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AIDING USAF/UPT AIRCREW SCHEDULING
USING NETWORK FLOW MODELS

by

Robert Michael Huelskamp

B.S., United States Air Force Academy

(1978)

SUBMITTED IN PARTIAL FULFILLMENT

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AIDING USAF/UPT AIRCREW SCHEDULING

USING NETWORK FLOW MODELS

by

ROBERT MICHAEL HUELSKAMP

ABSTRACT

thesis

Undergraduate Pilot Training(UPT) is a dynamic, high pressure
program which produces front line aviators for the United States Air Force.
The eleven month curriculum contains a complicated assortment of academic,
flight, and simulator training. Recent expansions in the UPT program and
increased emphasis on cost effective scheduling have rendered the current
manual scheduling methods obsolete.

This paper develops a micro-computer based scheduling algorithm which
aids UPT schedulers in finding feasible solutions to daily scheduling
problems. We formulate the problem as a two level network flow problem.
Level 1 uses both maximum flow and minimum cost flow formulations to solve
the instructor assignment problem. Level 2 addresses student scheduling and
uses a two pass, optimization based heuristic which assigns students via a
network transportation formulation.

The bi-level network formulation produces feasible daily schedules in
minutes on an IBM PC/XT compared to the hours required for the manual
method. It also performs feasibility checks at both levels and allows scheduler
interaction to effectively generate daily schedules.

Thesis Supervisor: James B. Orlin

Title: Associate Professor of Operations Research and Management

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CHAPTER 1

INTRODUCTION AND BACKGROUND

1.0 - OVERVIEW

The United States Air Force's Air Training Command is the largest training operation in the world. Its efforts are diverse as it prepares newly recruited personnel for virtually every USAF role. Perhaps the most critical training program within Air Training Command is Undergraduate Pilot Training(UPT). UPT prepares select military officers to be the front line aviators for the USAF. Training is conducted year round at several locations and produces over 2,500 fully qualified pilots annually.

For many years Air Training Command has placed great emphasis on conducting high quality training programs in a cost effective manner. In UPT, the emphasis has been on aggressive use of instructors and aircraft to provide the highest quality pilots. Supporting this effort to better manage resources each flying squadron in UPT has placed increasing importance on daily scheduling efforts. Historically, the daily scheduling has been accomplished heuristically, by hand. Little computer assistance was required or available due to the small size of the training squadrons. However, recent expansions of the UPT squadrons have led to tighter scheduling and increased difficulty in finding feasible solutions to daily training requirements. Paralleling this schedule tightening in UPT has been the introduction of powerful, affordable micro computers. It is my goal to develop a

scheduling algorithm on a micro computer which will aid UPT schedulers in finding feasible solutions to daily scheduling problems. In this chapter I will provide a brief background of Undergraduate Pilot Training and a description of the UPT scheduling environment.

1.1 - DEFINITION OF TERMS

DUTY DAY   The individual's work day. It begins when the pilot arrives in the squadron and ends when he/she departs.

LAUNCH   The initial takeoff of an aircraft mission.

RUNWAY SUPERVISORY
UNIT   A senior instructor and staff responsible for safe conduct of all air operations.

SLOT TIME   The assigned takeoff time(launch time) for an aircraft mission

SORTIE   An aircraft mission

SUPERVISOR
OF FLYING   A senior instructor responsible for monitoring all squadron activities.

TURN TIME   The time between successive launches for a particular pilot or aircraft

1.2 - DESCRIPTION OF UNDERGRADUATE PILOT TRAINING

Undergraduate Pilot Training(UPT) is the United States Air Force's school of flying in which all military aviators for the USAF are trained. The purpose of UPT is to provide a high quality, military pilot in a timely manner. The course of training lasts 11 months and exposes the student to all facets of military aviation. The USAF's Air Training Command(ATC) is responsible for the UPT program which is conducted simultaneously at 5 sites throughout the southern United States. The UPT bases are located at Williams AFB., Tempe, Arizona; Reese AFB., Lubbock, Texas; Vance AFB., Enid, Oklahoma; Laughlin AFB., Del Rio, Texas; and Columbus AFB., Columbus, Mississippi.

1.21 - CURRICULUM

The 11 month UPT program is multi-faceted involving several different areas of instruction. The program is divided into three major categories of training. They are 1) Academic(classroom) instruction, 2) Subsonic flight instruction, and 3) Transonic flight instruction. The program begins with one month of basic classroom instruction in aeronautics, aircraft systems, and weather. After this introductory course the students transition into subsonic flight training in the Cessna T-37 jet trainer. This training is conducted by USAF instructor pilots and lasts approximately 16 weeks. During the 16 weeks students receive training in basic aircraft control, takeoff and landing, acrobatics, inclement weather flying, navigation, and two-ship formation. The students "solo" after 15 hours and receive nearly 70 total hours of flight instruction in the T-37.

After mastering the T-37 the student graduates to the Northrop T-38 for additional training in a high speed, transonic flight environment. As in the T-37 the

student learns the basic skills needed for acrobatics, navigation, formation, etc. in the high speed environment. T-38 instruction is also provided by USAF instructor pilots and lasts approximately 22 weeks. Simultaneously with flight instruction in the T-37 and T-38 the student continues his academic schedule learning advanced aircraft systems, navigation, and advanced aerodynamics. In addition, the student receives training in various other areas such as ejection, survival, and parachuting.

1.22 - ORGANIZATION

Each of the 5 UPT bases conduct identical training programs throughout the year. The schools operate 50 weeks a year with a new class arriving every 6 weeks. This constant flow of students results in all forms of training being conducted simultaneously at each base. The UPT instructor staff at each base is divided along the same lines as the curriculum. Three squadrons(Academic, T-37, T-38) train independently, and each squadron maintains its own instructor force. The T-37 and T-38 squadrons have similar flight scheduling situations and similar constraints on the program. For this project I will focus on a typical T-37 squadron and its scheduling needs. Only minor constraint modifications would be necessary to apply results to a T-38 squadron.

1.23 - T-37 SQUADRON

The T-37 squadrons at each of the 5 UPT bases are organized in the same fashion. Each squadron operates year round and is divided into 6 training units and a squadron staff. A squadron will have approximately 90 assigned instructors fully qualified to instruct students in all phases of training. The heierarchy in the squadron can be seen in figure 1.1. The instructors in the 6 units are the primary trainers while the other staff instructors divide their time between student training and other duties.
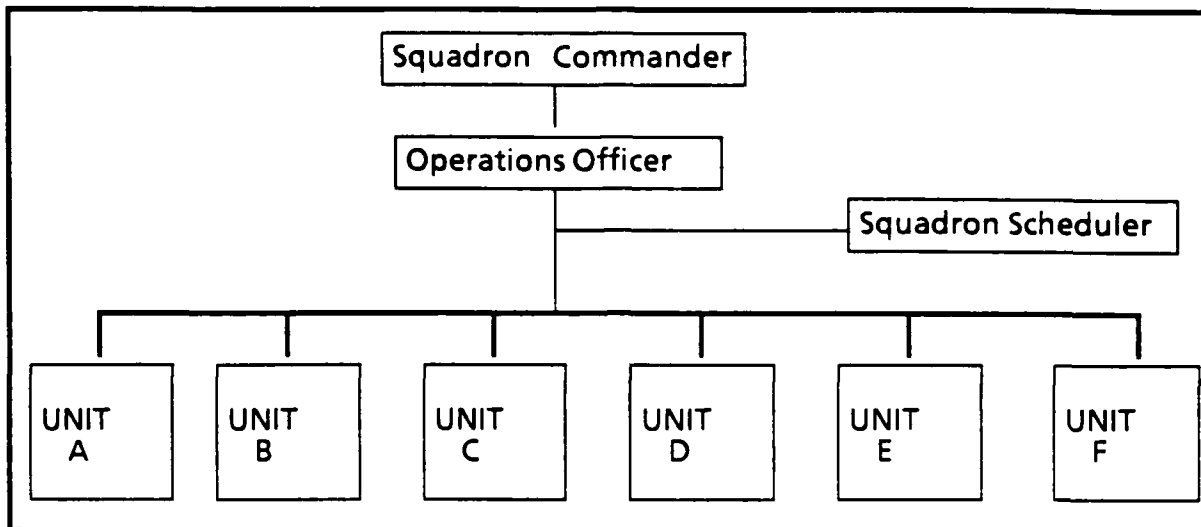
Figure 1.1 - Squadron Heierarchy

The makeup of each unit can be seen in figure 1.2. An average unit consists of a unit commander, his assistant, a scheduler, training officer, and 8 "line" instructors. Although each of these instructors are involved in daily flight instruction of students, the line instructors conduct the bulk of the training due to their lack of additional duties.
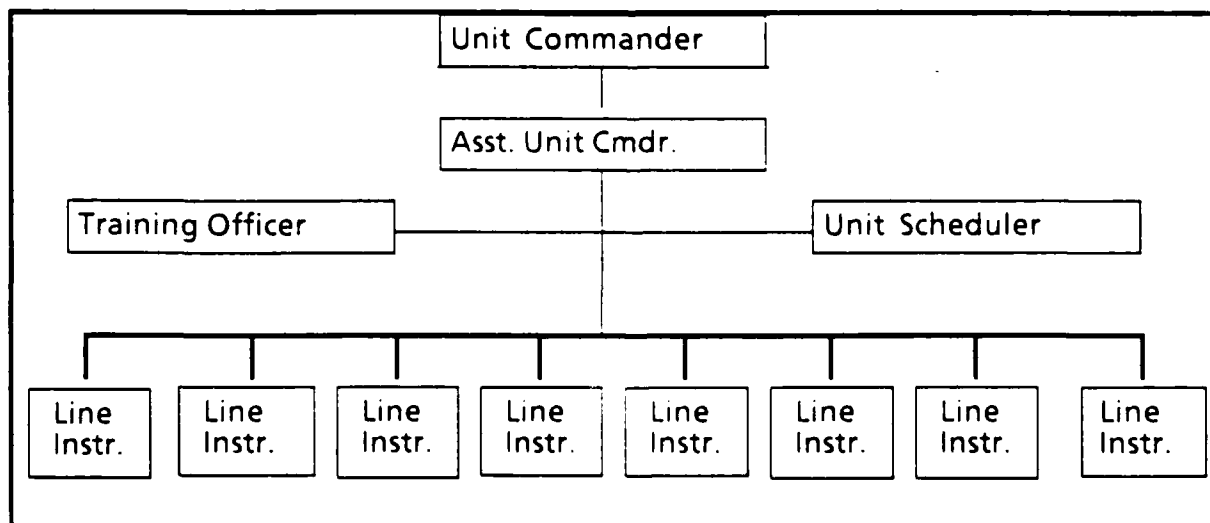
Figure 1.2 - Unit Makeup

Entering classes of students are assigned equitably to each unit as they arrive. Classes average 70 students with a new class entering every 6 weeks. Upon entering, a class is divided between 2 units resulting in a 3:1 student-instructor ratio. Thus a typical T-37 squadron will have nearly 200 students in various stages of training throughout the year.

1.3 - SCHEDULING ENVIRONMENT

Due to the staggered class arrangement in a squadron a wide variety of training is accomplished on a daily basis. This results in a homogeneous training schedule for the entire squadron year round. Each training day has a variety of tasks in the different units, but the distribution of tasks and total missions flown each day is fairly constant barring any unusual delays or losses due to weather, maintenance, etc.

1.31 - TIMELINE

The daily training program is driven by the squadron's timeline. The timeline is a computer monitored training flow schedule which reflects how well the squadron is maintaining its position relative to scheduled graduation dates. The timeline output is broken down into squadron, unit, and individual student levels to exhibit their relative positions. For example, if a student does not fly for an extended period of time due to weather or an illness the timeline will show how many days the student will graduate late if normal training pace is resumed. Due to the various student's flying skills a typical class will have students anywhere from 10 days ahead of the timeline(+10) to 20 days behind(-20). The combination of the student's individual timeline positions reflects the unit's timeline position. Normally, units prefer to remain +2 to +5 days ahead of the timeline to buffer any unexpected losses. Combining the unit timeline positions results in the squadron's position. Typically the squadron's timeline position hovers near 0 as the individual units struggle to maintain their positions.

A second important feature of the timeline output is the correction factors. Each student and unit receive a daily update on the number of sorties needed per day to return to a 0 timeline position by the graduation date. For the student, the

printout shows how many missions per day are required to graduate on time. Each flight receives its total missions/day requirement and, finally, the squadron receives input as to the total squadron missions/day needed to smoothly return to a normal training flow.

Allowing an individual student or unit to stray too far from the timeline position can have disasterous affects for the squadron. If too far ahead, students have poor continuity toward the program's end which may lead to unsafe flying conditions. If too far behind, the individual student or unit must put in excessive amounts of overtime resulting in rushed training and fatigue. These are just some of the problems which result from poor timeline management by a squadron.

1.32 - TYPICAL FLYING DAY

The homogeneity of the squadron's flying activities results in a fairly constant squadron-wide daily flying schedule. With the exception of a few night missions, the UPT flight instruction is conducted only in the daylight and twilight hours. The flying day extends from 15 minutes before sunrise to 15 minutes after sunset. Based on the time of year the flying day is anywhere from 11 to 15 hours long.

Agreement with the local FAA Air Traffic Control centers allows a new aircraft sortie to launch from the field every 90 seconds. Due to instructor/aircraft limitations and safety considerations, however, sorties are scheduled to launch with a minimum of 3 minute spacing. This allows for a maximum of 20 sorties per hour from 15 minutes before sunrise to 15 minutes after sunset. These maximums are rarely needed to maintain a good timeline position and primarily reflect a surge capability for the squadron. On average a squadron will need approximately 200 sorties/day to maintain its timeline position and will schedule about 15 sorties/hour.

Although the squadron flies a variety of sorties on a daily basis, nearly every sortie has the same flight profile. Each sortie will depart the home field, last 1.25

hours, and return to the home field for fuel and servicing. Of the total sorties approximately 10% will be flown solo by a student. The other 90% will require one instructor and one student per sortie.

1.33 - SCHEDULING PROCESS

The squadron scheduler is the central scheduler who reports directly to the Operations officer. He is responsible for monitoring squadron and unit timeline positions and allocating daily sorties to each unit based on need and capacity. Unit schedulers have similar monitoring and controlling responsibilities for their respective units and report directly to the unit commander. In all, 10 to 12 schedulers and assistants are actively involved in the process on a given day resulting in nearly 100 manhours daily to ensure a smooth flowing training schedule. The entire scheduling process is accomplished heuristically. The only computer assistance available is the daily timeline output discussed above. In the past year many squadrons have purchased personal computers for the squadron scheduler. However, these are used for little more than as a spreadsheet and as a printing device.

The squadron scheduler is primarily concerned about the total timeline position and is not responsible for the instructor-student pairings for each sortie. To the squadron scheduler all sorties are virtually the same and his primary responsibility is to ensure an equitable and feasible mixture of sorties among the units. The unit scheduler, on the other hand, has a slightly different scheduling problem. He is responsible not only for the number of sorties for his unit, but also for the pilot pairings for each sortie to maintain each student's timeline position.

The scheduling process can be seen in figure 1.3. Two weeks prior the unit schedulers "contract" for sorties based on 1) current timeline position, 2) projected instructor availability, and 3) desired timeline position. Each unit scheduler sends

his contract to the squadron scheduler who then determines the necessary daily totals for each day and negotiates with Maintenance Control. An example of a unit contract form can be seen in appendix A. Based on each unit's timeline position and
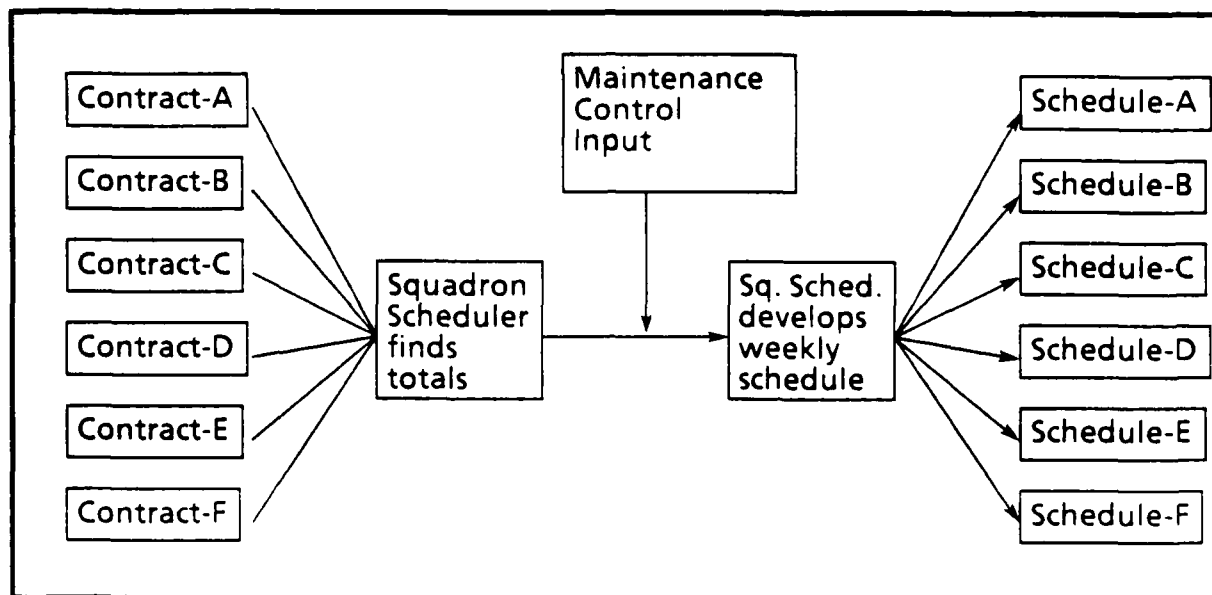
Figure 1.3 - Scheduling Process

capacity, and the capabilities of Maintenance Control the squadron scheduler attempts to develop a feasible schedule for the entire week. An obvious goal is to simply fill each unit's contract. However, this is rarely feasible due to conflicting contracts from the individual units. The squadron schedule for the entire week is arranged and distributed to the units two workdays prior to the start of the week. Each unit scheduler then manipulates student-instructor pairings on a day to day basis to optimize student training. Appendix B is an example of a weekly flying schedule for the T-37 squadron at Reese AFB.

1.34 - RECENT DEVELOPMENTS

For several years the method of scheduling currently used by squadron and unit schedulers was adequate due to the nature of training. Smaller class sizes and

more dependable aircraft systems resulted in fewer timeline constraints. This made squadron and flight scheduling easier as feasible solutions were more readily available. Typically an average duty day for an instructor was 8-10 hours and weekend flying was unheard of. Suboptimal feasible solutions from the units easily met timeline constraints and the squadron scheduler merely filled each unit's contract. No effort was made to maximize training as this would only result in early graduation and subsequent sequencing problems with other training programs.

Since 1980, however, the need for optimal scheduling has become paramount. Class sizes have increased significantly and constraints on the system have become much more binding. Feasible solutions to daily timeline scheduling requirements are much more elusive. A common approach used by many squadrons to find feasible solutions has been to increase the instructor duty day and to include weekend flying. 6 day work weeks are now the norm at most UPT bases. The manual heuristic method is becoming less effective and squadron and unit schedulers have less time to devote to scheduling since they, too, must fly more to meet timeline demands. All of these developments have significant morale, training, and safety implications as instructors and students work longer hours and become more fatigued.

CHAPTER 2

LITERATURE REVIEW

2.0 - INTRODUCTION

Under the current scheduling system it is virtually impossible to determine an optimal schedule due to the difficulty of the problem and time constraints. In the past no real attempt was made at computer aided scheduling due to the lack of facilities. The size of the training squadron was not large enough to justify powerful and expensive computer equipment used only for daily scheduling and data management. However, with the advent of the personal computer sufficient power may now be available to efficiently find nearly optimal solutions to the UPT scheduling problem. In this chapter I will further define the UPT scheduling problem by addressing the problem description, constraints, and structure.

2.01 - PROBLEM DESCRIPTION

The UPT scheduling problem can be subdivided into three basic levels. The first and most constrained level is the squadron scheduler's task of assigning instructor pilots to the daily task schedule(Level 1). Recall that each task has a fixed start time and each instructor has limited availability. After determining a feasible instructor-sortie matching for the entire squadron, the schedule is divided into the six independent flying units. This

second level of scheduling is performed by the unit scheduler who attempts to find a feasible student-instructor matching for all the unit's assigned tasks. The third level of the problem is addressed after the unit scheduler "fills" the schedule with feasible student/instructor matchings. At this level the unit scheduler determines the mission category to be flown by each student.

The first two levels of the problem are actual scheduling problems and are similar in many respects. Their specific constraints and structure will be addressed in the next two chapters. The third level, mission category assignments, is a data management problem in which the unit scheduler develops a priority queue for each student. A First-In/First-Out queue of mission categories ensures a balanced mix of mission types and good continuity of training.

2.02 - PROBLEM CONSTRAINTS

The squadron and unit schedulers work in unison to to find a feasible scheduling solution which maintains a smooth training program that meets Air Training Command guidelines for student training. Of the myriad of constraints on the system the following are most binding for the schedulers.

