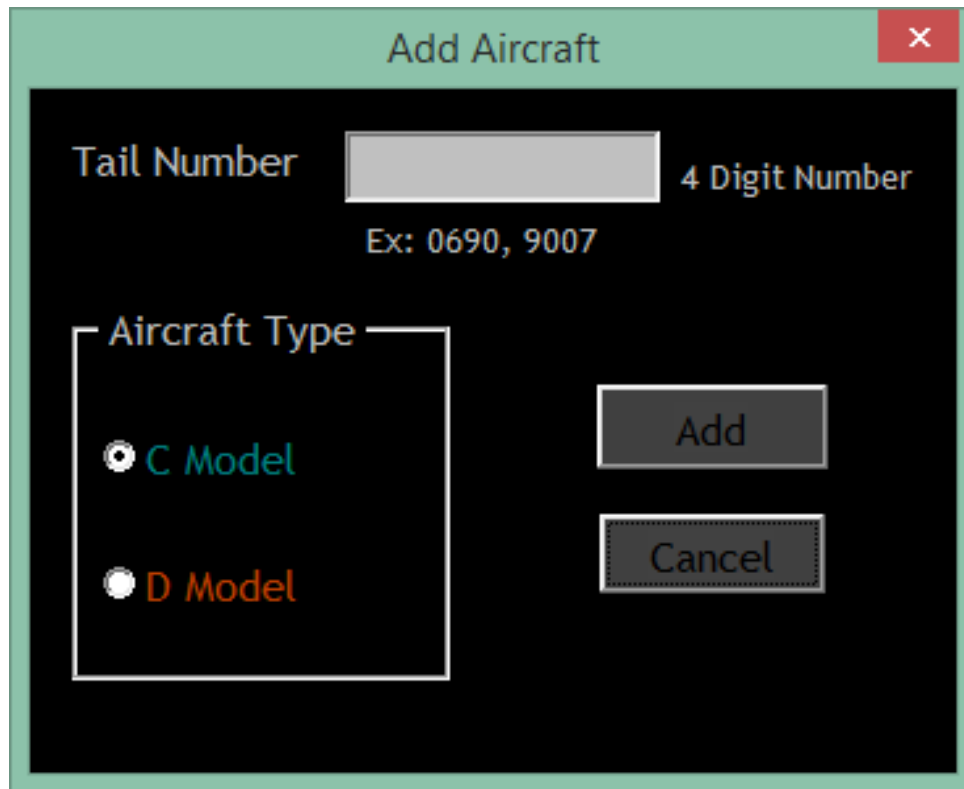
Figure 32-Pilot Calendar Userform



The image shows a userform titled "Aircraft List" with a green header bar and a red close button in the top right corner. The main area has a black background. It features two columns of aircraft models: "C Model" in green text and "D Model" in orange text. The "C Model" column contains a list of numbers from 0001 to 0011. The "D Model" column contains a list of numbers 0021, 0022, and 0023. To the right of these lists are four buttons: "Add Aircraft", "Delete Aircraft", "Edit Aircraft", and "Main Menu".

C Model	D Model	Action
0001	0021	Add Aircraft
0002	0022	
0003	0023	
0004		Delete Aircraft
0005		
0006		
0007		Edit Aircraft
0008		
0009		
0010		Main Menu
0011		

Figure 33-Aircraft List Userform



The 'Add Aircraft' userform has a light green title bar with a close button (X) on the right. The main area has a black background. At the top, the label 'Tail Number' is in yellow, followed by a white text input field. To the right of the field is the text '4 Digit Number' in yellow. Below the field is the example 'Ex: 0690, 9007' in yellow. Below this is a section titled 'Aircraft Type' in yellow, enclosed in a white border. Inside this section are two radio buttons: the first is selected and labeled 'C Model' in green, and the second is labeled 'D Model' in orange. To the right of the radio buttons are two grey buttons: 'Add' and 'Cancel'.