Level 1

1. 3 tasks maximum per day for each instructor pilot

2. 2.75 hour turn time for each instructor

3. Unit report time for all instructors is 1.75 hours prior to the 1st unit sortie of the day

4. Maximum flying day is 12 hours for each instructor

5. Maximum duty day (flying – additional duties) is 16 hours

Level 2

1. 3 tasks maximum per day for each student pilot

2. 2.75 hour turn time for each student

3. Unit report time for all students is 1.50 hours prior to the 1st unit sortie of the day

4. Student duty day must be less than 12 hours
5. Each student flies with a maximum of 5 different instructors during training

These and other training/scheduling constraints are contained in Air Training Command manual 51-37. In additíon to these "hard" constraints several "soft" constraints exists to provide optimal training. If possible, these constraints should be met as well.

1. Limit instructor duty day to 12 hours

2. Minimum of 1, maximum of 2 sorties per student per day

3. Maximum of 2 sorties per instructor per day

4. One sortie per day for staff/support personnel

5. Minimize instructor idle time between sorties

6. Five day work week

Obviously as each constraint is considered the difficulty of obtaining a feasible solution increases. Some constraints are more binding than others and dramatically increase the difficulty of the scheduling problem.

2.1 - AIRCREW SCHEDULING

The area of aircrew scheduling is one that has recieved much attention in recent years. In aircrew scheduling the primary concern is to sequence the movement of crew members in space and time to staff desired airplane

movements. Usually the aircrew schedule is determined after the airplane schedule since the airplane costs significantly dominate the crew costs.

Some of the best results in crew scheduling in general have been obtained in those areas where the problem can be formulated as a network flow model[43]. Unfortunately for the airline industry the variety of airplanes, crew domiciles, and complicated pilot workrules do not lend themselves to easy network formulation. The airline crew scheduling problem is generally broken down into two parts - generating pairings and constructing bid lines. A pairing is a sequence of trips that begin and end at the same domicile which one crew must complete. A bid line is a set of pairings that represent a monthly work schedule for a crew.

Baker[1] uses a set of heuristics to solve the pairing problem. He has solved a single domicile/900 trip crew scheduling problem for Federal Express Corporation to within 1% of the best known result. For bid line construction Finnegan[23] uses a matching algorithm to develop bid lines given a set of pairings. Marsten and Shepardson[46] use set patitioning ideas to solve both the pairing and bid line problems.

2.2 - VEHICLE SCHEDULING

Although the UPT crew scheduling problem involves aircraft and aircrew members, its network structure is much simpler when compared to the scheduling in the airline industry. This structure reduces the UPT problem from a complex airline scheduling problem to one which can be modelled as a production planning or vehicle scheduling problem. Vehicle scheduling problems can be viewed as routing problems with additonal time constraints imposed on the network. As a result, the tasks are accomplished

in both space and time. Vehicle scheduling problems can be broken down into three major classes -- arc-based scheduling, node-based scheduling, and a combination of both. In the arc-based scheduling a set of arcs in the network must be traversed. Examples include snow removal and the Chinese Postman problem with time constraints. In the node-based scheduling a collection of supply and demand nodes are given and at least one vehicle must travel from each supply node to its corresponding demand sight. Examples of this type of network include the dial-a-ride problem and the assignment problem. Finally, in the combined problem there specific nodes and arcs which must be serviced. School bus scheduling, where specific schools and streets must be serviced within time constraints, is an example of this type of scheduling[180]

In simple terms, the vehicle scheduling problem involves vehicles, customers, and a time schedule. The vehicles travel from customer to customer servicing customer needs(making deliveries, pickups, etc.) at specific times. The goal of the scheduler is to "optimally" route each vehicle such that all customers are serviced on time. In production scheduling, the "vehicles" are actually machines on which certain jobs(customers) must be completed. In this context the goal is to optimally schedule jobs to machines such that all jobs are completed on time.

Translated into the terms we are using for the UPT crew scheduling problem, the instructor pilots(level 1) and students(level 2) can be viewed as the "vehicles" or "machines" required to perform specific jobs. The jobs are tasks which must be accomplished at predetermined times. The scheduler's goal is to optimally assign tasks(jobs) to pilots(machines) such that all tasks are accomplished on time. Figure 2.1 is an illustration of the level 1 problem(matching instructors and tasks) viewed as a production scheduling problem.
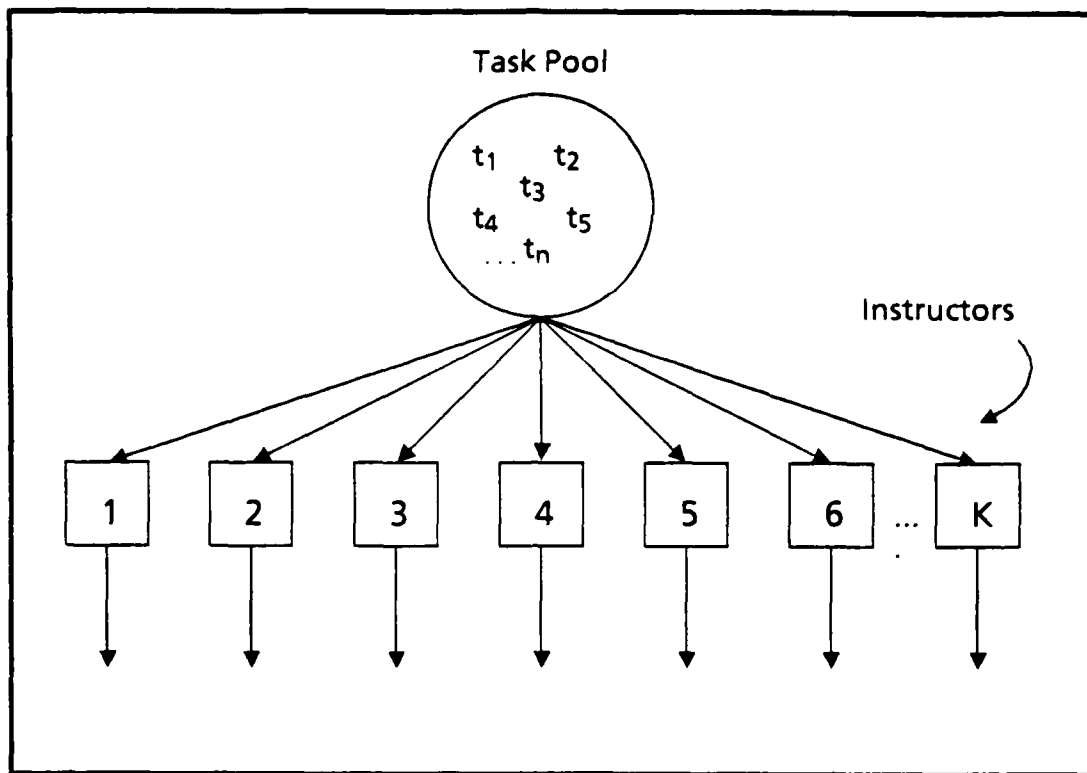
Figure 2.1 - Homogeneous, single-stage production scheduling

Our goal is to sequence the daily tasks $t_1, t_2,...,t_k$ through the instructors in an "optimal" manner subject to the constraints outlined in the previous section. Each task has a predetermined start/completion time and each pilot has a constraint of accomplishing only one task at a time. What an "optimal" matching of tasks to pilots actually is will be addressed in the next chapter. Figure 2.2 shows the level 2 problem which incorporates not only the time element but also the matching element. The task type must match with the student since the students are non-homogeneous.
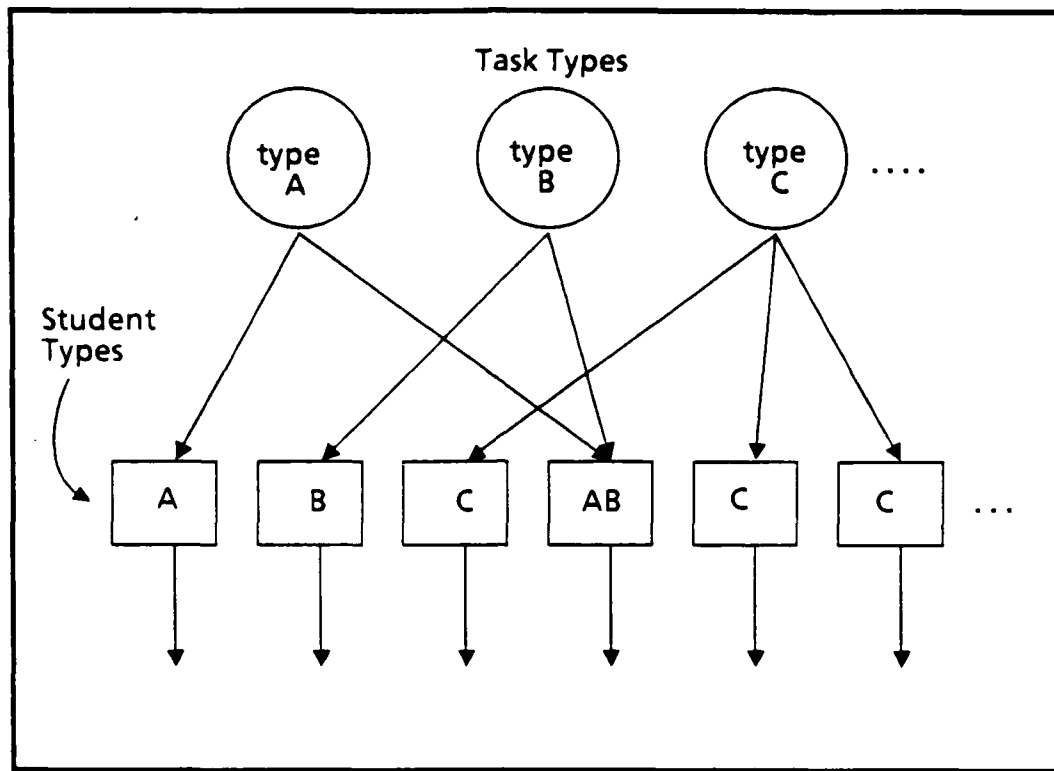
Figure 2.2 - Non-homogeneous, single-stage production scheduling

2.3 - VEHICLE SCHEDULING OUTLINE

The following outline from Bodin and Goldin[12] outlines a number of characteristics that further describe any vehicle scheduling problem. One can see from this outline that the UPT scheduling problem neatly fits into the category of pure vehicle scheduling problems. I have asterisked the item in each category which applies to the UPT problem.

A. Time to service a particular node or arc
    1. time specified and fixed in advance (pure vehicle scheduling problem) (*)
    2. time windows (combined vehicle routing and scheduling problem)
    3. time unspecified (vehicle routing unless precedence relationships exist)

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B. Number of domiciles
 1. one domicile (*)
 2. multiple domiciles

C. Size of vehicle fleet available
 1. one vehicle
 2. multiple vehicles (*)

D. Type of fleet available
 1. homogeneous case (all vehicles the same) (*)
 2. heterogeneous case (all vehicles not the same) (*)

E. Nature of demands
 1. deterministic (*)
 2. stochastic

F. Location of demands
 1. at nodes (not necessarily all) (*)
 2. on arcs (not necessarily all)
 3. mixed

G. Underlying network
 1. undirected
 2. directed (*)
 3. mixed

H. Vehicle capacity constraints
 1. imposed-all the same (*)
 2. imposed-not all the same
 3. not imposed

I. Maximum vehicle route-times
 1. imposed-all the same (*)
 2. imposed-not all the same
 3. not imposed

J. Costs
 1. variable or routing costs
 2. fixed operating or capital costs (*)

K. Objective
 1. minimize routing costs incurred
 2. minimize sum of fixed and variable costs
 3. minimize number of vehicles required (*)

L. Other (problem dependent) constraints

In category A the time to service a particular item is time specified and fixed in advance. As was mentioned before, this applies to the duration of a task(sortie length). This length is directed by regulation to be 1.25 hours for aircraft and simulator sorties. This item also applies to the specified start/finish time for each task. Again, the start time for each sortie is fixed in advance by Maintenance Control. Limited flexibility is available with respect to start times, but this is utilized only if no feasible schedule can be determined. The primary reason for strict start times is that several sorties are flown in a single aircraft or simulator. Obviously, if a sortie starts late all subsequent sorties in that aircraft/simulator must be pushed back proportionately. This rippling through the schedule may result in an infeasible turn time for a pilot flying that aircraft later in the schedule.

In category B the number of domiciles is limited to one. All sorties originate and terminate at the home airfield. This simplifies the problem since it allows greater flexibility of sortie assignments to pilots.

Category C, the size of the vehicle fleet, further defines the problem. The UPT problem has more than one vehicle(pilot) available for assignment to the multitude of tasks.

The type of fleet available, Category D, involves a set of homogeneous instructor pilots all possessing the same flying qualifications for the level 1 problem. The level 2 problem involves a set of non-homogeneous students which must be matched to instructors.

Categories E and F address the nature of demand at each node. The nodes in the UPT problem are the sorties to be flown. The demand at each node is deterministic. That is, each task "demands" exactly one instructor(level 1) and one student(level 2).

The underlying network, Category G, in the UPT problem is directed. This is so because of the precedence relationships among tasks. For example, of the five sorties assigned to a particular aircraft(s_1, ..., s_5) each has a specified start time. The sequence must be flown in ascending numerical order resulting in the directedness of the network.

In Category H, capacity constraints are imposed and are not necessarily the same for each pilot. The constraints in the previous section indicate that the maximum number of sorties per day is three for each pilot. Particular pilots (Commanders, staff, etc.) may be limited to a maximum of two or less due to additional duties. Unfortunately, this restriction on capacity for each pilot has been proven to be NP-hard [4]. Methods to accomodate this difficulty will be discussed in the following chapter.

Category I involves maximum vehicle route times. This category captures another major constraint of the UPT scheduling problem. Maximum route times equate to the maximum flying duty day for the pilots. As with the capacity constraints in Category H the duty day restriction adds considerably to the difficulty of the problem.

Category J- costs. The costs in the UPT scheduling problem can be viewed as fixed. There are no variable costs associated with overtime, instructor duty days, etc. The capital costs associated with pilot acquisition is a long term planning concern not a daily scheduling matter.

The primary objective of the UPT scheduler, Category K, is to minimize the number of pilots needed to fill the daily schedule. This objective can be used to determine if a particular task schedule is infeasible(i.e. is the minimum number of pilots needed greater than the number available?) It also indicates the number of pilots available for additional duties. Thus, the "minimize the number of pilots" objective allows the scheduler to iterate

through feasible schedules and to perform sensitivity analysis on the chosen schedule.

Finally, category L captures any remaining problem-dependent constraints. In our case this would include additional constraints such as unit report times which affect the length of a pilot's duty day.

In summary, The problem structure of the UPT scheduling problem can be viewed as a pure Vehicle Scheduling problem with a single domicile containing multiple homogeneous (level 1) /non-homogeneous(level 2) pilots. The task demands are deterministic at each node in a directed network of tasks. Pilot capacity and time constraints are imposed and the objective is to minimize(Level 1)/maximize(Level 2) the number of pilots needed to fill the schedule.

In the following two chapters I will address each level of the UPT scheduling problem in turn. Chapter 3 will focus on the formulation of the instructor scheduling problem while chapter 4 adresses the student - instructor matching problem.

CHAPTER 3

INSTRUCTOR SCHEDULING PROBLEM
(LEVEL 1)

3.0 - INTRODUCTION

In the formulation of the ATC Crew Scheduling problem I will divide the problem into three separate areas. The first area to be addressed is determining the minimum number of instructors needed to fill the daily schedule(Level 1). This is by far the most binding constraint on the problem as a whole since the instructor force is small compared to the number of students. As was mentioned in chapter 1 the instructor scheduling problem is addressed on a daily basis by the squadron scheduler. The squadron schedululer is responsible for scheduling all of the instructors equitably and within Air Training Command regulations and squadron guidelines[57]. In chapter 2 I determined that these regulations and guidelines coupled with the characteristics of the squadron indicate the problem is a pure vehicle scheduling type. The problem involves a single domicile containing multiple homogeneous pilots. The task demands are deterministic at each node in a directed network. Pilot capacity and time constraints exist, and the primary objective is to minimize the number of pilots needed to fill the daily schedule.

In formulating the Level 1 problem I will first look at a relaxed version without capacity and time constraints since these constraints render the problem NP complete. I will then look into methods to accomodate these restrictions.

3.01 - SAMPLE PROBLEM

To aid in visualizing the formulation of the problem I will use the following sample problem. The ten tasks listed in table 3.1 represent a small portion of a realistic schedule encountered by a squadron scheduler on a daily basis. Actual problems may have well over 200 such tasks to schedule daily (see appendix A).

The table includes a brief description of each task, the amount of pre-briefing time required, the task start time, the duration of the task, the amount of de-briefing required, and the total time period needed to accomplish the task. Each task is accomplished by a single instructor.

The sample problem can also be viewed as a network flow problem (figure 3.1). In this depiction the nodes are the tasks t_1, t_2, ..., t_{10} and the directed arcs represent feasible paths through the nodes. The time block required for each task is included in the node. An arc exists from nodes t_i to node t_j if the start of the time block for t_j is later than the end of the time block for t_i. Some arcs are not included in the network to prevent the depiction from becoming too cluttered. Obviously, if arcs exists from node t_i to node t_j and from node t_j to node t_k then an arc also exists from t_i to t_k.

Table 3.1 - Task Schedule

Task No.	Task Description	Pre-Brief Time B_i	Task Time		De-brief Time DB_i	Time Block
			Start S_i	End E_i		
1	Runway Supervisor(RSU)	15	0545	1100	15	0530-1115
2	Supervisor of Flying(SOF)	15	0615	1035	15	0600-1050
3	aircraft mission	60	0615	0735	40	0515-0815
4	aircraft mission	60	1015	1135	40	0915-1215
5	aircraft mission	60	1200	1320	40	1100-1400
6	simulator mission	30	1200	1315	30	1130-1345
7	aircraft mission	60	1450	1610	40	1350-1650
8	simulator mission	30	1430	1545	30	1400-1615
9	simulator mission	30	1350	1505	30	1320-1535
10	simulator mission	30	1700	1815	30	1630-1845
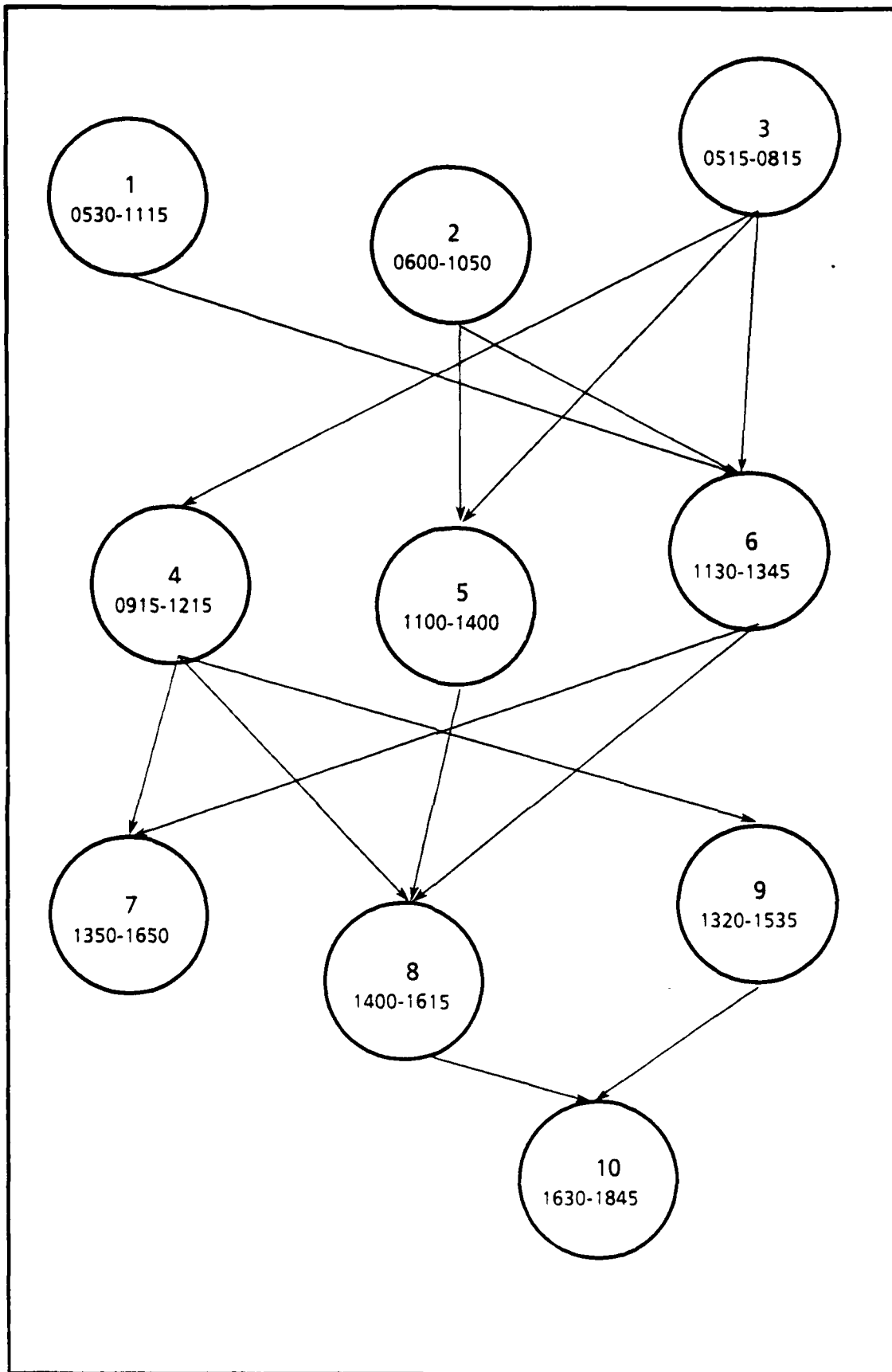
Figure 3.1 - Network depiction

3.1 - LEVEL 1 PROBLEM FORMULATION

The initial goal of the squadron scheduler is to merely find a feasible schedule of instructors which covers all the tasks. By determining the minimum number of instructors required to accomplish all assigned tasks the scheduler can quickly check for infeasibility. That is, if the minimum number of instructors needed is greater than the number available no feasible solution exists. If a feasible solution exists the scheduler can add optional, low priority tasks such as meetings, training sessions, etc. to any extra instructors to use the instructor pool to a maximum extent. In addition to determining the minimum number of instructors needed to fill the schedule the scheduler can attempt to minimize some sort of cost function as well. Costs can be assigned to indicate the desirability of a particular pilot's schedule. The cost is directly proportional to idle time in the schedule. Accomplishing all the tasks with little or no idle time between tasks is much more desirable than having large amounts of idle time in the schedule. Using the minimum number of pilots as an input to a cost(idle time) minimization problem the scheduler can find a low cost feasible solution to the Level 1 problem.

Using the directed, acyclic network representation in figure 3.1 the problem reduces to finding the minimum number of disjoint paths which cover all the nodes in the network. Once these paths have been found, each path can be interpreted as a schedule for a particular instructor. The squadron scheduler can then assign each available instructor a set of tasks corresponding to a path in the network. This problem, which is often referred to as a Dilworth decomposition problem.

3.11 - DILWORTH DECOMPOSITION

Ford and Fulkerson[28] give an excellent description of how to solve the Dilworth decomposition problem using a partially ordered set. A partially ordered set P is a set with a transitive, antisymmetric order relation ")" where $t_i \rangle t_j$ is represented in the network by a directed arc from node t_i to t_j. The Level 1 problem can be written as a partially ordered set in the following manner.

(3.1) $\qquad t_i \rangle t_j$ if and only if $S_j - B_j \leq S_i + D_i + DB_i$.

That is, task t_i must be completed prior to the pre-briefing time for t_j. Figure 3.2 is a partially ordered set. A *chain* in P is a set where

(3.2) $\qquad t_1 \rangle t_2 \rangle \ldots \rangle t_k$.

This coincides with a directed chain in the network. A *decomposition* of P is a partition of the partially ordered set into disjoint chains. This is also referred to as a chain cover. The decomposition is *minimal* if it covers the nodes with the smallest number of chains. Finally, two distinct members of P are *unrelated* if neither $t_i \rangle t_j$ nor $t_j \rangle t_i$. These unrelated members form the antichain.

> **Dilworth's Theorem:** *Let P be a finite or countably infinite partially ordered set. then the cardinality of the minimal decomposition (chain cover) is equal to the cardinality of the maximal number of unrelated members (antichain) of P.*

By connecting Dilworth's theorem to the following Max Flow theorem we can solve the problem of finding the minimal chain decomposition[28].

> **Konig-Egervary Theorem:** *Let G = [S.T:A] be a bipartite graph. The maximal number of arcs of G that are pairwise node disjoint is equal to the minimal number of nodes in a S, T disconnecting set of nodes.*

The disconnecting set of nodes is a set which blocks all chains from S to T.

According to Ford and Fulkerson

> Another statement of this theorem is sometimes given in terms of m by n arrays that contain two kinds of cells, admissible and inadmissible. Suppose we refer to the rows and columns of the array by the common term "lines". A set of lines *covers* the admissible cells of the array if each admissible cell belongs to some line of the set. A set of admissible cells is *independent* if no two cells of the set lie in the same line. By constructing from the array the bipartite graph G composed of nodes
>
> (3.3) $S = \{x_1, \ldots, x_m\}, \qquad T = \{y_1, \ldots, y_n\}$
>
> and arcs (x_i, y_j) corresponding to admissible cells, one sees the notion of "independent set of admissible cells corresponds to "pairwise node disjoint arcs", and hence the Konig-Egervary theorem becomes: *the maximal number of independent admissible cells is equal to the minimal number of lines that cover all admissible cells.*

For the Level 1 problem, then, the maximal number of independent admissible cells is equal to the minimal number of instructors to accomplish all the tasks in the schedule.

By reconstructing the partially ordered set P in figure 3.1 into a bipartite graph $G = [S, T; A]$ consisting of 2n nodes $S = \{t_1, t_2, \ldots, t_{10}\}$ and $T = \{t_1, t_2, \ldots, t_{10}\}$ and defining arcs by the rule: $(t_i, t_j) \; \varepsilon \; A$ if and only if $t_i \rangle t_j$ we can find the minimal chain decomposition (cover) by using an algorithm which determines the maximal number of independent admissible cells.

3.12 - MINIMAL DECOMPOSITION ALGORITHM

To find the minimal decomposition in the partially ordered set we can use the labelling process for maximal flows. First the bipartite graph G is depicted in an array format. The columns and rows of the array are the elements of S and T respectively. Inadmissible cells, cells where no arc (t_i, t_i) exists, are marked with an X; while admissible cells, cells where arcs (t_i, t_i) do exist, are left blank. From this format the algorithm can be quickly executed.

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The goal of the algorithm is to place as many 1's as possible in admissible cells. The only restriction is that no more than one 1 can be in any row or column. The algorithm proceeds as follows:

Step 1 - Start with any feasible placement of 1's in the array. (recall only one 1 can be in any row or column).

Step 2 - Label all rows which do not contain a 1.

Step 3 - Select an unscanned, labelled row and scan it for admissible cells.

Step 4 - Label the columns which contain the admissible cells found in step 3 with the row number being scanned. If a column is already labelled do not relabel it.

Step 5 - repeat steps 3 and 4 until all labelled rows have been scanned and the appropriate columns have been labelled.

Step 6 - Select an unscanned, labelled column and scan it for a 1. If a 1 is found label the row containing the 1 with the column number.

Step 7 - Repeat step 6 until all labelled columns have been scanned and the appropriate rows have been labelled.

Step 8 - Repeat steps 3 through 7 until one of the following occurs:

Case 1 -- A labelled column is scanned and no 1 is found. This is called a *breakthrough*.

Case 2 -- No more row or column labels are possible (*no breakthrough*).

STOP.

If Case 1 occurs then the current placement of 1's is not maximal and the chain decomposition is not minimal. The number of 1's in the array can be increased by one in the following manner:

Step 1 - In the just labelled column which has no 1 place a 1 in the row indicated by the column's label.

This row will now have two 1's in it since the row was previously scanned. The other 1 must now be moved somewhere else in its column since no more than a

single 1 can be in any row. The conflicting 1 is moved in the following manner:

> Step 2 - Move the conflicting 1 to the row indicated by its column label. Repeat this step for all subsequent conflicts until a conflicting 1 is moved to a row in which no conflict occurs.

STOP.

This method will always increase the number of 1's in the array by one because eventually a conflicting 1 will be moved into one of the original scanned rows which did not have a 1.

After increasing the number of 1's in the array all labels are removed and the entire process is repeated until Case 2 occurs. When Case 2 occurs no more row or column labels are possible and there is no breakthrough. At this point the number of 1's is maximal and the minimal chain decomposition is reached.

At this point an example of the algorithm is appropriate. Using the partially ordered set in figure 3.1 the array representation can be seen in table 3.2. Like the bipartite graph the array depiction includes all feasible arcs (t_i, t_j) $t_i \varepsilon S$, $t_j \varepsilon T$. The feasible arcs are the admissible cells(those without an X).

Table 3.2 - Array Depiction of the Bi-Partite Graph

Tasks	1	2	3	4	5	6	7	8	9	10	
1	X	X	X	X	X						
2	X	X	X	X							
3	X	X	X								
4	X	X	X	X	X	X					
5	X	X	X	X	X	X	X		X		
6	X	X	X	X	X	X			X		
7	X	X	X	X	X	X	X	X	X	X	
8	X	X	X	X	X	X	X	X	X		
9	X	X	X	X	X	X	X	X	X		
10	X	X	X	X	X	X	X	X	X	X	
											Labels

The next array in table 3.3 shows the results of the labelling algorithm. Initially six 1's are placed in the admissible cells(Step 1). No other 1's can be added so far since any addition would violate the restriction of one entry per line. The associated chain decomposition is read from the array to be {1, 6, 10; 2, 5, 8; 3, 4, 7; 9}. We will now determine if this decompostion into 4 chains is minimal. (Step 2) Rows 7, 8, 9, and 10 do not have 1's and are labelled (indicated by ----). (Step 3) Row 8 is scanned yielding one admissible cell. (Steps 4) The column containing this cell is labelled with the number 8. (Step 5) Scanning row 9 yields no new labels. (Step 6.7) Column 10 is scanned for a 1 which is found in row 6. Row 6 is labelled by the column number 10. (Step 8) Repeating steps 3 through 7 for row 6 labels columns 7 and 8. These columns in turn label rows 4 and 5 respectively. Scanning row 4 labels column 9(note:

column 10 is already labelled), and scanning row 5 results in no new labels. Finally, scanning column 9 yields no 1. Thus we have a breakthrough, indicated by a O, and the process is complete.

Table 3.3 - Labelling Scheme

Tasks	1	2	3	4	5	6	7	8	9	10	
1	X	X	X	X	X	1					
2	X	X	X	X	1						
3	X	X	X	1							
4	X	X	X	X	X	X	1		O		7
5	X	X	X	X	X	X	X	1	X		8
6	X	X	X	X	X	X			X	1	10
7	X	X	X	X	X	X	X	X	X	X	----
8	X	X	X	X	X	X	X	X	X		----
9	X	X	X	X	X	X	X	X	X		----
10	X	X	X	X	X	X	X	X	X	X	----
							6	6	4	8	Labels

Using the two step procedure to resolve conflicts a 1 is placed in the breakthrough cell - row 4, column 9. The conflicting 1 in row 4 is in column 7. This 1 is moved to the row indicated by column 7's label - row 6. Similarly the conflicting 1 in row 6 is moved to row 8. Since row 8 is the original labelled row no conflict exists. Table 3.4 displays the conflict resolution and the new configuration of 1's. Notice the number of 1's has increased by one from six to seven.

Table 3.4 - Conflict Resolution

Tasks	1	2	3	4	5	6	7	8	9	10	
1	X	X	X	X	X	1					
2	X	X	X	X	1						
3	X	X	X	1							
4	X	X	X	X	X	X			1		
5	X	X	X	X	X	X	X	1	X		
6	X	X	X	X	X	X	1		X		
7	X	X	X	X	X	X	X	X	X	X	----
8	X	X	X	X	X	X	X	X	X	1	10
9	X	X	X	X	X	X	X	X	X		----
10	X	X	X	X	X	X	X	X	X	X	----
										9	Labels

Repeating the entire process on the new configuration yields rows 7, 9, and 10 as not having any 1's. The only admissible cell is in row 9. However, the labelling process quickly results in no breakthrough. Thus the configuration in table 3.4 is maximal. The new chain decomposition from the array is {1, 6, 7: 2, 5, 8, 10: 3, 4, 9}. This decomposition into three chains is minimal by Dilworth's theorem. The bold lines in figure 3.2 are the minimal chains in the partially ordered set resulting from the algorithm. According to Papdimitriou and Steiglitz, labelling algorithms of this type for the bipartite matching problem require $O(min (|S|,|T|) \cdot |A|)$ time[50].
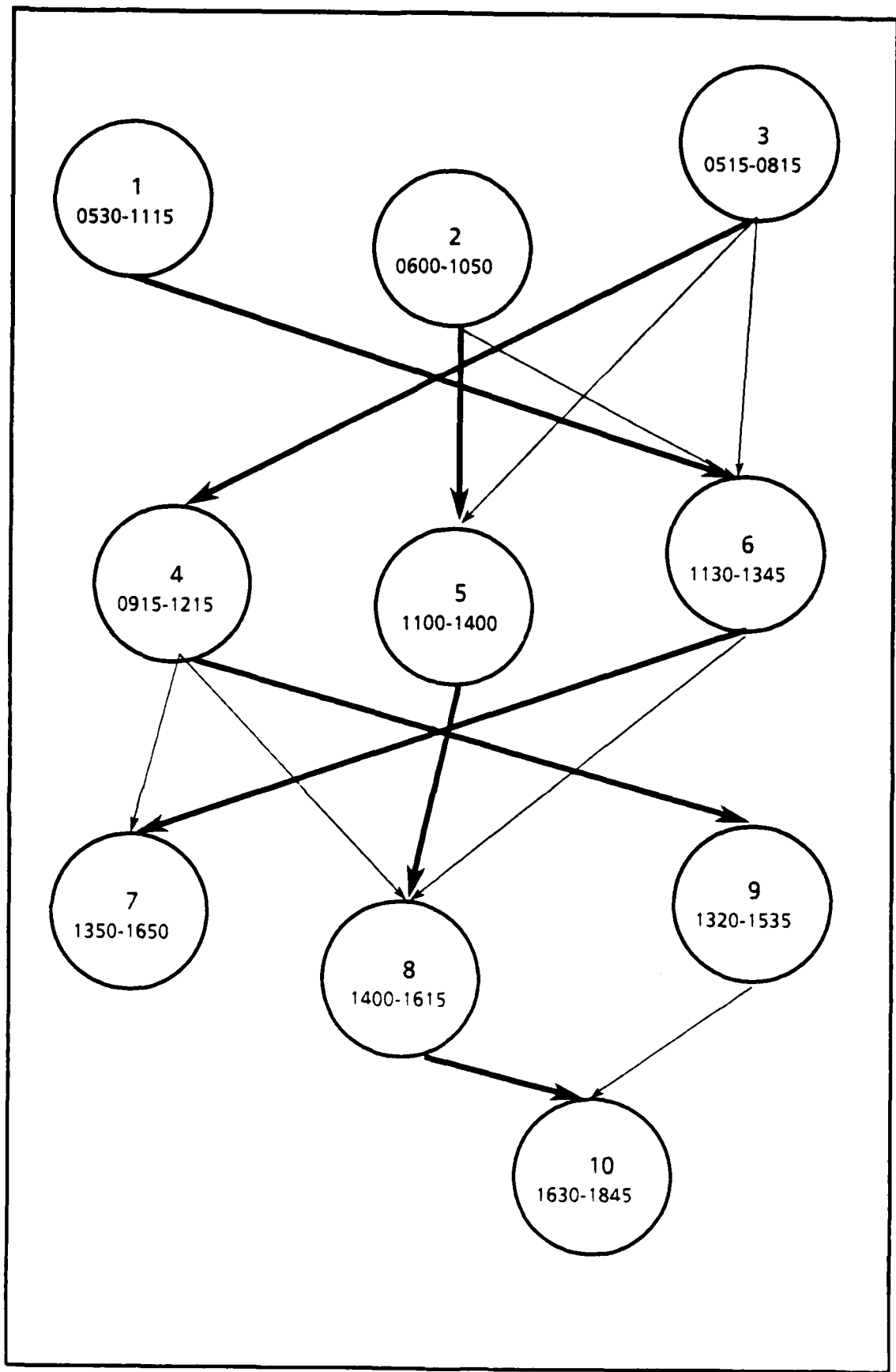
Figure 3.2 - Network depiction of the Dilworth chains

3.13 - EXPLOITING SPECIAL STRUCTURE

On occaision the Level 1 scheduling problem exhibits special structure which can be exploited in determining the minimal chain decomposition. If the members of the partially ordered set can be renumbered so that $t_i \leq t_j$ implies that the predecessors of t_i are included in the predecessors of t_j then the *Staircase rule* applies. Unlike the labelling algorithm just described, this simple rule requires no iterations. If the array can be rearranged such that the set of all inadmissible cells has a staircase form, the rule applies.

> **Staircase Rule**: *Select any admissible cell that borders the staircase of inadmissible cells and place a 1 in it. Delete the row and column and repeat the process.*[FF 65]

By exchanging the rows and columns in the example array, the array displays the staircase form (table 3.5).

Table 3.5 - Staircase Form

Tasks	1	2	3	4	5	6	9	7	8	10	
3	X	X	X	1							
2	X	X	X	X	1						
1	X	X	X	X	X	1					
4	X	X	X	X	X	X	1				
6	X	X	X	X	X	X	X	1			
5	X	X	X	X	X	X	X	X	1		
8	X	X	X	X	X	X	X	X	X		
9	X	X	X	X	X	X	X	X	X	1	
10	X	X	X	X	X	X	X	X	X	X	
7	X	X	X	X	X	X	X	X	X	X	

Using the staircase rule, starting at the top left, 1's are placed at each border point. The corresponding minimal chain decomposition can be seen directly to be {1, 6, 7; 2, 5, 8: 3, 4, 9, 10}. These chains are not the same chains determined by the labelling process. I will discuss how to decide between alternative solutions in the next section. Obviously, this structure should be exploited whenever possible since it quickly determines the minimal decomposition in O(N) steps. As was mentioned earlier, the staircase form may exist in the Level 1 problem.

3.2 - MAXIMUM FLOW FORMULATION

An alternative formulation for the Level 1 problem is an adaptation of the Dilworth Chain decomposition. The formulation, which uses a maximum flow procedure, is the basis for the vehicle scheduling algorithm developed by Bodin, Rosenfield, and Kydes in UCOST[14]. Using the bipartite graph representation $G = [S, T; A]$ discussed earlier, figure 3.3 shows the sample problem constructed as a bipartite graph. The node sets S and T each contain all the nodes of the partially ordered set, P. Notice in this configuration that all feasible arcs (t_i, t_j) $t_i \epsilon S, t_j \epsilon T$ are included in the graph unlike the network depiction of the partially ordered set in figure 3.1. In addition to S and T two nodes are added to the network - a super source, s, and a super sink, t. Each node in S is connected to the super source, and each node in T is connected to the super sink. The capacity on all arcs connected to the source and sink is 1. Finally, one additional directed arc from the sink to the source is added to complete the circulation.
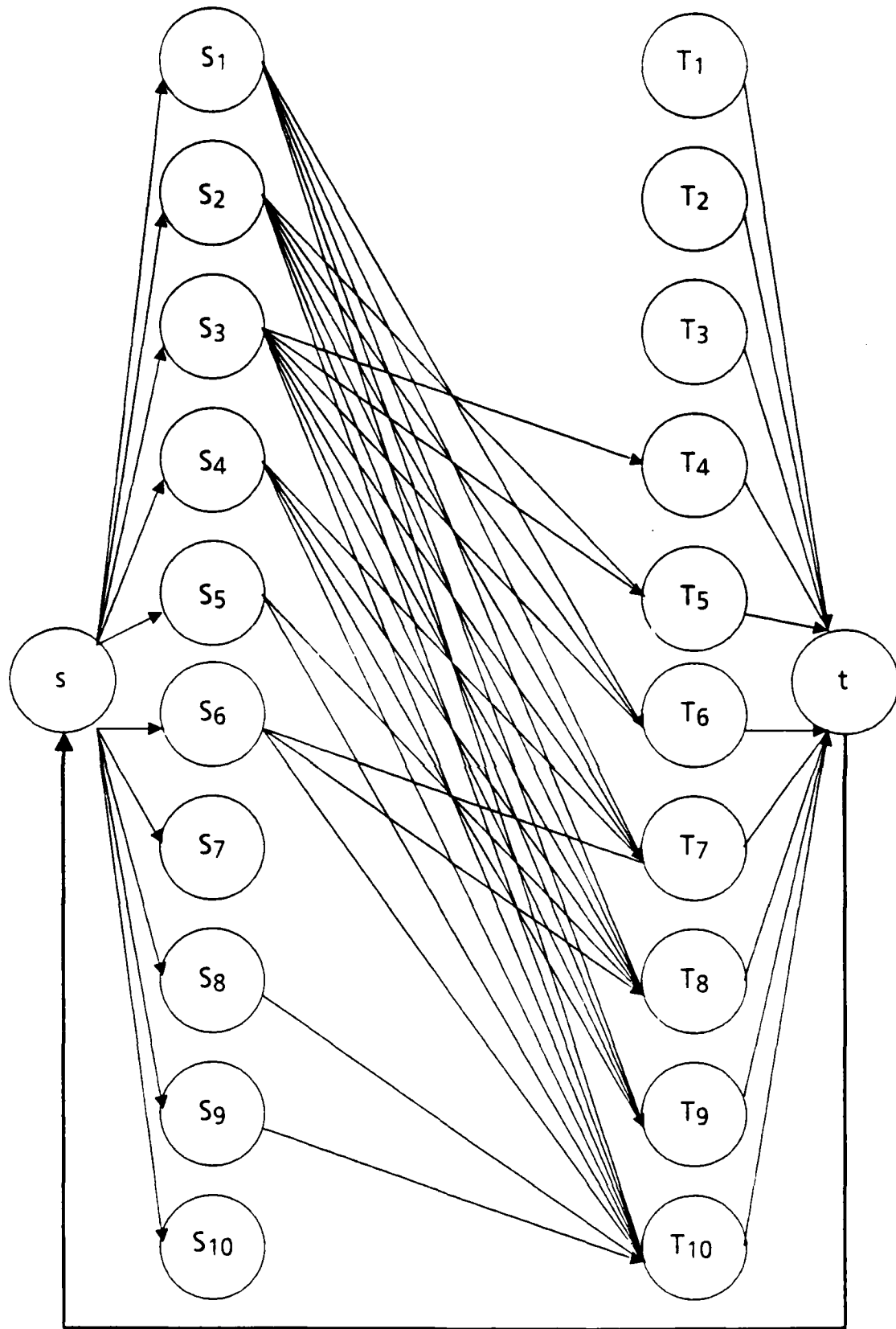
Figure 3.3 - Maximum Flow Representation

Using x_{ij} to represent the flow on arc (t_i, t_j) the formulation becomes

(3.4)   Maximize x_{ts}

(3.5)   s.t. $\Sigma_j\, x_{ij} - \Sigma_k\, x_{ki} = 0$ $i,j,k \,\varepsilon\, S,T,s,t$

(3.6) $0 \leq x_{ij} \leq 1,\text{ integer}$

Equation 3.5 is the flow balance equation requiring that the flow out of a node minus the flow into the node must equal zero, and 3.6 captures nonnegativity and flow capacity restriction for each arc. Finally, we let

$$D = \{\, x_{ij} \,\varepsilon\, A;\; i \,\varepsilon\, S, j \,\varepsilon\, T;\; x_{ij} = 1\,\}.$$

The arcs in D are used to determine the minimum number of disjoint chains in G. By the Konig - Egevary Theorem

(3.7)   minimum number of chains $= |S| - |D|$.