Add Aircraft

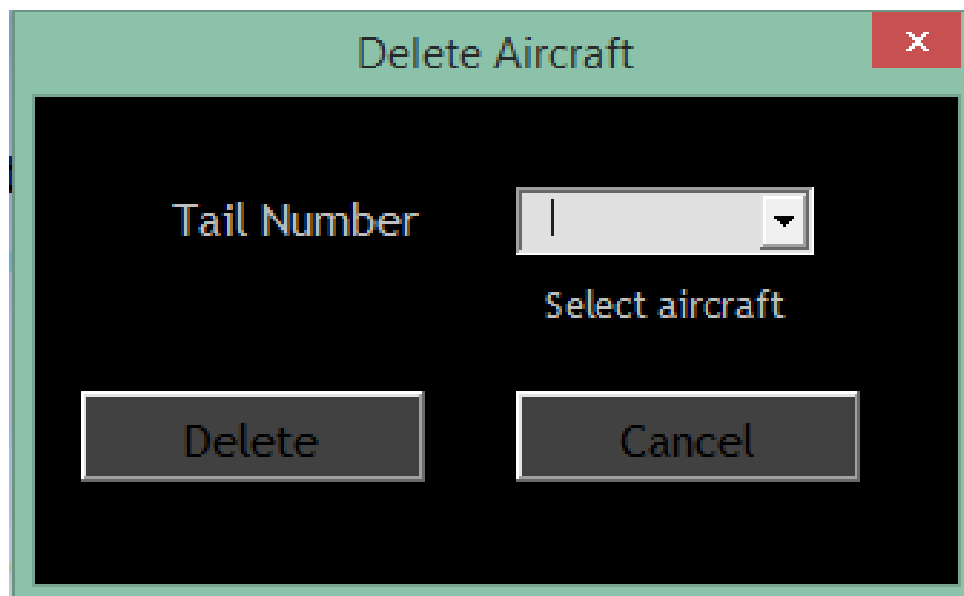
Tail Number 4 Digit Number
Ex: 0690, 9007

Aircraft Type

☒ C Model
☐ D Model

Add
Cancel

Figure 34-Add Aircraft Userform



The 'Delete Aircraft' userform has a light green title bar with a close button (X) on the right. The main area has a black background. At the top, the label 'Tail Number' is in yellow, followed by a white text input field with a dropdown arrow on the right. Below the field is the text 'Select aircraft' in yellow. At the bottom are two grey buttons: 'Delete' and 'Cancel'.