Using the optimal solution to the max flow formulation the arcs in D can be used to determine the task chains for each instructor. Let (S_i, T_j) be an arc in D where S_i is chosen so there is no flow into T_i(i.e. S_i is the start of a schedule). Eliminate arc (S_i, T_j) from D and find the arc $(S_j, T_K) \,\varepsilon\, D$. This arc is linked to the previous one since nodes S_j and T_j represent the same task. Continue the procedure until an arc is found (S_m, T_n) such that there is no flow out of node S_n. The chain sequence

$$(S_i, T_j), (S_j, T_k), \ldots, (S_m, T_n)$$

represents a feasible schedule associated with tasks t_i, t_j, t_k, . . ., t_n in the partially ordered set P. The process is repeated in this manner until all $|S| - |D|$ chains are found by eliminating all arcs in D. The max flow solution to the sample problem is in figure 3.4. The arcs in D are

$$D = (S_1,T_6), (S_2,T_5), (S_3,T_4), (S_4,T_9), (S_5,T_8), (S_6,T_7), (S_8,T_{10}).$$

The number of chains is $|S| - |D| = 10 - 7 = 3$. The sequence in each chain is $\{1,6,7\}$, $\{2,5,8,10\}$, and $\{3,4,9\}$.

A theorem of Hopcroft and Karp[38] shows the bipartite matching problem can be solved in $O(|V|^{0.5} \cdot |A|)$ time. It is the asymptotically fastest algorithm known for the bipartite matching problem. The fact that this algorithm is a special case of the max-flow algorithm applied to a simple network was first pointed out by Even and Tarjan[22].
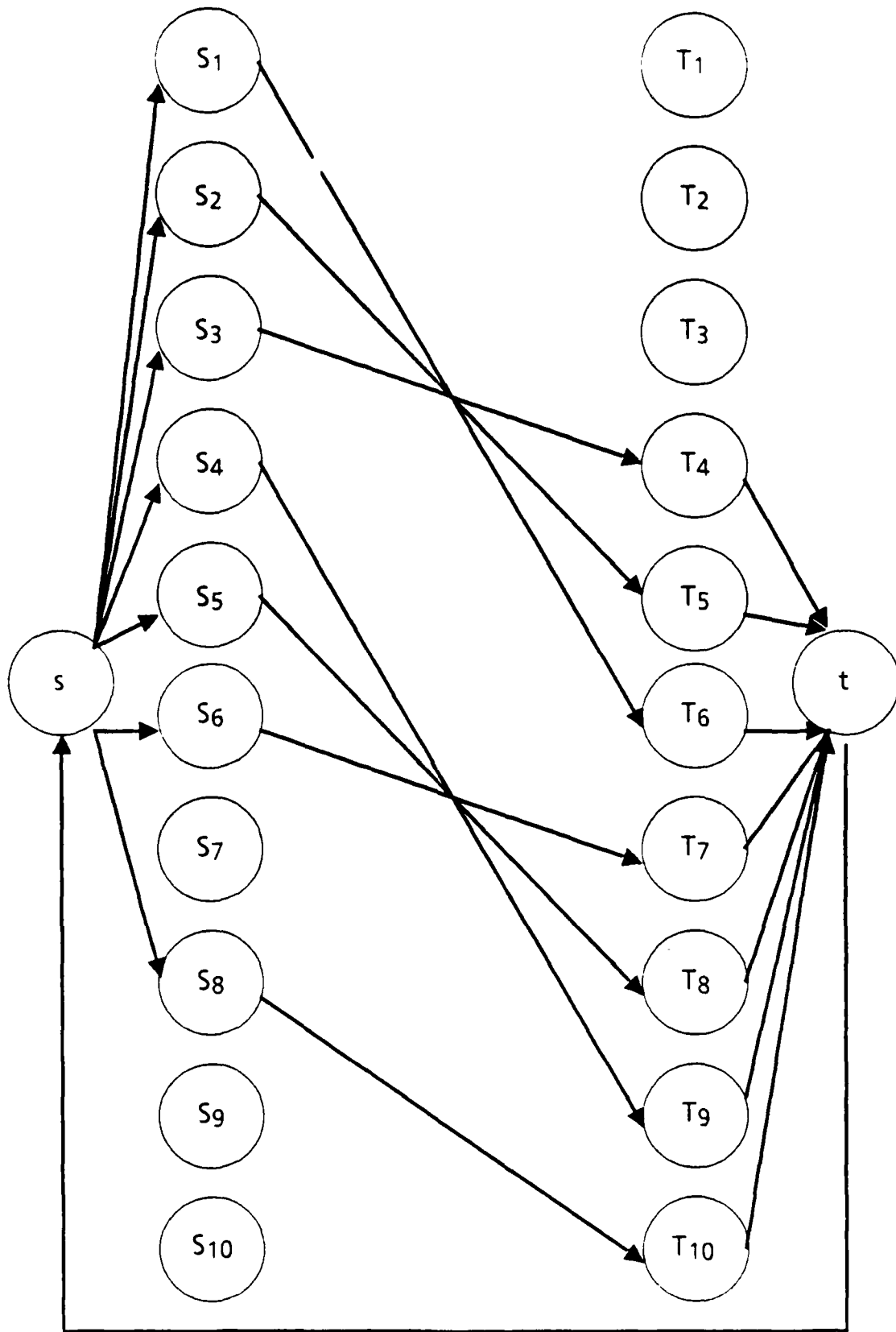
Figure 3.4 - Maximum Flow Solution

3.3 - MINIMUM COST FLOW FORMULATION

After using Dilworth's decomposition to determine the minimum number of instructors to accomplish all the tasks, the next step is to use these instructors in the most efficient or least cost manner. As was shown in the sample problem the minimal chain solution might not be unique. The Dilworth decomposition only provides the minimal number of chains and does not attempt to find a "best" solution in terms of some cost function. To find the least cost, minimal chain decomposition I will use the minimum cost network flow formulation. The use of this formulation to solve vehicle scheduling problems was first developed by Dantzig and Fulkerson[19].

Bradley, Hax, and Magnanti[15]; Papadimitriuo and Steiglitz[50] and others discuss this formulation in detail. To transform the Level 1 problem into a *minimum cost flow* problem two nodes must be added to the partially ordered set P. The first node, s, is the source node which can be interpreted as the pool of instructors. The second node, b, is the sink node which can be interpreted as the officer's club bar. An arc is added from s to each task node $t_1, t_2, \ldots, t_n$ in P and from each task node to the sink node t. In all (2·num. nodes) arcs are added. The cost assigned to each of these arcs is 0. The cost, c_{ij}, for each arc in P is proportional to the idle time between tasks t_i, t_j where

(3.8)   Idle Time $= S_j - B_j - (E_i + DB_i)$.

For the sample problem I will assign a cost of 1 for every 15 minute block of idle time (or portion thereof) between two tasks. To prevent the number of arcs from getting too large and to align the problem with realistic scheduling, arcs representing idle time greater than a user specified amount (a) will be

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excluded from the network. This will eliminate solutions with excessive idle time for an instructor. For the sample problem, I will restrict the idle time to 3 hours or less. Arcs longer than 2 hours will not be included in the network. The associated cost(idle time) matrix for the feasible arcs is in table 3.6. The resulting minimum cost flow network is in figure 3.4. The source node has a supply of 3 instructors, and the sink node has a demand of 3 instructors. The objective is to flow the 3 instructors through all the task nodes to the sink node with the least total idle time between tasks. The following linear programming formulation solves the problem.

(3.9) $$\text{Minimize } \Sigma_i \Sigma_j \ c_{ij} x_{ij}$$

(3.10) $$\text{s.t.} \quad \Sigma_j x_{ij} - \Sigma_k x_{ki} = b_i \quad i \ \varepsilon \ P, s, t$$

(3.11) $$\Sigma_j x_{ij} = 1 \qquad j \ \varepsilon \ P$$

(3.12) $$\Sigma_i x_{ij} = 1 \qquad i \ \varepsilon \ P$$

(3.13) $$0 \le x_{ij} \le 1, \text{integer}$$

$$x_{ij} = \begin{cases} 1 & \text{if arc } (i,j) \text{ is in the solution} \\ 0 & \text{otherwise} \end{cases}$$

Equation 3.10 is the flow balance equation requiring that the flow out of a node minus the flow into the node must equal the net supply(demand) at the node. b_i equals zero for all nodes in P. For s,t b_i equals + or - the minimal number of instructors from the Dilworth decomposition. Equations 3.11 and 3.12 ensure that a task node is covered only once in the solution.

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Table 3.6 - Cost Matrix for Feasible Arcs

Tasks	1	2	3	4	5	6	7	8	9	10
1	X	X	X	X	X	1			8	
2	X	X	X	X	1	3				
3	X	X	X	4						
4	X	X	X	X	X	X	7	7	5	
5	X	X	X	X	X	X	X	0	X	
6	X	X	X	X	X	X	1	1	X	
7	X	X	X	X	X	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	1
9	X	X	X	X	X	X	X	X	X	4
10	X	X	X	X	X	X	X	X	X	X

The solution to the minimization problem is the chain decomposition
{1, 6, 7; 2, 5, 8, 10; 3, 4, 9} which is the same as the decomposition determined
by the max flow labelling algorithm.

The resulting costs are

Chain	Cost
1-6-7	2
2-5-8-10	2
3-4-9	9
Total	13

The alternative decomposition {1, 6, 7; 2, 5, 8; 3, 4, 9, 10} determined by the
staircase rule results in a total cost of 16. Thus, by using this two step process
the solution provides the most efficient way, in terms of idle time, to schedule
the minimum number of instructors needed to accomplish all the tasks.
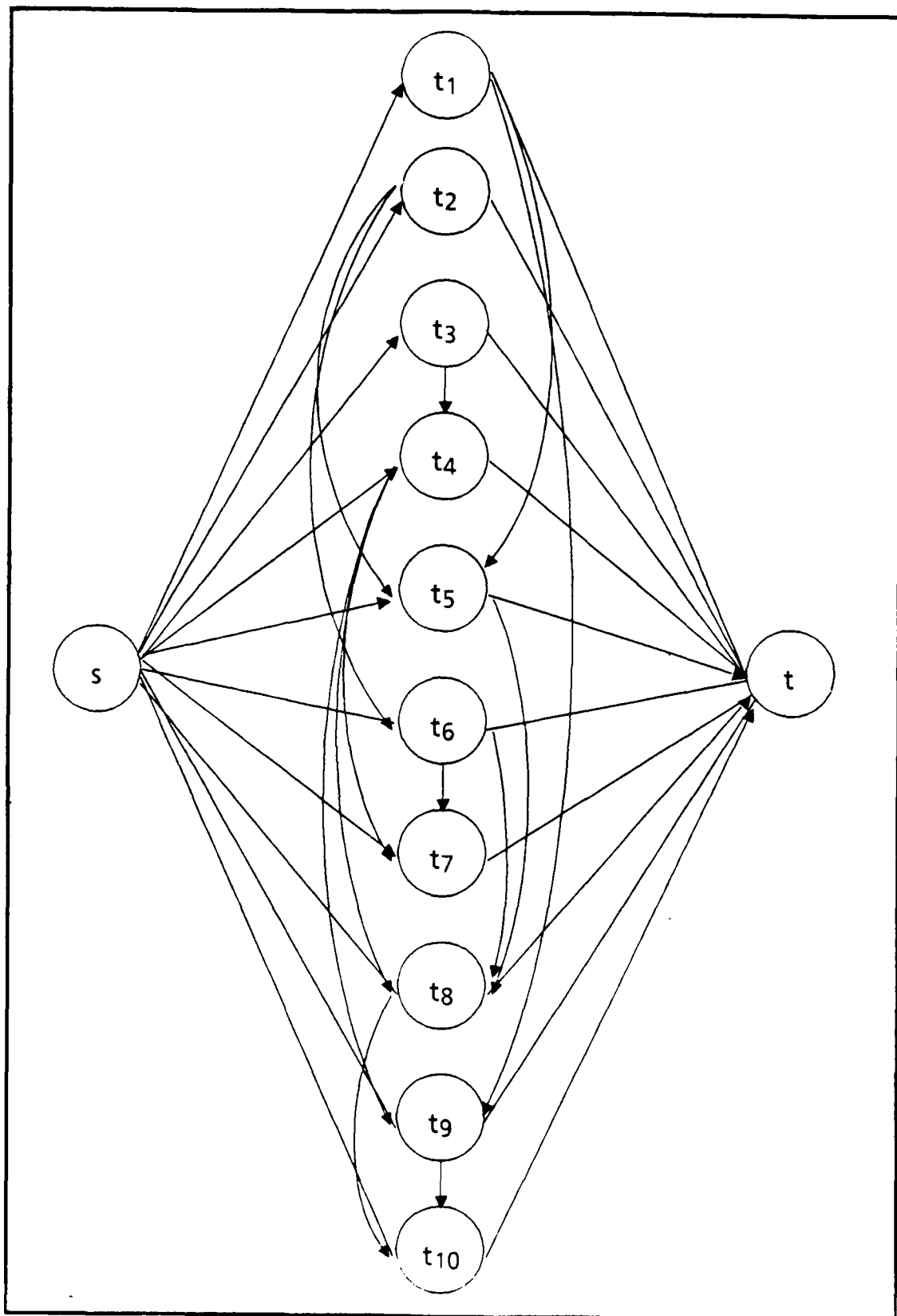
Figure 3.5 - Minimum Cost Network Flow Depiction

3.4 - HEURISTIC MODIFICATIONS

After determining the optimal solution to the relaxed Level 1 problem, the difficulty of meeting the relaxed constraints can now be addressed. The relaxed solution technique cannot directly accomodate the 12 hour duty day or the maximum of 3 tasks per instructor limitations[4]. This is evident in the solution to the relaxed sample problem in table 3.7.

Table 3.7 - Instructor Duty Schedule

Task Chain	Task Descriptions	No. Tasks	Duty Day
1 - 6 - 7	SOF - simulator - aircraft	3	0530 - 1650
2 - 5 - 8 - 10	RSU - Aircraft - simulator-sim.	**4**	**0600 - 1845**
3 - 4 - 9	Aircraft - aircraft - simulator	3	0515 - 1535

The solution violates both constraints(indicated by bold type). Of the two constraints the duty day restriction is the least binding and might possibly never be a factor. This occurs because the minimum cost flow formulation will attempt to pack the tasks in each chain with the minimum amount of idle time between tasks. Since the vast majority of tasks require 3 hours or less total time to complete, and since 3 tasks is maximum, the average time performing tasks will be less than 9 hours per instructor. This leaves a full 3 hours in the duty day to absorb the two idle periods between tasks. Thus, it is highly unlikely that the duty day constraint will ever be violated by a chain containing 3 or less tasks.

Although table 3.7 indicates the relaxed solution violates both constraints, reducing the number of tasks in all chains to 3 or less will

alleviate both problems. Obviously, the scheduler must add one more instructor to the schedule. The process of trimming chains and adding instructors is an interactive one. The squadron scheduler may have several options available. For instance, in the sample problem the scheduler could trim the first or last task of the long chain, or he could divide the chain into two chains of 2 tasks each. All of these divisions will result in slightly different total idle time. The scheduler considers various items such as workload balancing, seniority, time-off requests, etc. to determine the best schedule. Also, the scheduler could add lower priority tasks such as medical appointments, training sessions, etc. which are time flexible and can fit anywhere in the schedule.

Finally, if several chains of length 4 or more exist in the schedule the scheduler can incrementally increase the minimum number of instructors(if available) for the minimum cost flow formulation. The solution will always use the added instructors since the arc costs from P to s and t is zero. The least cost solution for the sample problem using 4 instructors is in table 3.8.

Table 3.8 - Least cost schedule

Task Chain	Task Descriptions	No. Tasks	Chain Cost	Duty Day
1 - 6 - 7	SOF - simulator - aircraft	3	2	0500 - 1650
2 - 5 - 8	RSU - Aircraft - simulator	3	1	0530 - 1615
3 - 4	Aircraft - aircraft	2	4	0445 - 1215
9 - 10	Simulator - simulator	2	4	1250 - 1845

Notice that the formulation did not merely trim a task off the longest chain to obtain the optimal solution. The highest cost arc is between tasks 4 and 9. Since there is a feasible arc from task 9 to task 10 with a cost less than 5, the formulation trims off task 10 from the long chain and eliminates the highest cost arc(4,9) by linking tasks 9 and 10. The resulting total cost is 11. This cost is less than the relaxed solution since the fourth instructor is added.

There are several other feasible solutions to the problem. Some of the alternate solutions have only slightly higher total idle time. A list of the alternate feasible solutions is in table 3.9.

Table 3.9 - Alternative solutions

Feasible Decompositions		Total Cost
Number	Chains	
1	{1,6,7},{2,5,8},{3,4},{9,10}	11
2	{1,6,7},{2},{5,8,10},{3,4,9}	12
3	{1,6,7},{2,5,8},{10},{3,4,9}	12
4	{1,6,7},{2,5,8},{3},{4,9,10}	12
5	{1,6,7},{2,5},{8,10},{3,4,9}	13

Notice that the solution which merely subdivides the infeasible chain into two feasible chains(decomposition no. 5) results in the highest cost. This shows that the "obvious" solution might not always be the best soluti n. However, this is not to imply that the scheduler will always use the least cost solution. Based on the scheduler's input some other slightly different yet higher cost solution may better fit the needs of the squadron.

After determining the task schedule for the entire squadron the scheduler assigns each task chain to individual instructors based on unit needs, instructor requests, and chain make-up. The scheduler then makes a final adjustment to the duty day. The lenght of day determined by the algorithm only includes the time required to accomplish all tasks. It does not include the individual instructor's initial briefing upon arrival at the squadron. The initial briefing occurs 30 minutes prior to the first activity of the day for each instructor. Thus, after determining an instructor's schedule, the squadron scheduler adds 30 minutes to the beginning of each chain to obtain the instructor report times. This process is equivalent to the vehicle scheduling procedure of adding vehicle deadheading time from a garage. The duty day time in table 3.8 includes the briefing time for each instructor.

CHAPTER 4

STUDENT SCHEDULING PROBLEM
(LEVEL 2)

4.0 - INTRODUCTION

After the squadron scheduler finds a feasible set of task assignments for the instructors in the Level 1 problem, the unit schedulers can address the student scheduling problem. Although similar network structures exist in both problems, the Level 2 problem has a vastly different population of pilots, set of constraints, and an altogether different set of objectives.

As was mentioned in chapter 1 the student scheduling problem is addressed on a daily basis by the unit schedulers. The unit scheduler is responsible for equitably scheduling the unit's students to maintain proper timeline flow and to meet Air Training Command regulations and squadron guidelines[57]. Having received the Level 1 scheduling output which describes the daily activities of the unit's instructor force, each of the six unit schedulers attempts to "optimally" match students and instructors to produce an effective, smooth flowing schedule for the unit. Each unit schedules its students independently as the students progress through the various stages of training.

4.01 - CONSTRAINTS

Recall that the constraints on the Level 2 problem go beyond those of the Level 1 problem. The student population has the same duty day and maximum number of tasks restrictions as the instructor force, and additional continuity constraints which limit the task types for each student. Thus, unlike the Level 1 problem which is concerned only with the precedence relationships among tasks, the Level 2 problem involves the proper matching of students and instructors. This matching concerns whether a given student is allowed to perform a task with the instructor previously assigned to that task by the Level 1 scheduler. In the vehicle scheduling or production planning context, this restriction is equivalent to determinimg whether a particular vehicle/machine has the proper capacity, tooling, etc. to perform an available task. In short, the student pilots do not form a homogeneous group of individuals. A summary of the Level 2 problem constraints are:

1) 3 tasks maximum per student per day

2) 2.75 hours minimum between task starts(turn time)

3) 12 hour maximum duty day

4) Limited instructor matchings available

4.02 - SAMPLE PROBLEM

To aid in visualizing the formulation of the Level 2 problem I will continue to use the sample problem of the previous chapter. Assume that the ten tasks are all assigned to four instructors in a single unit. Assume also that the unit scheduler has six students available for assignment to the tasks. Actual unit scheduling problems usually involve fifteen instructors, thirty students, and over forty tasks per day(see appendix B). Table 4.1 is a summary of the results of the instructor scheduling problem. It contains the

task list with the instructor assignments determined by the Dilworth/Min-cost flow procedure. Column 4, the adjacency list, is an alternative representation of the array in table 3.2 listing all feasible matchings of tasks in the schedule.