Delete Aircraft

Tail Number Select aircraft

Delete
Cancel

Figure 35-Delete Aircraft Userform

×

Aircraft Calendar

Cancel

Save

C Model

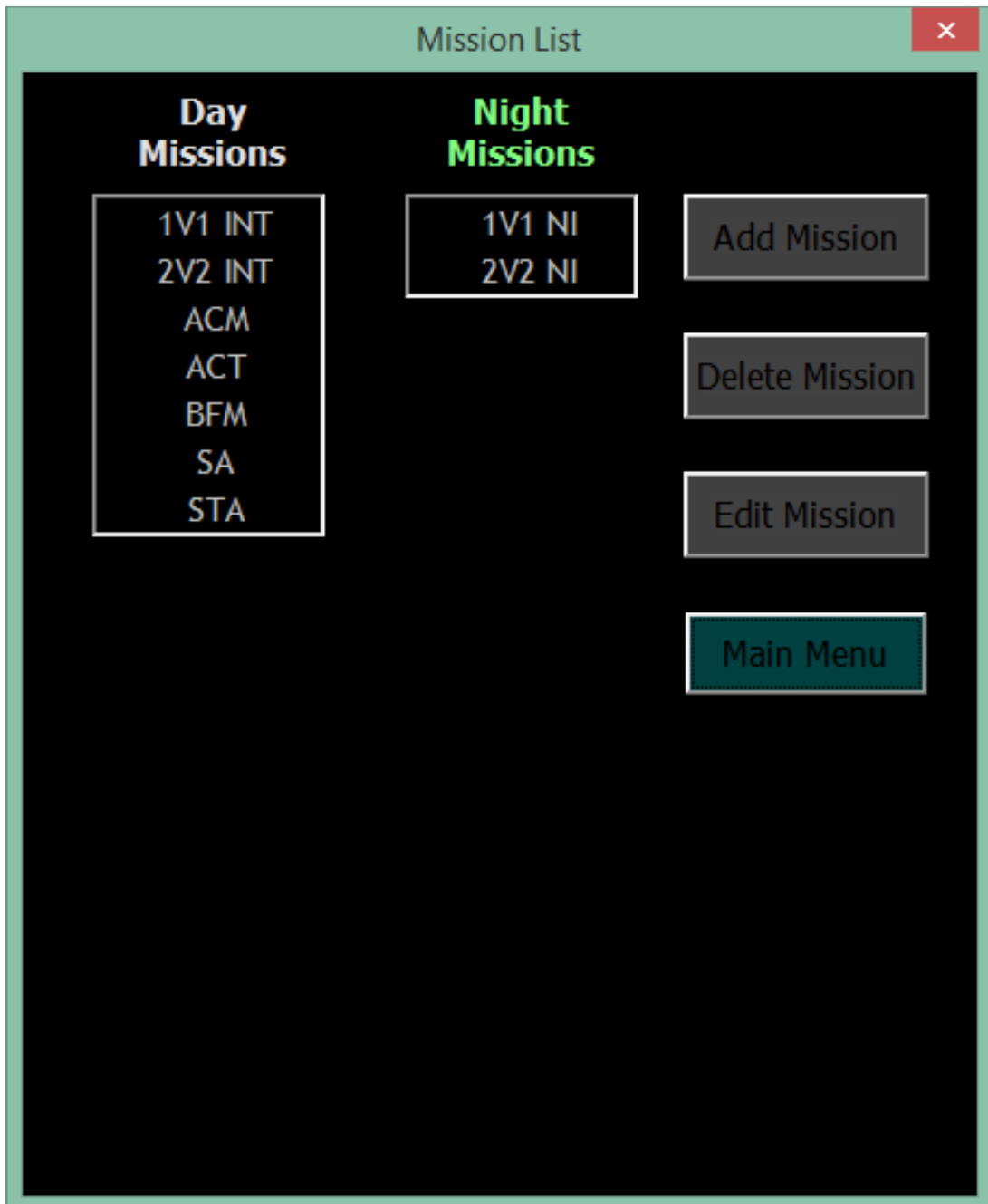
D Model

AVAILABILITY

0001	☒ All Day Available	☐ All Day Off	☐ Specific Events
0002	☒ All Day Available	☐ All Day Off	☐ Specific Events
0003	☒ All Day Available	☐ All Day Off	☐ Specific Events
0004	☒ All Day Available	☐ All Day Off	☐ Specific Events
0005	☒ All Day Available	☐ All Day Off	☐ Specific Events
0006	☒ All Day Available	☐ All Day Off	☐ Specific Events
0007	☒ All Day Available	☐ All Day Off	☐ Specific Events
0008	☒ All Day Available	☐ All Day Off	☐ Specific Events
0009	☒ All Day Available	☐ All Day Off	☐ Specific Events
0010	☒ All Day Available	☐ All Day Off	☐ Specific Events
0011	☒ All Day Available	☒ All Day Off	☐ Specific Events
0021	☒ All Day Available	☐ All Day Off	☐ Specific Events
0022	☒ All Day Available	☐ All Day Off	☐ Specific Events
0023	☒ All Day Available	☒ All Day Off	☐ Specific Events

Figure 36-Aircraft Calendar

80



The image shows a software window titled "Mission List" with a red close button in the top right corner. The window has a black background and is divided into three main sections. On the left, under the heading "Day Missions", is a white-bordered box containing a list of mission types: "1V1 INT", "2V2 INT", "ACM", "ACT", "BFM", "SA", and "STA". In the center, under the heading "Night Missions" (which is highlighted in green), is a white-bordered box containing "1V1 NI" and "2V2 NI". On the right side of the window, there are four buttons: "Add Mission", "Delete Mission", "Edit Mission", and "Main Menu". The "Main Menu" button is highlighted with a green border and a dotted pattern.

Day Missions	Night Missions	Actions
1V1 INT 2V2 INT ACM ACT BFM SA STA	1V1 NI 2V2 NI	Add Mission
		Delete Mission
		Edit Mission
		Main Menu

Figure 37-Mission List Userform

Add Mission

Mission Name

Ex: BFM, ACT

Mission Type

☒ Day Mission

☒ Night Mission

Aircraft Requirement

☐ 4-Ship

☐ 3-Ship

☐ 2-Ship

☐ 1-Ship

Mission Duration

☐ 1:00

☐ 1:15

☐ 1:30

☐ 1:45

☐ 2:00

Add

Cancel

Figure 38-Add Mission Userform

✕

Flight Block Hours

Day Time Block Hours

1st Block

08:00

11:00

☒ SOF
☐ RSU
☐ BO
☐ SIM

2nd Block

12:00

15:00

☒ SOF
☐ RSU
☐ BO
☐ SIM

3rd Block

4th Block

Night Time Block Hours

1st Block

2nd Block

3rd Block

First T/O

Last Land

Duty

First T/O

Last Land

Duty

Cancel

Save

Figure 39-Block Hours Userform

×

Weather-Mission-Limitations

Available Missions according to Weather Forecast

MISSION	DAY-TIME			NIGHT-TIME			
	BLK-1	BLK-2	BLK-3	BLK-4	NBLK-1	NBLK-2	NBLK-3
1V1 INT				1V1 NI			
2V2 INT				2V2 NI			
ACM							
ACT							
BFM							
SA							
STA							