Table 4.1 - Instructor -Task Assignment Summary

Task	Description	Instructor	Task Adjacency List
1	RSU	4	6 - 7 - 8 - 9
2	SOF	3	5 - 6 - 7 - 8 - 9
3	Aircraft	1	4 - 5 - 6 - 8 - 9
4	Aircraft	1	3 - 7 - 8 - 9 - 10
5	Aircraft	2	2 - 3- 8 - 10
6	Simulator	4	1 - 2 - 3 - 7 - 8 - 10
7	Aircraft	4	1 - 2 - 4 - 6
8	Aircraft	2	1 - 2 - 3 - 4 - 5 - 6 - 10
9	Simulator	1	1 - 2 - 3 - 4 - 10
10	Simulator	2	4 - 5 - 6 - 8 - 9

Table 4.2 shows the preference list for the student - instructor matchings. In it the six students are listed with their instructors in order of preference, the most preferred being the student's assigned instructor.

Table 4.2 - Student Preference List

Student	Instructor preference most--------least		
1	4	3	1
2	2	3	
3	1		
4	2	4	
5	4		
6	1	2	

4.1 - PROBLEM FORMULATION

The goals of the unit scheduler are quite different than those of the squadron scheduler. The squadron scheduler's goal is to maximize the use of each instructor during the day thus providing the best work environment for the instructor. The unit scheduler, on the other hand, wishes to disperse daily activities among students so that no student is accomplishing several tasks in a given schedule. This allows a better training environment for the students as adequate preparation time is alloted for each activity. As a result, the objective of the unit scheduler is threefold. First, the unit scheduler attempts to schedule each student at least once a day if possible. This allows a good flow of activity for each student and prevents students from being idle for an entire day.

The second objective is to provide proper continuity of instruction for each student. If a student is involved with too many instructors he/she may receive inconsistent training due to the variety of techniques used by each instructor. Each student is assigned to one instructor for training and administrative purposes. In addition to the assigned instructor, each student receives training from one or more additional instructors as he/she progresses through the program. For continuity purposes it is best if a student's assigned instructor conducts roughly sixty percent of the training. The remaining forty percent is conducted by the alternate instructors.

The third objective of the unit scheduler clearly shows the difference between Level 2 and Level 1 scheduling. Whereas the squadron scheduler's goal is to minimize idle time for the instructors, the unit scheduler attempts to maximize idle time for the students. Due to the demanding nature of the training it is very difficult for a student to maintain a competent level of performance if there is little or no idle time between tasks. Both the safety of the mission and the student's ability to receive training are hindered if no rest periods exist between activities.

4.11 - SIMPLE ASSIGNMENT PROBLEM

The nature of the unit scheduler's objectives indicate that the Level 2 problem falls into the general category of assignment problems. Most textbooks on Mathematical Programming, Networks, and Combinatorial Optimization cover solution techniques to simple assignment problems[15,50]. The assignment problem is a more involved version of the bipartite matching problem discussed in chapter 3. In addition to the bipartite graph, $G = \{S,T;A\}$, a number $w_{ij} \geq 0$ for each arc $(S_i,T_j) \in A$

represents the weight or disutility of the matching. We then find the matching with the minimum amount of weight. Figure 4.1 shows the sample problem as an assignment problem. The bipartite graph is comprised of the set of students, S, and the set of instructor-task matchings, T, from table 4.1. The asssigned instructor for each task is adjacent to the task in figure 4.1. The set of connecting arcs in A are those which link each student in S to a feasible instructor/task in T. The weights on the arcs capture the instructor preference objective of the unit scheduler. Less weight is given to more preferred student-instructor pairings. Arcs linking a student with his/her assigned instructor have the minimum weight, while alternative pairings are given more weight according to the preference order for each student. For example, student one in the sample problem has an instructor preference list of 4,3,1 in table 4.2. Thus any arc in A connecting student one(node 1 in S) with a task performed by instructor four(nodes 1,6,7 in T) will have a weight of 1 since the instructor is the student's most preferred instructor. Similarly, arcs in A connecting student one with tasks in T performed by instructors three or one will have proportionately greater weights respectively. This weighting is accomplished for all arcs in A. Figure 4.1 shows the feasible arcs for the sample problem. There are 29 feasible arcs in all.

Finally, to convert the Level 2 problem into the assignment problem two adjustments must be made to the graph, G. First, the number of student nodes in S must equal the number of task nodes in T. Since this is usually not the case in most assignment problems, artificial or 'dummy' nodes must be added. In the sample problem four 'dummy' student nodes(labelled $D_1, \ldots D_4$ in 4.1) are added. The second adjustment requires the graph G be 'complete'. That is, all nodes in S must be connected to all nodes in T. Since the arcs in A do not accomplish this, artificial arcs are added to G to make the graph complete.

These additional arcs are represented by dashed lines in figure 4.1. To prevent figure 4.1 from becoming too cluttered only the artificial arcs from student node 3 and 'dummy' node D_2 are included in the depiction. Obviously, these arcs create infeasible student-instructor matchings because all feasible matchings are contained in the set A. To prevent these infeasible matchings from entering the solution a very large weight, M, is assigned to each artificial arc. Thus, the minimization algorithm will attempt to eliminate the high weight arcs from the solution. If a prohibited student-instructor matching cannot be eliminated from the optimal solution then the problem, as stated, is infeasible.
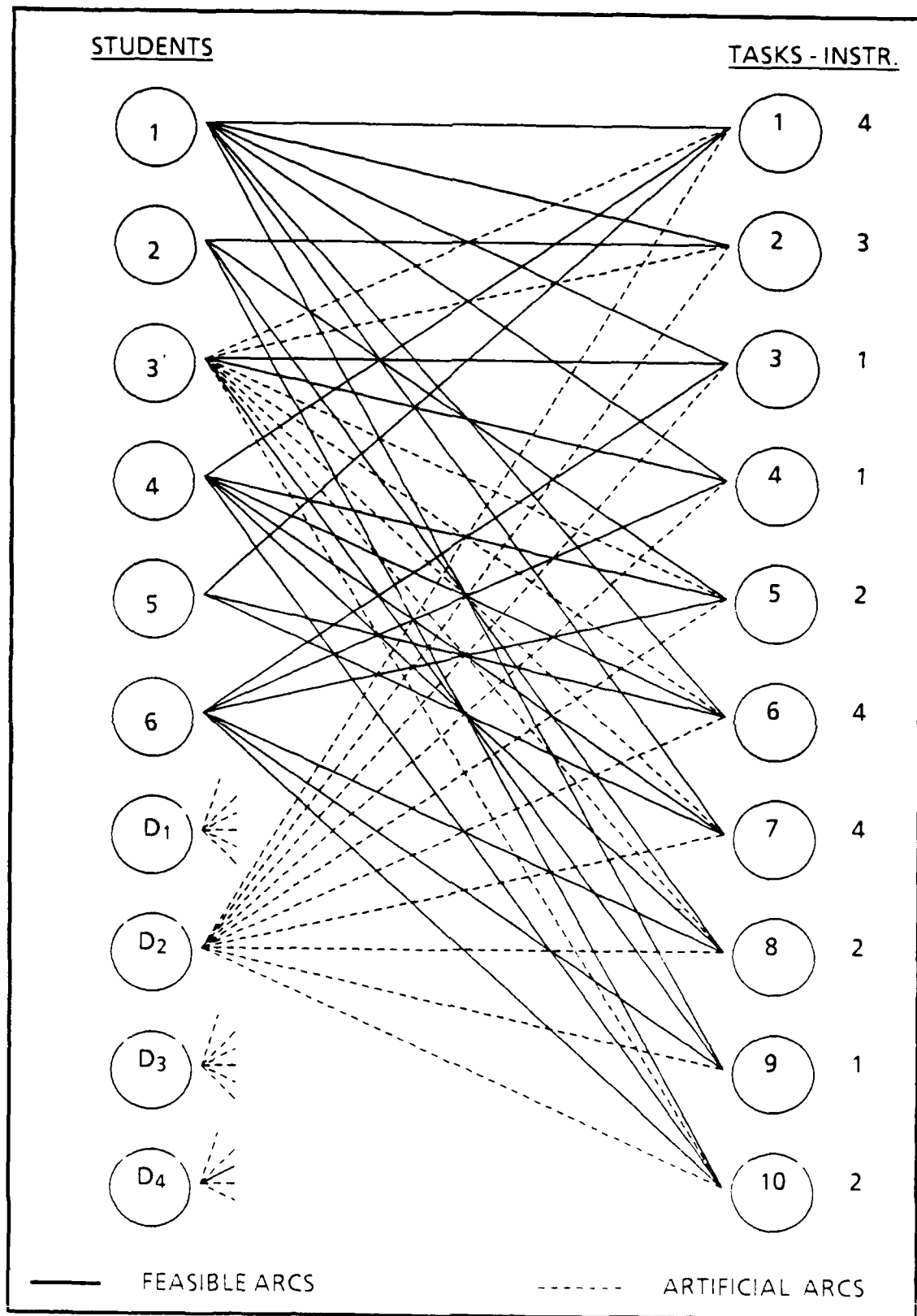
Figure 4.1 - Sample Assignment Problem

If we let the decision variable

$$x_{ij} = \begin{cases} 1 & \text{if student i is assigned to instructor/task j} \\ 0 & \text{otherwise} \end{cases}$$

the optimal assignment results from the following formulation:

(4.1)   Minimize $\sum_i \sum_j w_{ij} x_{ij}$

(4.2)   Subject to $\sum_j x_{ij} = 1$ $(i = 1, 2, \ldots, n)$

(4.3) $\sum_i x_{ij} = 1$ $(j = 1, 2, \ldots, n)$

(4.4) $0 \le x_{ij} \le 1, \text{integer}$ $(i, j = 1, 2, \ldots, n)$

Equation 4.2 allows each student to be assigned to exactly one instructor/task. Equation 4.3 indicates that each task is to be performed by exactly one student.

As written, the assignment problem is formally an integer program since the decision variables x_{ij} are restricted to be zero or one. However, by replacing the constraint in 4.4 with $x_{ij} \ge 0$ and having a supply of one unit at each node in S and a demand of one unit at each node in T, the problem becomes a transportation problem. Due to the theory of total unimodularity[50] this formulation will always have integer solutions and a network flow algorithm will solve the integer problem directly.

The optimal simple assignment solution to the sample problem is indicated by the bold lines in figure 4.2. Notice that each of the six students is assigned to a task accomplished by his/her assigned instructor.
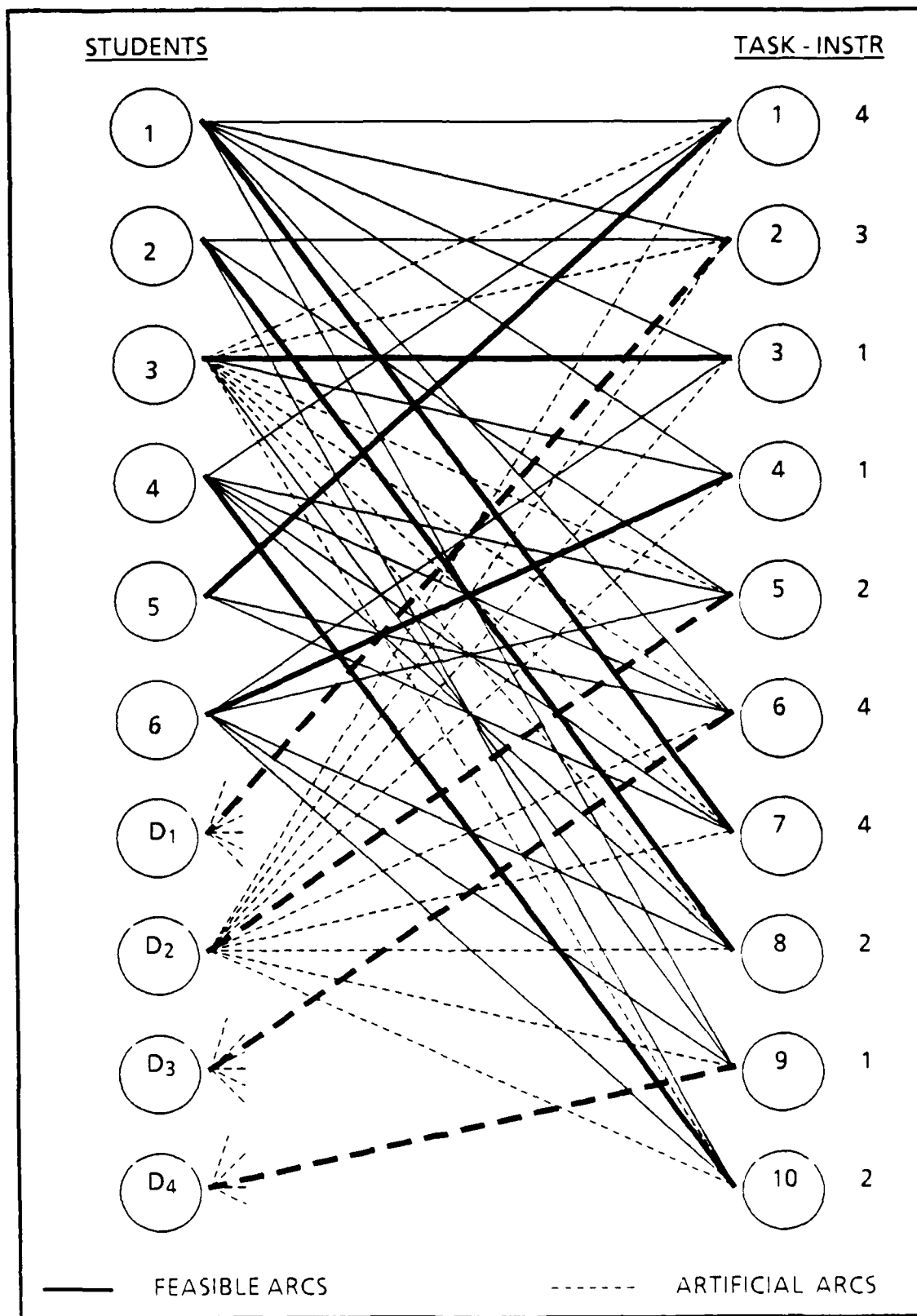
Figure 4.2 - Optimal Solution to Sample Assignment Problem

Although the simple assignment formulation quickly accomodates the unit scheduler's first two objectives by (1) attemping to assign each student a task, and by (2) scheduling events to include the arcs in G with the lowest total weights(most preferred pairings), it cannot accomodate the sequential nature of the tasks. Recall that the tasks in T have an ordered relationship which indicates that more than one task can be accomplished by a particular student in S. However, the simple assignment formulation allows only a one-to-one matching in the optimal solution due to equations 4.2 and 4.3. Thus the formulation assigns the most preferred set of tasks to the students and assigns the remaining tasks to the dummy nodes. There is no capability of assigning a remaining task to a student even though it may be feasible(i.e. an arc exists from t_i to t_j in the partially ordered set). For example, student 6 can accomplish both task 4 and task 9 (which was assigned to a dummy node by the simple assignment problem) with his/her assigned instructor. In the following three sections I will discuss formulations which can accomodate the ordered relationship.

4.12 - INTEGER PROGRAMMING

One approach to solving the Level 2 problem optimally is through the use of integer programming. The student scheduling problem is similar in form to the capital budgeting problem discussed in literature[15]. The decision variables in the capital budgeting problem x_{ij} are taken to be 0 or 1 and represent a go / no-go decision with $x_{ij} = 1$ indicating that student i is matched with task j. Assuming w_{ij} is the weight or cost of the matching the problem can be stated as:

$$(4.5) \qquad \text{Minimize} \quad \Sigma_i \Sigma_j w_{ij} x_{ij} \qquad (i=1,...,m), (j=1,...,n)$$

$$(4.6) \qquad \text{Subject to:} \quad \Sigma_j x_{ij} \leq b_i \qquad (i=1, 2, ..., m)$$

$$(4.7) \qquad \qquad \qquad \Sigma_i x_{ij} = 1 \qquad (j=1, 2, ..., n)$$

$$(4.8) \qquad \qquad \qquad x_{ij} = 0 \text{ or } 1$$

Equation 4.6 ensures that student i does not perform more than a pre-specified total number of tasks, b_i (i.e. 1, 2, or 3 maximum). Equation 4.7 requires that all tasks be covered exactly once.

In this simple form the integer programming formulation fails to capture the conflicting nature of the tasks. That is, it is possible to assign two simultaneous tasks to a single student. It is necessary, then, to add multiple-choice constraints to the formulation based on the information in the adjacency list. For example, in the sample problem only one of tasks 1,2,3 may be accomplished by a single student. The constraint

$$(4.9) \qquad \qquad x_{i1} + x_{i2} + x_{i3} \leq 1 \qquad (i=1,2,...,m)$$

must be added to capture this logical constraint. Other logical constraints for the sample problem are:

(4.10)	$x_{i1} + x_{i4} + x_{i5} \leq 1$	$(i = 1,2,\ldots,m)$
(4.11)	$x_{i2} + x_{i4} \leq 1$	$(i = 1,2,\ldots,m)$
(4.12)	$x_{i4} + x_{i5} + x_{i6} \leq 1$	$(i = 1,2,\ldots,m)$
(4.13)	$x_{i6} + x_{i9} \leq 1$	$(i = 1,2,\ldots,m)$
(4.14)	$x_{i5} + x_{i7} + x_{i9} \leq 1$	$(i = 1,2,\ldots,m)$
(4.15)	$x_{i8} + x_{i7} + x_{i9} \leq 1$	$(i = 1,2,\ldots,m)$
(4.16)	$x_{i7} + x_{i10} \leq 1$	$(i = 1,2,\ldots,m)$

In all, eight additional constraint equations must be added for each student to properly formulate the simple example as an integer program. This explosion of constrain equations is typical for integer programming problems and is prohibitive in formulating realistic problems.

4.13 - SET COVERING/ COMPLETE ENUMERATION

An alternative approach to solving the Level 2 problem is through complete enumeration. By listing all possible combinations of solutions to the problem the best feasible combination can be selected. This process generates thousands of possible combinations for even the simplest problem and requires a large amount of processing time. Improvements can be made by quickly eliminating obviously unreasonable solutions once a "good" solution is found. The major airline industry uses this enumeration and elimination process in solving aircraft and crew scheduling. According to Simpson 35 it is not unlikely for an airline to have several million alternatives available when

searching for the optimal solution. Due to the amount of computer power required to solve problems through complete enumeration, it is impractical to use this technique for the Level 2 problem.

4.14 - HEURISTICS

In many cases involving integer programming practitioners must turn to heuristics in order to "solve" real-world problems. Often the specific problem has special characteristics which lend themselves to heuristic techniques. Moreover, according to Fisher[24], even if an optimization method is applicable, the first step in such a method is usually the application of a heuristic to obtain a good starting solution.

However, several problems may arise when using the heuristic approach. First, the heuristic only provides an approximate solution to the integer program. Secondly, the heuristic method does not lend itself to sophisticated analysis of its performance. And third, the heuristic solution is usually highly problem specific and cannot be modified to solve other similar problems. Nonetheless, even though recent work by Cornuejols, Fisher and Nemhauser[18]; Geoffrion and Graves[30]; Marsten, Muller and Killion[45]; and others[42,58] provide a growing list of successful applications of optimization methods in solving real problems, there is still a large gap that only heuristic methods can currently fill.

4.2 - HEURISTIC METHOD FOR THE LEVEL 2 PROBLEM

One approach for obtaining an approximate solution to the Level 2 scheduling problem is a heuristic which utilizes a two-step simple assignment process. In the following three sections I will discuss the heuristic solution method; its advantages; its potential worst case problems, and methods to accomodate those problems.

4.21 - STEP 1

In the first step of the method the unit scheduler attempts to ensure that each student has at least one activity. In this step every effort is made to match a student with his/her assigned instructor. In short, the scheduler wishes to optimally assign each student once. In the Level 2 problem of matching m students to n tasks, $m < n$, the heuristic accomplishes this by using the network transportation formulation described in section 4.11. As was mentioned earlier, the minimum cost formulation will assign tasks to students in such a manner such that each student is assigned a task and the total weight is minimal. The first step, then, selects the best set of m assignments from all possible sets of m assignments. The solution will be optimal for the Step 1 problem and will also perform an infeasibility check. Since the formulation has a supply of 1 at each student node the solution requires that each student be scheduled once. With the minimum weight objective function the formulation will always utilize feasible arcs when possible since the weight of artificial arcs is prohibitively high. Thus, if the optimal Step 1 solution includes more than n-m arcs with $w_{ij} = M$ the solution is infeasible. This "student lock-out" infeasibility is discussed in detail in section 4.24.

4.22 - STEP 2

After optimally assigning m tasks to the student group the scheduler then attempts to assign the remaining n-m tasks to the available students. To do this using the assignment algorithm of Step 1 two updates must be made to the graph, G, of figure 4.1. The first update raises to M the weight on all arcs incident to the tasks assigned in Step 1. Thus any assignment of a student to these tasks in Step 2 is infeasible since the tasks were already assigned in the previous step. The second update involves the feasibility of remaining assignments based on the results of Step 1. Using the adjacency list the algorithm updates all remaining feasible arcs from Step 1 to determine if they are still feasible in Step 2. If student i is assigned to task j in Step 1 then, necessarily, the student is prohibited from accomplishing any remaining task which is not on the adjacency list of j. Thus, the weight of all arcs linking i to tasks which conflict with j is increased to M. After these updates, the set of arcs, A', consist only of those arcs in A which are feasible for 1) the Instructor Preference matrix, 2) the Step 1 assignments, and 3) the Adjacency (no conflict) List. The Step 2 assignment problem with updated feasible arc set A' for the sample problem is in figure 4.3. The number of feasible arcs for this problem is reduced from 29 to 9. The unassigned tasks from Step 1 are in bold print.
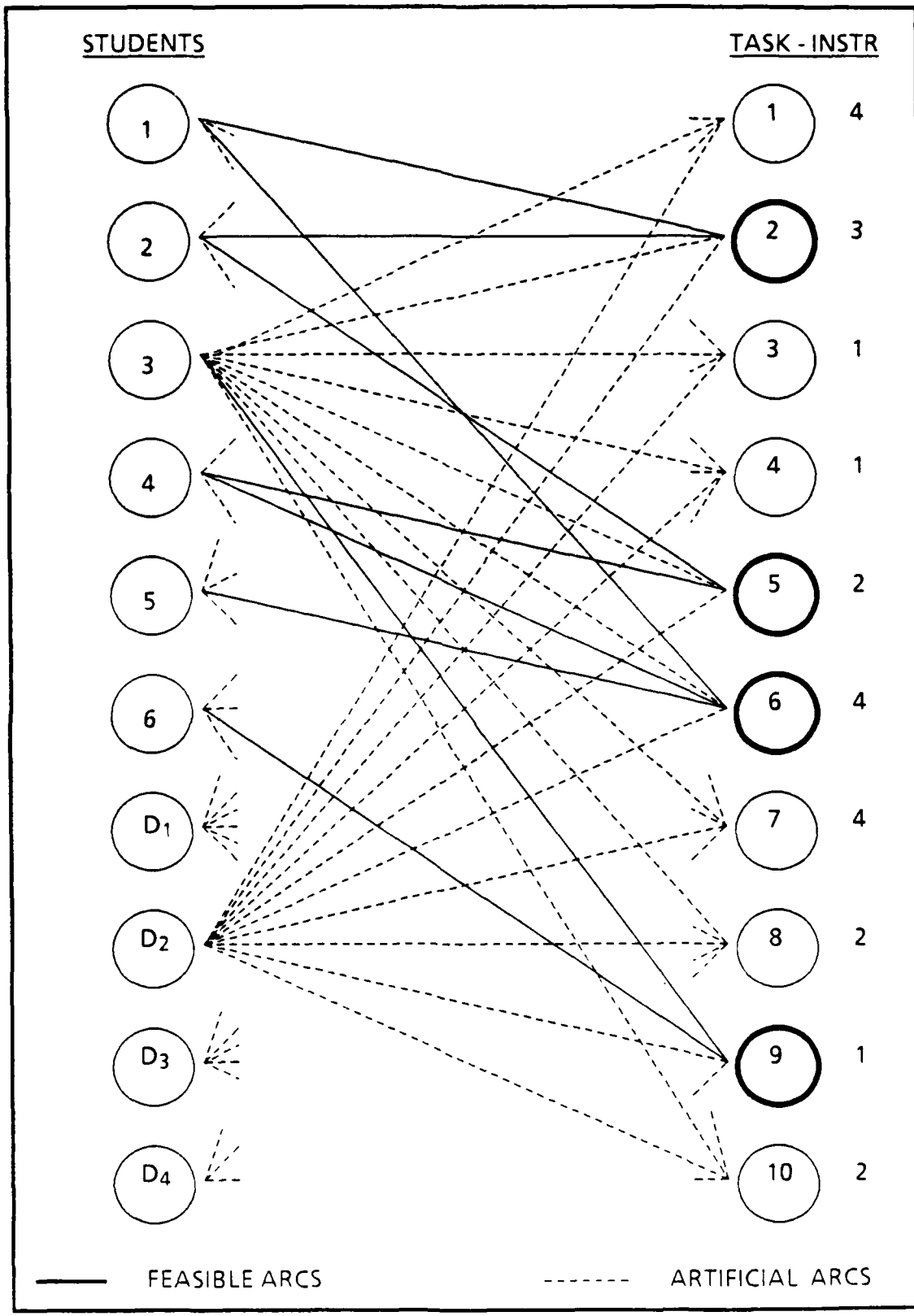
Figure 4.3 - Step 2 Sample Assignment Problem

-75-

With these updates, a second set of assignments is made using the same optimality criterion as in the previous step. In essence, after the updates, Step 2 is optimized as an independent problem. The set of assignments is optimal for the Step 2 problem. This does not imply that the combination of locally optimal solutions for the two steps is optimal for the schedule as a whole. However, if both steps have optimal solutions the combined solution to the entire schedule will be feasible and, in most cases, quite close to optimal. The combined solution for the sample problem is in figure 4.4. Notice that all tasks are assigned to students(i.e. no tasks are assigned to 'dummy' nodes), all multiple task assignments are feasible, and that 9 of the 10 matchings link the student with his/her preferred instructor.

Just as in Step 1, infeasibility can enter the problem in Step 2. Although the student lock-out infeasibility does not apply since all students are assigned a task in Step 1, it is possible to have a "task lock-out" infeasibility in this step. Task lock-out infeasibility occurs when no student is available to accomplish a specific task. This type of infeasibility is discussed in section 4.24.
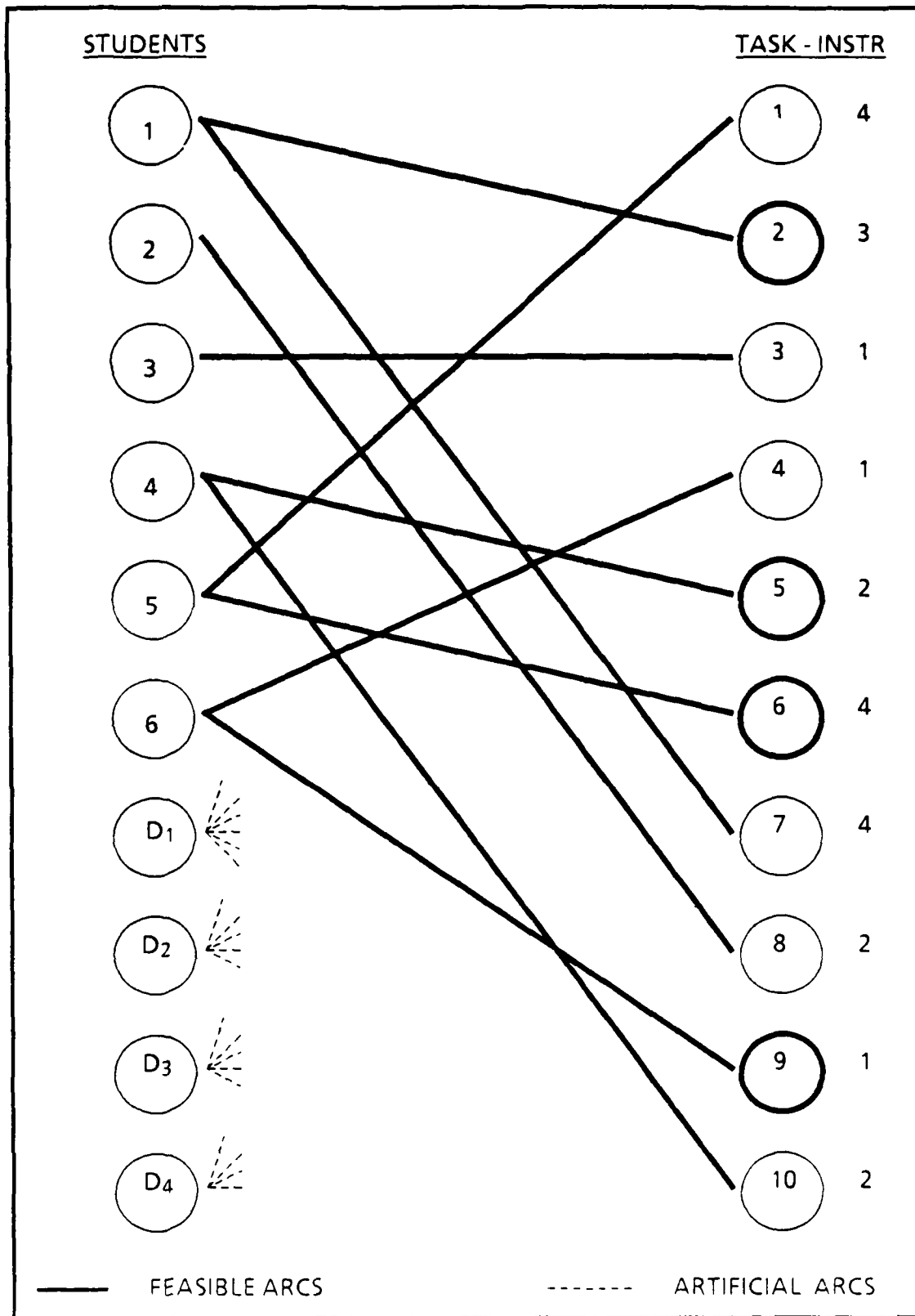
Figure 4.4 - Heuristic Solution to the Sample Assignment Problem

4.23 - ADVANTAGES TO THE HEURISTIC METHOD

There are several advantages to the heuristic solution method for the Level 2 scheduling problem.

1)The first advantage is <u>simplicity</u>. Because the heuristic models the problem as a two step simple assignment problem, any network flow algorithm will solve the problem directly with integer solutions. Computer programming is straightforward, and many off the shelf network flow algorithms are available.

2) Another advantage is <u>speed</u>. Since the solution method uses a network flow algorithm, the Level 2 solution is obtained in seconds. The speed of the entire process is limited only by the time necessary for data entry.

3) A major advantage of the heuristic is the <u>weight updating procedure</u>. Integer programming and other optimization methods do not allow elaborate weight updating with such simplicity as the two step heuristic. In addition to updating arcs for feasibility after the Step 1 assignments, the heuristic can update remaining feasible arcs for desirability as well. Recall that the objectives of the unit scheduler are threefold.

> 1. Schedule each student at least once   (Step 1)
> 2. Match students with more preferred instructors   (Step 1, 2)
> 3. Maximize student idle time between events   (Step 2)

The third objective, previously unaddressed, can easily be accomodated by the heuristic. Based on the assignments of Step 1, the scheduler can assign lower weights to those arcs in A' which provide greater idle time between feasible tasks for each student. This arc weight modification results in Step 2 assignments which favor greater idle time for the students involved.

4) A fourth advantage is <u>acceptability</u>. The heuristic method employed to solve the Level 2 problem closely models actual scheduling practices used

by unit schedulers on a daily basis. Rarely does a unit scheduler have the time to optimally assign the entire schedule by hand. His/her realistic goal is to provide each student with one "good" instructor-task matching and to merely 'fill' the remaining tasks with feasible pairings. The two step assignment method accomplishes these goals easily in much the same manner as the unit scheduler. This will aid in the method's acceptability to current unit schedulers since it does not require radical changes in scheduling practices.

5) Finally, the Level 2 heuristic is an <u>optimization-based heuristic</u>. Optimization methods are an integral part in the design of the heuristic. This master-slave relationship is very effective in solving many real world problems which do not lend themselves to optimization techniques directly. Ball et al.[5] demonstrates the advantage of using matching algorithms as an ingredient of the heuristic for vehicle scheduling.

4.24 - PROBLEMS WITH THE HEURISTIC METHOD

As was mentioned in sections 4.21 and 4.22 two types of infeasibility, 'student lock-out' and 'task lock-out', can occur in the Level 2 problem. The student lock-out infeasibility, which occurs in the Step 1 process, results in an unassigned student. Figure 4.5 shows a simple example of this type of infeasibility. If a single instructor is the only member of the student preference list for 's' students and he/she performs 't' tasks, t<s, in the unit schedule then s-t students will be locked-out of the schedule. This student lock-out infeasibility is <u>unrelated to the solution method employed</u> and can only be avoided through proper planning by the unit scheduler. The scheduler must develop the preference list so instructors are assigned to students in

proportion to the availability of the instructor. Thus, a supervisor who is limited to one student activity per day should not be a primary instructor to more than one student. Also, those students who are assigned to supervisors should have sufficient depth in the preference list to ensure enough options exist in case the supervisor is unavailable. The sample problem is an example of proper planning to avoid this type of infeasibility. In table 4.1 instructor #3 is the supervisor and is assigned a single task by the unit scheduler. Notice in table 4.2 that no student has instructor #3 as a primary instructor and two students(1,2) have the supervisor as an alternate instructor. This scheduling foresight results in greater flexibility in the schedule and virtually eliminates student lock-out infeasibility.
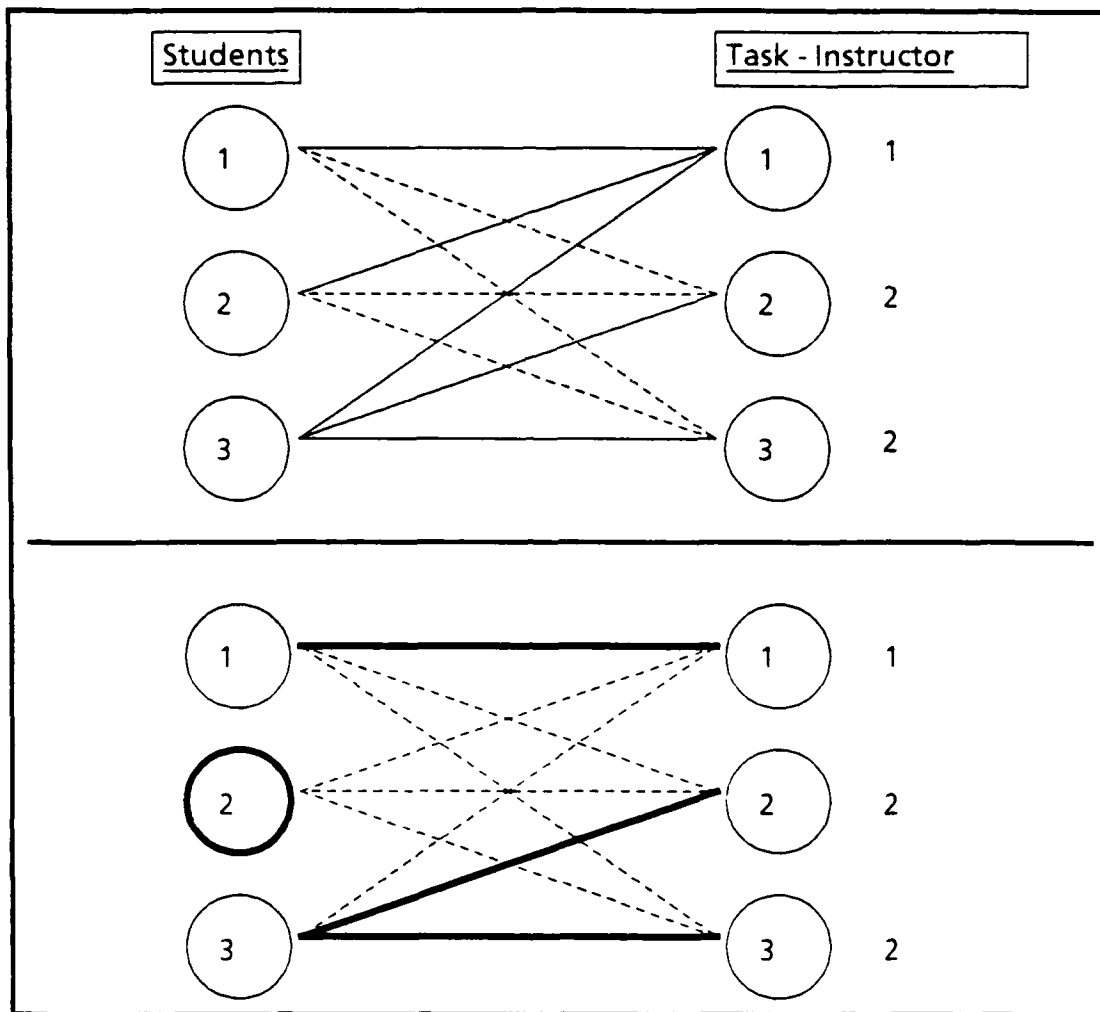
Figure 4.5 - Student Lock-out Infeasibility

The second type of infeasibility, task lock-out, occurs in Step 2 of the heuristic and results in an unassigned task. Task lock-out results primarily from the heuristic method although it can occur in optimization methods as well. However, the two step heuristic method may result in an infeasible solution where an optimization method would not. Figure 4.6 provides an example where the heuristic solution is infeasible while an optimization solution is feasible. In the example only tasks 1 and 3 can be performed by a single student. The heuristic method in 4.6b incorrectly assigns task 1 to

student 2 in Step 1 because of its low cost. Unfortunately, this assignment results in infeasibility in Step 2 since no student is available for task 3. Thus, task 3 is improperly locked-out of the solution. The correct solution in 4.6c optimally assigns all tasks to students at the lowest overall cost.

Because the Step 1 assignment process does not consider its effect on the Step 2 process, task lock-out infeasibility may result. Although the problem is a serious one, for the vast majority of cases it is highly unlikely to occur. This is due to the density of feasible arcs, A, in the graph. Three factors contribute to the density. First, the student preference list usually contains two or more instructors for each student. Thus, students will have feasible arcs to several instructor-task nodes in the unit schedule.

Second, the instructor force is small relative to the students. The average instructor is accomplishing several tasks in the daily schedule. This has a multipicative effect on the number of feasible arcs for each student in the graph. Also, the large student/instructor ratio results in a low task/student ratio in the schedule. The task/student ratio usually hovers near 1.5 which indicates only 50% of the student pool is needed to solve the Step 2 problem.

Third, proper construction of the student preference lists adds to the density of A. Just as in the case of student lock-out, the scheduler can avoid task lock-out in Step 2 by properly assigning instructors to students. Task lock-out would occur if an instructor who is not on several student's lists is performing many tasks in the schedule. Thus, although students are available, none match properly with the instructor of the task. By assigning those instructors who will be doing most of the work to the majority of students sufficient density in A will occur to prevent task lock-out infeasibility.
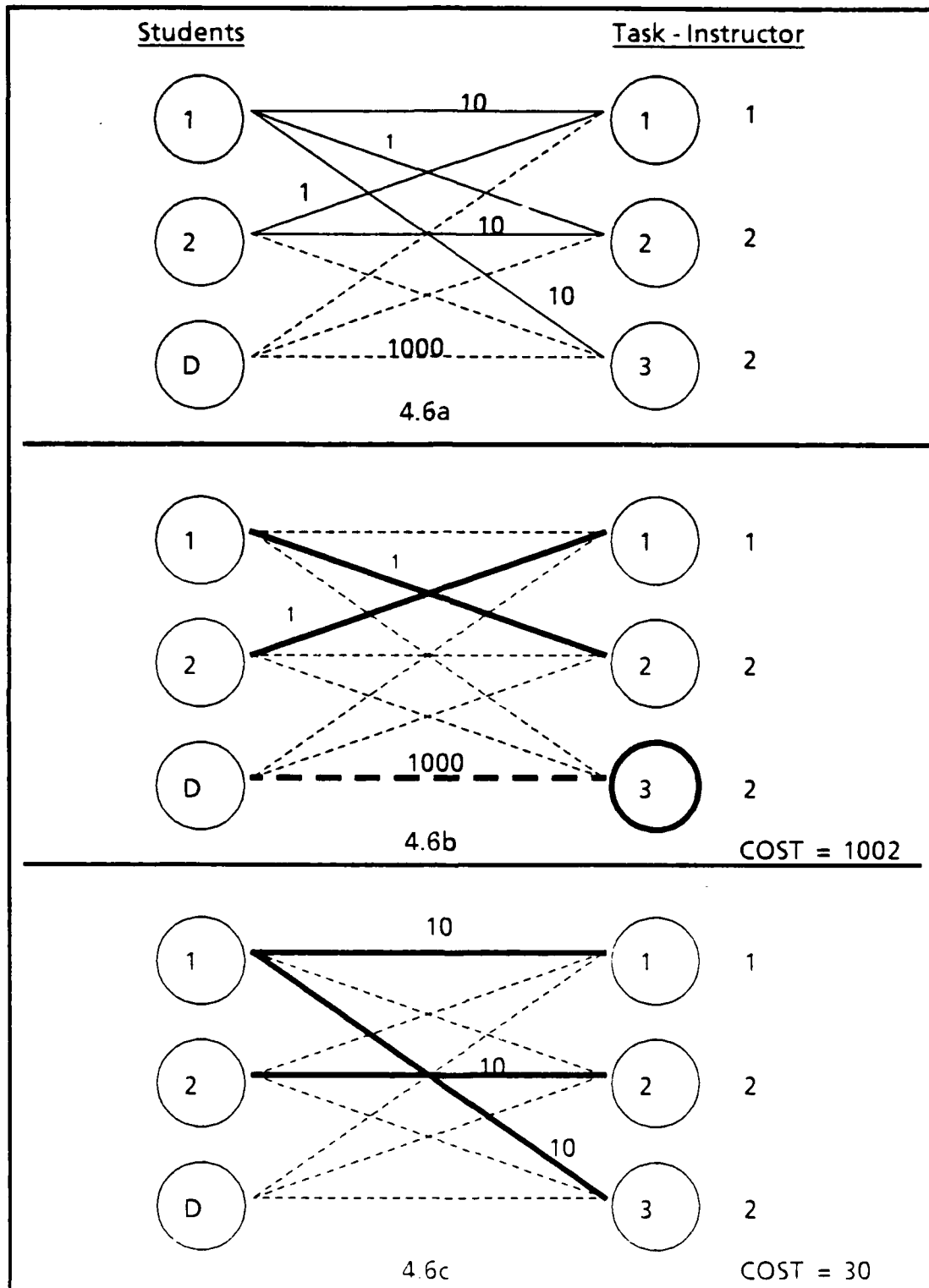
Figure 4.6 - Task Lock-out Infeasibility

The sample problem illustrates these three points well. Three instructors(1,2,4) are performing three tasks each. Also, these instructors fill all of the primary assignments and one-half of the secondary assignments in the student preference list. Thus, even though two students(3,5) have only one assigned instructor each and the task/student ratio is a high 1.67, the heuristic method solves the problem with no infeasibility. A lower task/student ratio and greater depth in the student preference list will make the possibility of task lock-out infeasibility due to the heuristic method even more remote.