Cancel

Save

Figure 40-Weather Mission Evaluation Userform

Mission

Block

Take-off - Landing

Acraft #

C #

D #

C-D Com

Pilots

Search

Missions

1

2V2 INT

1

08:00

11:00

4

4

0

C_C_C_C

COCHRAN

NELSON

FRAWLEY

BANGERT

Total Mandatory Flight #:1

Duty

Block

Pilot

Index: 1 / 3

SOF

1

FLORES

Next

Assign

Exclude

Exc. All

New Search

Duty

1

SOF

Blk 2

ERDEMIR

Total Mandatory Duties #:1

Mission

Delete

Generate Schedule

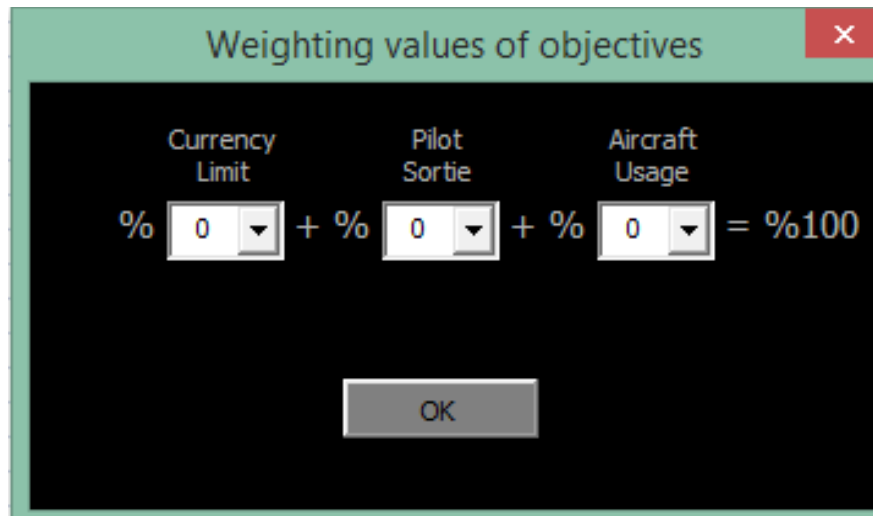
Auto-Search

Start Over

Delete

Figure 41-Manual Input Userforms

Figure 42-Generated Schedule Userform



A screenshot of a software window titled "Weighting values of objectives" with a red close button in the top right corner. The window has a black background. It contains three labels: "Currency Limit", "Pilot Sortie", and "Aircraft Usage". Below each label is a percentage sign followed by a white box containing the number "0" and a small downward arrow. These are separated by plus signs, followed by an equals sign and "%100". At the bottom center is a grey "OK" button.

Weighting values of objectives

Currency Limit Pilot Sortie Aircraft Usage

% 0 + % 0 + % 0 = %100

OK

Figure 43-Weighting Values of Objectives Userform

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Vita

First Lieutenant Ugur ERDEMİR was born in İstanbul. He graduated from Air Force Academy in İstanbul, in 2006 and he earned the degree of Bachelor of Science in Computer Engineering. In the same year, he began his flight training in the 2nd Main Jet Base in İzmir. In 2009, after graduating from F-16 Basic Training Program, he was assigned to the 192nd Squadron, Balıkesir as a wingman. He entered Graduation School of Engineering and Management, Air Force Institute of Technology in 2012.

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13. SUPPLEMENTARY NOTES This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.					
14. ABSTRACT In current air forces, due to different types of aircrafts and missions, lots of flight schedules are published every day. All flying units make their flight schedules each of which contain decisions of the best pilot-mission-aircraft triplet according to unit's own constraints and rules. In this study, main objective is to build a decision support system to assist the schedulers in fighter squadrons. Scheduling in fighter squadrons are complex and time consuming due to the combination of the large number of constraints and limited number of schedulers. Also, dynamic environment of the operation area that increases uncertainty level of the problem makes flight scheduling a difficult job. For this reason, building flight schedules without any supplementary tools takes a large amount of time. Thus, air forces are in need of automated decision support systems for flight scheduling. The required Decision Support System is coded in Microsoft Excel Visual Basic to produce flight schedules which are now made manually. To generate feasible schedules, Greedy Randomized Adaptive Search Procedures is implemented and generated schedules are scored to attain best solution. Following that, performance of DSS and scoring method are evaluated to analyze solution technique.					
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