CHAPTER 5

COMPUTATIONAL RESULTS

5.0 - INTRODUCTION

After sucessfully applying the algorithms of chapters 3 and 4 to the sample problem, the next logical step is to test them on actual USAF/ATC scheduling problems. The 559th Flying Training Squadron located at Randolph AFB, San Antonio, Texas supplied the test data which contains information about tasks, instructors, and students for the week of February 24-28, 1986. This data is included in appendicies A, B, and C. Unfortunately, due to the dynamic nature of the 559th scheduling environment, the number of schedulers involved, and the inability to work side by side; no direct comparison is possible between the algorithms of this paper and the actual scheduling results used by the 559th. Hopefully, greater interaction will result as an outgrowth of this paper and more conclusive analysis of the scheduling methods used may be conducted.

This chapter is divided into two sections. In the first section I will briefly discuss the Level 1 program and describe the computational results of the solution method. The second section focuses on the Level 2 program and its results. A more detailed discussion of both programs is in appendix D. All

programs are in Fortran 77 and were written, compiled, and executed on an IBM PC/XT.

5.1 - LEVEL 1 PROGRAM RESULTS

Recall that the Level 1 problem is twofold. The first problem is to determine the minimum number of instructors needed to accomplished all scheduled tasks. Then the most efficient way of using the instructors is found. The Level 1 program uses the minimum cost network flow code RELAX developed at M.I.T. by Bertsekas and Tseng[9,10]. The program uses RELAX to solve both phases of the Level 1 scheduling problem.

Phase 1 of the program recasts RELAX as a maximum flow code to determine the lower bound on the number of instructors as outlined in section 3.6. The program then uses the phase 1 output as input to phase 2. Phase 2 uses RELAX to solve the minimum-cost flow problem described in section 3.7. Finally, a simple heuristic checks the task string length for each instructor and trims those strings longer than three tasks.

Table 5.1 is a compilation of the 559th task data in appendix A. The table displays the task breakdown, by type, for each day of the week. Aircraft tasks require 3 hours to accomplish, simulator tasks 2 hours 15 minutes, cross country tasks are all day affairs, and SOF/RSU/Other tasks are variable in length.

Table 5.1 - Task breakdown by type and day

TASK TYPE	MON.	TUES.	WED.	THURS.	FRI.
Aircraft	50	55	57	55	49
Simulator	28	26	30	25	30
Cross Country/O&B	5	6	5	4	13
RSU/SOF/Other	7	8	7	7	7
TOTAL	90	95	99	91	99

Table 5.2 displays the phase 1 and phase 2 output on the number of instructors needed to fill the daily schedules. On average, the program determined the lower bound(phase 1 output) in approximately 20 seconds with the longest running under 30 seconds. The phase 2 numbers also required less than 30 seconds. Row 3 shows the difference in the output. This difference is a function of the length-of-day and task-chain length restrictions imposed on the Level 1 problem. Recall the phase 1 output is the solution to the relaxed problem without these constraints. In phase 2 the program attempts to match the phase 1 output but adds an instructor for every constraint violation in the relaxed solution. Thus, the phase 2 schedule output will always be feasible for the number of instructors listed by the phase 2 program.

Row 4 of table 5.2 displays the percentage of violations in the phase 1 solution with respect to the total number of tasks scheduled. The average percentage of violations for the week is 5.3%. Thus, the relaxed solution output of phase 1 is, on average, 95% accurate and requires only minor adjustments by the heuristic. Based on this test, the percentage of violations appears to decrease on those days with greater number of tasks. Only the phase 2 output for Monday is significantly different than the other days.

However, there is nothing unique about the task breakdown or schedule makeup for that day which would indicate a high percentage of violations in the phase 1 solution. The deviation may be due to the low total number of tasks and low aircraft/simulator ratio on Monday. Excluding the output for Monday, the average percentage of violations drops to 4.2% for the remaining four days.

Table 5.2 - Number of Instructors Needed

PHASE	MON.	TUES.	WED.	THURS.	FRI.
PHASE 1 (Lower Bound)	31	38	37	34	42
PHASE 2 (# In Schedule)	40	43	41	38	45
PHASE 2 - PHASE 1	9	5	4	4	3
% Violation	10.0 %	5.3%	4.0%	4.4%	3.0%

Figures 5.1 is a summary of the daily phase 2 schedules generated by the Level 1 program. The average total elapsed time from program initiation to schedule printout was less than 90 seconds with little variance. The output contains feasible task strings for the instructors and flags all duty day violations. The heuristic program prints "Duty day violation" and adds an instructor for al task strings with duration longer than 12 hours. Only four such violations exist for the entire week. The vast majority of singleton task strings in the schedules are tasks of long duration such as cross country missions or SOF duties. Two and three task strings are made up primarily of the shorter duration aircraft, simulator, and RSU tasks.

TASK STRING NUMBER	PHASE 2 DAILY SCHEDULES				
	MON.	TUES.	WED.	THURS.	FRI.
1	79	65	88	79	80
2	80	66	89	81	81
3	81	67	90	82	82
4	82	82	91	83	83
5	83	83	92	84	84
6	1-19-89	84	94	86	85
7	2-20-38	85	1-21-98	90	86
8	3-21-39	86	2-23-46	1-18-37	87
9	4-88-34	87	3-24-47	2-19-38	88
10	76	89	4-25-48	3-20-39	89
11	5-22-40	93	5-27-50	4-21-75	90
12	6-24-36	1-23-46	6-28-51	5-22-41	91
13	78	2-24-47	7-29-52	6-23-42	92
14	7-23-41	3-25-48	8-30-53	7-67-73	1-20-98
15	8-26-44	4-26-49	9-73-80	52	2-21-41
16	9-25-37	5-27-50	10-35-81	8-25-44	3-22-42
17	10-28-86	6-28-51	11-32-55	9-26-45	4-23-43
18	D. D. V.*	7-29-52	12-33-56	10-27-46	5-60-68
19	11-29-42	8-30-53	13-36-85	11-29-48	6-24-44
20	12-27-45	9-31-54	58	12-30-49	7-26-40
21	13-31-49	10-32-55	14-37-86	13-31-50	8-27-47
22	14-32-50	11-33-70	15-38-87	14-32-87	9-29-49
23	15-33-75	12-35-72	59	15-33-53	10-30-72
24	16-66-74	13-36-73	16-39-95	16-34-54	11-31-74
25	17-35-77	56	60	17-36-80	12-64-73
26	18-30-43	14-37-74	17-40-99	56	13-32-75
27	51	15-38-75	61-18-41	57-65-35	14-33-76

Figure 5.1 - Phase 2 Schedules for the Week

TASK STRING NUMBER	PHASE 2 DAILY SCHEDULES				
	MON.	TUES.	WED.	THURS.	FRI.
28	52-57-64	57	62-26-49	55	15-35-78
29	72	16-39-76	63-97-44	58-71-78	16-36-79
30	53-59-67	17-40-77	64-70-77	59-64-51	17-34-77
31	46	58	65-71-78	60-28-47	50
32	54-60-68	18-41-78	66-31-54	61-68-40	51-19-39
33	47	19-42-79	67-74-82	62-69-76	52-59-67
34	55-61-69	59	68-75-83	63-70-77	99
35	48	20-43-80	69-76-84	66-72-91	53-61-69
36	56-63-71	88	93-34-57	88	54-28-48
37	58-65-73	21-44-81	D. D. V.*	85-24-43	56-63-71
38	84-62-70	60-34-71	96-72-79	89-74	57-62-70
39	87-85-90	61-69-95	19-42		58-66-46
40	D. D. V.*	64-94-91	20-43		93-65-95
41		92-22-45	22-45		D. D. V.*
42		62-69			96-25-45
43		63-90			18-38
44					55-94
45				.	97-37

Figure 5.1 - Phase 2 Schedules for the Week

5.11 - SCHEDULE ADJUSTMENTS

If the number of instructors planned for by the squadron scheduler is less than the number required to fill the phase 2 schedule in row 2 of table 5.2 above, the scheduler has two options. The scheduler can add instructors to the schedule, if available and rerun the program to obtain an improved feasible schedule. If no additional instructors are available, the current number of tasks is infeasible and the scheduler must eliminate low priority tasks from the schedule. For example, in the schedule for Monday (see figure 5.1), if the 1655 simulator task (#78) in bold print in line 13 is a low priority task, the scheduler can easily eliminate it and reduce by one the required number of instructors.

Conversely, if the number of instructors required by the phase 2 schedule is less than the number available, the scheduler can add tasks to the schedule(meetings, appointments, etc.) or relieve the extra instructors from duties for the day.

After the squadron scheduler makes minor adjustments to the phase 2 schedule to best suit the squadron's needs, he/she then divides the task strings among the six units in the squadron. This decomposition is based on the "contracts", mentioned in chapter 1, submitted by each unit scheduler. The actual unit contracts for the week are in appendix B. From these contracts the squadron scheduler knows the desired task makeup of each unit for every day of the week. For example unit "B" requested the following sixteen tasks for its seven instructors for Wednesday, Feb. 26th:

> 1) 1 SOF task
> 2) 1 RSU task
> 3) 8 Aircraft missions
> 4) 6 Simulator missions

Table 5.3 shows the contracted work schedule, broken down by instructor, for unit B. Instructor #1 is the supervisor and must perform the SOF task while instructor #6 is qualified to perform the RSU task. All instructors can perform any combination of aircraft or simulator tasks, but no instructor may have more than three tasks. Finally, unit B is to work the early shift in the squadron.

Table 5.3 - Unit B Contract, by Instructor

INSTRUCTOR NUMBER	TASK PERIOD		
	1	2	3
1	OFF	OFF	SOF
2	OFF	1	OFF
3	1	1	1
4	1	1	1
5	1	1	1
6	1	RSU	1
7	1	1	OFF
TOTAL = 16	5	6	5

Using the phase 2 schedule for Wednesday, unit B's contract, and knowing unit B is on the early shift: the squadron scheduler could select the task assignments listed in table 5.4. In all, six task strings are used to fill the contract for unit B exactly with all the items requested above. One task string is divided between instructors #2 and #7.

Table 5.4 - Assigned Schedule for Unit B , by Instructor

INSTRUCTOR NUMBER	TASK-STRING LINE NUMBER (from fig. 5.1)	TASK PERIOD		
		1	2	3
1	6	OFF	OFF	94 (SOF)
2	15	OFF	80 (SIM)	OFF
3	28	62 (SIM)	26 (ACFT)	49 (ACFT)
4	32	66 (SIM)	31 (ACFT)	54 (ACFT)
5	27	61 (SIM)	18 (ACFT)	41 (ACFT)
6	29	63 (SIM)	97 (RSU)	44 (ACFT)
7	15	9 (ACFT)	73 (SIM)	OFF
TOTAL = 16		5	6	5

The squadron scheduler would repeat this process for the remaining five units until all 99 tasks in the Wednesday schedule are filled.

5.2 - LEVEL 2 PROGRAM RESULTS

The Level 2 problem discussed in chapter 4 addresses the student assignment process at the unit level. As with the Level 1 program, the Level 2 optimization-based heuristic program uses the minimum-cost network flow code RELAX in both steps of the program.

Both Step 1 and Step 2 of the heuristic program recast RELAX as a transportation network code to solve the student assignment problems described in section 4.2. For each step RELAX required less than 3 seconds to determine the optimal student-task pairings for the test problems. This speed is primarily a function of smaller problem size encountered by the unit scheduler.

For the Level 2 test I will continue to use the unit B data for Wednesday, February 26th. The Level 1/Phase 2 schedule for the instructors of unit B, summarized in table 5.4, is the input to the two step Level 2 program. Additional data required by the Level 2 program is the Student Preference Matrix for the unit B students. The actual preference matrix from appendix C for the ten students in unit B is displayed in table 5.5.

Table 5.5 - Student Preference matrix

STUDENT NUMBER	INSTRUCTOR NUM.			
	1st	2st	3rd	4th
1	2	7	3	
2	6	3		
3	5	6		
4	7	6	1	2
5	2	1		
6	4	3	5	
7	7	3		
8	5	3		
9	6	2		
10	4	5		

Notice in the table the effective assignment of instructors to students accomplished by the unit B scheduler. Instructor #1, the supervisor, is not a most preferred instructor for any student. Also, the supervisor is only included in the lists for two students (4,5). The remaining 23 entries in the matrix are evenly divided both in number and order of preference among the six remaining unit B instructors. This effective planning results in no student or instructor being dominant in the assignment process, increases scheduling flexibility, and greatly reduces the likelihood of encountering student or task lock-out infeasibility in the solution. The task/student ratio is a reasonable 1.6. This ,too, reduces the possibility of infeasibility.

Table 5.6 contains the results of the Level 2 program for unit B. This schedule displays the task number, instructor and student for each task, and a brief description of each task. The time required from Level 2 program initiation to printed output was less than 15 seconds. No task or student lock-out infeasibility occured as each task is assigned to a student, and each student performs at least one activity. Of the 16 assignments, 12 match a student with his/her 1st preference instructor, 3 match the student with the 2nd preference instructor, and 1 requires a student to perform a task with a 3rd preference instructor. The task assignments for the six students performing two tasks each (1,2,3,7,9,10) are all feasible and have an average idle time of 2.16 hours between tasks.

MICROCOPY RESOLUTION TEST CHART

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CHAPTER 6

CONCLUSIONS AND EXTENSIONS

6.0 - THESIS REVIEW

Undergraduate Pilot Training is a dynamic, high pressure program which produces front line aviators for the United States Air Force. The eleven month curriculum contains a complicated assortment of academic, flight, and simulator training. Scheduling the instructors, students, and activities on a daily basis is the responsibility of the squadron scheduler and six unit schedulers. For many years the manual method of scheduling currently used by the schedulers was adequate due to the nature of training. Small class sizes and more dependable aircraft systems resulted in fewer scheduling constraints. In recent years, however, the need for optimization based scheduling has become paramount. Class sizes have increased dramatically, and the aging aircraft fleet has become less reliable. As constraints on the scheduling process grow even tighter, feasible solutions to daily schedules become more elusive. The current scheduling process consumes many man-hours as the manual heuristic becomes less effective.

In this paper we attempt to alleviate some of the scheduling difficulties by developing a micro computer based algorithm which will quickly find

feasible solutions to both the squadron and unit level scheduling problems. In the past, micro computers lacked the necessary capacity to slove the UPT scheduling problem, and larger mini or mainframe computers were not available for use by the UPT squadrons. However, with the advent of powerful micro computers and by dividing the scheduling process into two smaller problems we obtain tractable problems which can be solved on a micro computer.

In chapter 3 we address the instructor scheduling problem and formulate it as a network flow problem. Using a maximum flow formulation and Dilworth's theorem we find the minimum number of instructors needed to accomplish all tasks in the schedule. Then, using the minimum cost flow formulation we tightly schedule tasks to instructors in order to best utilize the instructor force.

With the Level 1 output of chapter 3 we then decompose the problem into the six smaller units. The Level 2 optimization-based heuristic is chapter 4 assigns students to tasks based on the previous Level 1 instructor assignments. We formulate the student scheduling problem as an assignment problem. The heuristic utilizes a 2 step network transportation formulation to feasibly assign all tasks to students. With this result the scheduling process is complete. The Level 1 and Level 2 programs assign tasks to instructors and students in a manner which accomodates each individual's needs and preferences.

6.1 - CONCLUSIONS

As a result of this research effort we have made several conclusions about the current UPT aircrew scheduling efforts and the solution method proposed in this paper.

1) Our solution method is <u>much faster</u>. Currently, seven to ten squadron officers expend up to 100 man-hours daily on the UPT scheduling problem. The solution methods in this paper require only a few minutes on a micro computer to generate feasible schedules for the entire squadron.

2) Our solution method is <u>less expensive</u>. The current scheduling method not only requires a great amount of time, it also demands an extremely high skill level to implement. Thus, the squadron must use experienced instructors to construct daily schedules. The micro computer based method in this paper requires a much lower skill level for day-to-day operation. The skill of the experienced scheduler is captured by the various cost functions, task priorities, and preference matricies. Thus, fewer and less skilled people can effectively complete the daily schedule, and highly skilled officers are available for more important instructional duties.

3) Our solution method results in <u>better schedules</u>. Due to the complexity of the scheduling problem and the inadequicies listed above, the manual method often results in ineffective or infeasible use of resources. The optimization based solution method in this paper exploits the underlying network structure of the problem, performs a fast infeasibility check on the problem, and always produces feasible schedules. Also, the method schedules instructors tightly to eliminate long duty days. Thus, fewer instructors can accomplish the daily schedule in less time.

4) Our solution method is <u>interactive</u>. Studies have shown that the most successful computer based scheduling packages are those which are a tool, not a replacement, for the master scheduler. The interactive nature of our solution method adds flexibility by providing an expert scheduler the ability to modify the schedule to best fit the squadron's needs. The interactive approach also greatly simplifies the programs as complicated or "fuzzy" decisions are left to the master scheduler.

Thus, the union of a master scheduler and an effective, optimization based solution method results in a low cost scheduling process. The interactive process produces feasible schedules in minutes and releases highly skilled instructors to perform more important tasks.

6.3 - EXTENSIONS

There are several areas which one can explore as an extension to this thesis. Preferably, any future research on the UPT scheduling problem can be sponsored by the USAF Air Training Command and involve a high level of interaction between the researcher and the practitioner. For this reason future research efforts would be most effective if conducted in conjunction with Air Training Command headquarters in San Antonio, Texas.

The first extension is to analyze the effects of different cost functions on the solution method. The use of non-linear or quadratic cost functions may more accurately reflect the desired practices of the squadron. This would enhance the acceptability of the solution method by providing more realistic schedules. Again, without extensive interaction with actual UPT schedulers elaborate cost function updates may be largely ineffective.

A second extension is to further analyze the phase 2 performance of the Level 2 method. The worst case performance of the Level 2 heuristic is improper infeasibility and can result from a number reasons. Thus, further investigation of the robustness of the heuristic is possible. Variables affecting the heuristic method are 1) the total number of tasks, instructors, and students in the schedule, 2) the task/student ratio, and 3) the depth of the student preference lists. Analysis of the heuristic method in these areas would determine the usefulness of the method on larger and more complex problems.

Investigating the applicability of exact algorithms for the Level 2 scheduling problem is a third extension of this thesis. Although we mention in chapter 4 that exact algorithms currently are not executable for the UPT problem on micro computers, the power and capabilities of these computers is rapidly advancing. Thus, one could investigate the applicability of set covering, integer programming, branch and bound, and/or Lagrangian relaxation methods to better solve the Level 2 problem.

Finally, the UPT scheduling problem is one which is amenable to the field of Expert Systems. Expert systems work best on those problems which have simple structure but require a large degree of expertise to solve. The dynamic nature of the UPT scheduling environment demands experienced squadron and unit schedulers who must adapt student and instructor assignments to changing weather and revised task schedules. The mental checklists used by the schedulers would be a basis for the expert system which could then be used by less skilled workers.

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APPENDIX A

This appendix contains the five daily schedules developed manually by the 559 FTS squadron scheduler. Using contract inputs from each unit the squadron scheduler constructed the complete schedule and assigned tasks to units. Aircraft and cross-country start times are located in the center section of the schedule; simulator start times are in the upper right corner; and SOF/RSU/other start times are in the lower right corner. Using these schedules and the Student preference lists of appendix C the unit schedulers construct daily unit schedules.

DAILY FLYING PLAN   559 F.. Billygoats   Mon 24 Feb 86 G |~~~~ SIMS ~~~~|

ID						SIMS Time	1	2	3	4
501	0845 A	1130 Uog	1415 BLEY	1659 B	1944	0630	D		D	
504	0848	1133	1418	1703	1947	0700		D		D
507	0851 F	1136 Uog	1421 D...#	1706 B	1950	0755	C		C	
510	0854	1139	1424	1709	1953	0825		E		E
513	0857	1142	1427	1712	1956	0920	A		A	
516	0901 F	1145 A	1430 D...#	1715	1959	0950		F		F
519	0904	1148	1433	1718	2003	1045	D		D	
522	0907	1151	1436	1721	2006	1115		C		C
525	0910 F	1154 A	1439 E...#	1724	2009	1210	C		E	
528	0913	1157	1442	1727	2012	1240		A		A
531	0916 F	1201 C ob	1445 *1630	1730	2015	1335	F		B	
534	0919	1204	1448	1733	2018	1405		B		D
537	0922	1207	1451	1736	2021	1500	D		D	
540	0925 SE	1210 A	1454 E...#	1739	2024	1530		A		A
543	0928	1213	1457 ^1406	1742	2027	1625	U		U	
546	0931	1216	1501	1745	2030	1655		B		B
549	0934 D	1219 C ob	1504 *1648	1748	2033	1750				
552	0937	1222	1507 ^1421	1751	2036	1820				
555 D	0940 D	1225 F	1510 A...#	1754	2039					
558	0943	1228	1513	1757	2042					
702	0946	1231	1516 ^1430	1801	2045					
705 D	0949 D	1234 A ob	1519 *1704	1804	2048	Sunrise: 0704				
708	0952	1237	1522	1807	2051	Sunset : 1828				
711	0955	1240	1525 ^1439	1810	2054					
714 D	0958 D	1243 F	1528 A...#	1813	2057					
717	1002	1246	1531	1816	2101					
720	1005	1249	1534	1819	2104					
723 C	1008 D	1252 F	1537 F...#	1822	2107					
726	1011	1255	1540 ^1454	1825	2110	SOF				
729 C	1014 D	1258 F	1543 F..#	1828	2113	0555 Ogle				
732	1017	1302	1546 .	1831	2116	1033 Meyer				
735	1020	1305	1549	1834	2119	1512 Huse				
738 E	1023 F ob	1308 *1452	1552 SE	1837	2122					
741	1026	1311	1555	1840	2125	1951 Close				
744	1029	1314	1558 ^1510	1843	2128					
747 E	1032 D	1317 305xc	1602 *****	1846 *****	2131 *****	RSU				
750	1035	1320	1605	1849	2134	0645 D/D				
753 E	1038 C ob	1323 *1508	1608 Uog	1852	2137	0946 E/D				
756	1041	1325	1611	1855	2140	1248 Ck/A				
759	1044	1329	1614 ^1528	1858	2143	1549 F/A				
803 E	1047 E	1332 B	1617 Uog	1902	2146	1851 Close				
806	1050	1335	1620	1905	2149					
809	1053	1338	1623 ^1537	1908	2152	Dispatcher				
812 E	1056 E	1341 B	1626 Dot	1911	2155	0510 Open :				
815	1059	1344	1629	1914	2158	1951 Close:				
818 Dot	1103 E	1347 B	1632 B	1917	2202					
821	1106	1350	1635	1920	2205	Snack Bar				
824	1109	1353	1638	1923	2208	0555 C/C				
827 A	1112 C ob	1356 *1541	1641 B	1926	2211	1200 B/B				
830	1115	1359	1644	1929	2214	1806 Close				
833	1118	1403	1647	1932	2217					
836 A	1121 Uog	1406 B...#	1650 B	1935	2220					
839	1124	1409	1653	1938	2223					
842	1127	1412	1656	1941	2410					

Total sorties: 82   Cap: 20/3   ***** PT *****

	Local	OBL	OBR	XC	NITE	Sims	
PIT	42	6	6	0	0	30	A: 0512 - 0612
UPGRADE	5	0	0	0	0	2	B: 1017 - 1117
SUPPORT	22	0	0	1	0	0	

501	0845 A	1130 C	1415 D	1659 Uog	1944
504	0848	1133	1418	1703	1947
507	0851 A	1136 Uog	1421 D	1706 ATCSE	1950
51?	0854	1139	1424	1709	1953
513	0857	1142	1427	1712	1956
516	0901 A	1145 Upg	1430 D	1715 ATCSE	1959
519	0904	1148	1433	1718	2003
622	0907	1151	1436	1721	2006
525	0910 SE	1154 C ob	1439 *1624	1724	2009
528	0913	1157	1442	1727	2012
531	0916 Chou	1201 E	1445 D	1730	2015
634	0919	1204	1448	1733	2018
637	0922	1207	1451	1736	2021
640	0925 F	1210 C ob	1454 *1639	1739	2024
643	0928	1213	1457	1742	2027
646	0931	1216	1501	1745	2030
649 D	0934 F	1219 E	1504 C	1748	2033
552	0937	1222	1507	1751	2036
555 D	0940 F	1225 E	1510 C	1754	2039
558	0943	1228	1513	1757	2042
702	0946	1231	1516	1801	2045
705 D	0949 F	1234 C ob	1519 *1704	1804	2048
708	0952	1237	1522	1807	2051
711	0955	1240	1525	1810	2054
714 D	0958 D	1243 E	1528 B	1813 Kngy	2057
717	1002	1246	1531	1816	2101
720	1005	1249	1534	1819	2104
723 D	1008 D	1252 A	1537 B	1822 Sch	2107
726	1011	1255	1540	1825	2110
72? Rowcl	1014 D	1258 A	1543 B	1828 Dot	2113
732	1017	1302	1546	1831	2116
735	1020	1305	1549	1834	2119
738 Dot	1023 D	1308 F	1552 B	1837 F.nt	2122
741	1026	1311	1555	1840	2125
744	1029	1314	1558	1843	2128
747 E	1032 D	1317 A ob	1602 *1746	1846	2131
750	1035	1320	1605	1849	2134
753 E	1038 D	1323 F	1608 SE	1852	2137
756	1041	1326	1611	1855	2140
759	1044	1329	1614	1858	2143
803 E	1047 B	1332 F ob	1617 *1802	1902	2146
806	1050	1335	1620	1905	2149
809	.1053	1338	1623	1908	2152
812 E	1056 B	1341 F	1626 A	1911	2155
815	1059	1344	1629	1914	2158
818 E	1103 B	1347 F ob	1632 *1817	1917	2202
821	1106	1350	1635	1920	2205
824	1109	1353	1638	1923	2208
827 C	1112 B	1356 D	1641 Upg	1926	2211
830	1115	1359	1644	1929	2214
833	1118	1403	1647	1932	2217
836 C	1121 B	1406 D	1650 Upg	1935	2220
839	1124	1409	1653	1938	2223
842	1127	1412	1656	1941	2405

SIMS

	1	2	3	4
0645	D		D	
0715		E		E
0810	C		C	
0840		A		A
0935	F		F	
1005		D		D
1100	B		U	
1130		C		C
1225	E		E	
1255		A		A
1350	F		F	
1420		D		D
1515	B		C	
1545		M		A
1640	A		A	
1710		U		U
1805	B		B	
1835		B		B

Sunrise: 0703
Sunset : 1829

need IP for Dr. Chou

SOF
0549 E-Collins
0927 King
1305 Wagner
1643 Hamilton
2022 Close

RSU
0639 D/D
0932 C/D
1225 F/A
1518 B/A
1811 Close

Dispatcher
0504 Open :
2022 Close:

Snack Bar
0549 C/C
1137 B/B
1726 Close

Total sorties: 81   Cap: 20/3

	Local	OBL	OBR	XC	NITE	Sims
PIT	53	6	6	0	0	32
UPGRADE	5	0	0	0	0	3
SUPPORT	10	0	0	0	1	1

							SIMS 1	2	3	4
0601		0845 E	1130 C	1415 B	1659 3305	1944	0630 D		D	
0604		0848	1133	1418	1703	1947	0700	D		D
0607		0851 A	1136 C	1421 B	1706 B	1950	0755 C		C	
0610		0854	1139	1424	1709	1953	0825	E		A
0613		0857	1142	1427	1712	1956	0920 F		F	
0616		0901 A	1145 C ob	1430 *1615	1715 B	1959	0950	D		D
0619		0904	1148	1433	1718	2003	1045 B		B	
0622		0907 SE	1151 DVOrt	1436 B	1721 B	2006	1115	C		C
0625		0910	1154	1439	1724	2009	1210 C		U	
0628		0913	1157	1442	1727	2012	1240	E		E
0631		0916 F	1201 Uog	1445 B	1730 B	2015	1335 A		F	
0634		0919	1204	1448	1733	2018	1405	F		B
0637		0922 F	1207 Uog	1451 C	1736	2021	1500 C		C	
0640		0925	1210	1454	1739	2024	1530	A		A
0643		0928	1213	1457	1742	2027	1625 U		A	
0646		0931 F	1216 E	1501 C	1745	2030	1655	B		B
0649		0934	1219	1504	1748	2033	1750			
0652		0937	1222	1507	1751	2036	1820			
0655 D		0940 F	1225 E	1510 C	1754	2039				
0658		0943	1228	1513	1757	2042				
0702 D		0946 D	1231 E	1516 C	1801	2045	Sunrise: 0702			
0705		0949	1234	1519	1804	2048	Sunset : 1830			
0708		0952	1237	1522	1807	2051	IP for DVort			
0711 D		0955 D	1240 E	1525 C	1810	2054				
0714		0958	1243	1528	1813	2057				
0717 D		1002 D	1246 A ob	1531 *1716	1816	2101				
0720		1005	1249	1534	1819	2104				
0723		1008	1252	1537	1822	2107				
0726 Dot		1011 D	1255 A	1540 A.ct	1825	2110	SOF			
0729		1014	1258	1543	1828	2113	0602 Mever			
0732 ATCSE		1017 D	1302 A	1546 A	1831	2116	1046 Ogle			
0735		1020	1305	1549	1834	2119	1530 B-Collins			
0738		1023	1308	1552	1837	2122				
0741 C		1026 D	1311 F	1555 A	1840	2125	2015 Close			
0744		1029	1314	1558	1843	2128				
0747		1032	1317	1602	1846	2131	RSU			
0750 C		1035 B	1320 F	1605 Chown	1849	2134	0652 C/D			
0753		1038	1323	1608	1852	2137	0957 E/D			
0756 C		1041 B	1326 F ob	1611 *1755	1855	2140	1303 B/A			
0759		1044	1329	1614	1858	2143	1609 F/A			
0803		1047	1332	1617	1902	2146	1915 Close			
0806 C		1050 B	1335 F	1620 Rowc	1905	2149				
0809		1053	1338	1623	1908	2152	Dispatcher			
0812 E		1056 B	1341 F ob	1626 *1811	1911	2155	0517 Open :			
0815		1059	1344	1629	1914	2158	2015 Close:			
0818		1103	1347	1632	1917	2202				
0821 E		1106 C	1350 F	1635 Uog	1920	2205	Snack Bar			
0824		1109	1353	1638	1923	2208	0602 C/C			
0827 E		1112 C	1356 SE	1641 Dot	1926	2211	1216 B/B			
0830		1115	1359	1644	1929	2214	1830 Close			
0833		1118	1403	1647	1932	2217				
0836 E		1121 C ob	1406 *1550	1650 ATCSE	1935	2220				
0839		1124	1409	1653	1938	2223				
0842		1127	1412	1656	1941	2386				

Total sorties: 81   Cap: 21/3   ***** PT *****

	Local	OBL	OBR	XC	NITE	Sims	
PIT	58	5	5	0	0	30	D: 1311 - 1411
UPGRADE	3	0	0	0	0	2	E: 1525 - 1625
SUPPORT	10	0	0	0	0	0	

ATC 206 B   Wed 26 Feb 86 G   -109-   559 FTS Billygoats

										1	2	3	4
0601	0845	Dot	1130	C	1415	Uog	1659		1944	0600 D		D	
0604	0848		1133		1418		1703		1947	0630 \	D		D
0607	0851	AtcSE	1136	C	1421	Upg	1706		1950	0725 C		C	
0610	0854		1139		1424		1709		1953	0755	C		E
0613	0857		1142		1427		1712		1956	0850 E		E	
0616	0901	AtcSE	1145	C	1430	A	1715		1959	0920	U		D
0619	0904		1148		1433		1718		2003	1015 D		A	
0622	0907		1151		1436		1721		2006	1045	A		C
0625	0910	3305	1154	F ob	1439	*1624	1724		2009	1140 C		C	
0628	0913		1157		1442		1727		2012	1210	F		F
0631	0916	Uog	1201	F	1445	A. ct	1730		2015	1305 E		E	
0634	0919		1204		1448		1733		2018	1335	B		B
0637	0922		1207		1451		1736		2021	1430 U		A	
0640	0925	Uog	1210	F	1454	F	1739		2024	1500	A		F
0643	0928		1213		1457		1742		2027	1555 F		B	
0646	0931		1216		1501		1745		2030	1625	B		B
0649	0934	D	1219	E	1504	F	1748		2033	1720 M			
0652	0937		1222		1507		1751		2036	1750			
0655	0940	D	1225	E	1510	4ship	1754		2039				
0658	0943		1228		1513		1757		2042				
0702	0946		1231		1516		1801		2045				
0705	0949	D	1234	E	1519	4ship	1804		2048	Sunrise: 0701			
0708	0952		1237		1522		1807		2051	Sunset : 1831			
0711	0955		1240		1525		1810		2054				
0714 D	0958	D	1243	E	1528	4ship	1813		2057				
0717	1002		1246		1531		1816		2101				
0720	1005		1249		1534		1819		2104				
0723 D	1008	D	1252	B	1537	4ship	1822		2107				
0726	1011		1255		1540		1825		2110	SOF			
0729 D	1014	D	1258	B	1543	Chwob	1828	*2013	2113	0614 Watson			
0732	1017		1302		1546		1831		2116	1035 Huse			
0735	1020		1305		1549		1834		2119	1456 England			
0738 D	1023	D	1308	B	1552	Dotob	1837	*2022	2122				
0741	1026		1311		1555		1840		2125	1917 Close			
0744	1029		1314		1558		1843		2128				
0747 C	1032	D	1317	B	1602	B	1846		2131	RSU			
0750	1035		1320		1605		1849		2134	0704 D/D			
0753 C	1038	SE	1323	SE	1608	B	1852		2137	0950 C/D			
0756	1041		1326		1611		1855		2140	1237 A/A			
0759	1044		1329		1614		1858		2143	1524 B/A			
0803 C	1047	C ob	1332	*1517	1617	B	1902		2146	1811 Close			
0806	1050		1335		1620		1905		2149				
0809	1053		1338		1623		1908		2152	Dispatcher			
0812 E	1056	A	1341	3305	1626	B	1911		2155	0529 Open :			
0815	1059		1344		1629		1914		2158	1917 Close:			
0818 E	1103	A	1347	F ob	1632	*1817	1917		2202				
0821	1106		1350		1635		1920		2205	Snack Bar			
0824	1109		1353		1638		1923		2208	0614 C/C			
0827 E	1112	A ob	1356	*1541	1641		1926		2211	1150 B/B			
0830	1115		1359		1644		1929		2214	1726 Close			
0833	1118		1403		1647		1932		2217				
0836 E	1121	C	1406	Dot	1650		1935		2220	** Annual spin *			
0839	1124		1409		1653		1938		2223	** seminar **			
0842	1127		1412		1656		1941		2355	* 0800 and 1500			

Total sorties: 71   Cao: 20/3   ***** PT *****

	Local	OBL	OBR	XC	NITE	Sims	A: 1730 – 1830
PIT	42	4	4	0	0	30	B: 0937 – 1037
UPGRADE	4	0	0	0	0	2	C: 1617 – 1717
SUPPORT	13	2	2	0	0	1	D: 1317 – 1417

						SIMS	1	2	3	4
0601	0845 A	1130 E	1415 D	1659	1944	0700	D		D	
0604	0848	1133	1418	1703	1947	0730		D		D
0607	0851 Uog	1136 C xc	1421 *****	1706 *****	1950 *****	*****0825	E		E	
(●)	0854	1139	1424	1709	1953	0855		E		A
0613	0857	1142	1427	1712	1956	0950		X		B
0616	0901 Uog	1145 E	1430 D	1715	1959	1020		D		D
0619	0904	1148	1433	1718	2003	1115	E			D
0622	0907 B	1151 E	1436 D	1721	2006	1145	S			S
0625	0910	1154	1439	1724	2009	1240	S		B	
0628	0913	1157	1442	1727	2012	1310	S			S
0631	0916 B	1201 A xc	1445 *****	1730 *****	2015 *****	*****1405	S		A	
0634	0919	1204	1448	1733	2018	1435	D			X
0637	0922 B	1207 B	1451 D	1736	2021	1530	F		C	
0640	0925	1210	1454	1739	2024	1600		M		B
0643	0928	1213	1457	1742	2027	1655	B		B	
0646	0931 SE	1216 B	1501 D	1745	2030	1725				
0649	0934	1219	1504	1748	2033	___				
0652	0937	1222	1507	1751	2036					
0655	0940 D	1225 C xc	1510 *****	1754 *****	2039 *****					
0658	0943	1228	1513	1757	2042					
0702	0946 D	1231 B	1516 F	1801	2045					
0705	0949	1234	1519	1804	2048	Sunrise: 0700
0708	0952	1237	1522	1807	2051	Sunset : 1831
0711	0955 F ob	1240 *1425	1525 F	1810	2054					
0714	0958	1243	1528	1813	2057					
0717 D	1002 D	1246 C xc	1531 *****	1816 *****	2101 *****					
0720	1005	1249	1534	1819	2104					
0723	1008	1252	1537	1822	2107					
0726 D	1011 D	1255 A	1540 A xc	1825 *****	2110 *****	SOF				
0729	1014	1258	1543	1828	2113	0617 King
0732 D	1017 D	1302 C xc	1546 *****	1831 *****	2116 *****	1043 Wagner
0735	1020	1305	1549	1834	2119	1509 Smith
0738	1023	1308	1552	1837	2122					
0741 D	1026 F ob	1311 *1455	1555 A xc	1840 *****	2125 *****	1935 Close
0744	1029	1314	1558	1843	2128					
0747	1032	1317	1602	1846	2131	RSU				
0750 E	1035 D	1320 C xc	1605 *****	1849 *****	2134 *****	0707 D/D
0753	1038	1323	1608	1852	2137	0959 E/D
0756 E	1041 D	1326 Uog	1611 A xc	1855 *****	2140 *****	1251 A/A
0759	1044	1329	1614	1858	2143	1543 F/A
0803	1047	1332	1617	1902	2146	1835 Close
0806 E	1050 D	1335 C xc	1620 *****	1905 *****	2149 *****					
0809	1053	1338	1623	1908	2152	Dispatcher
0812 E	1056 F	1341 Uog	1626 B	1911	2155	0532 Open :
0815	1059	1344	1629	1914	2158	1935 Close:
0818	1103	1347	1632	1917	2202					
0821 ATCSE	1106 F	1350 E.ct	1635 B	1920	2205	Snack Bar
0824	1109	1353	1638	1923	2208	0617 C/C
0827 Dot	1112 E	1356 C xc	1641 *****	1926 *****	2211 *****	1203 B/B
0830	1115	1359	1644	1929	2214	1750 Close
0833	1118	1403	1647	1932	2217					
0836 3305	1121 E	1406 D	1650 B	1935	2220					
0839	1124	1409	1653	1938	2223					
0842	1127	1412	1656	1941	2314					

Total sorties: 66   Cap: 21/3   ***** PT *****

	Local	OBL	OBR	XC	NITE	Sims	C: 1641 – 1741
PIT	42	2	2	11	0	21	E: 1436 – 1536
UPGRADE	4	0	0	0	0	2	F: 0610 – 0710
SUPPORT	5	0	0	0	0	7	

APPENDIX B

This appendix contains the contracts submitted by the unit schedulers to the squadron scheduler for the week. Each contract requests tasks by type for every day of the week. The requests are based upon instructor availability, duty day limitations, and student training requirements. These contracts are used by the squadron scheduler to determine total task assignments as well as task string assignments to individual units.

WEEKLY SCHEDULING REQUEST

INSTRUCTOR PILOTS	MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY			FLIGHT
SMITH	1	OFF	1	1	OFF	1	1	Smith	1	1	OFF	1	OFF	SOF	SOF				**A**
HAVERKAMP	1	1	1	1	1	1	1	O	1	1	O	1	1	XC					
BURGSTAHLER	1	1	1	1	1	1	1	1	1	1	Box	1		XC					**WEEK OF**
ERICHSEN	1	1	1	1	1	1	1	1	1	1	1	1		XC					**24-28 FEB**
																			X-C REMARKS
																			4 X-C THIS
GUEST HELP																			
KENAGY	1			1			1			1			1						
SCHMELL		1			1			1			1			1					
IPs AVAILABLE	5	4	4	5	4	4	5	3	4	5	2	4	1	1	0				
TEAM CAPABILITY								1			1								
NUMBER OF TRAINEES	8			8			8			8			8						
X ACFT INCREMENT	.74			.74			.74			.74			.74						
ATTRITION FACTOR	.769			.769			.769			.769			.769						**TOTALS**
• AIRCRAFT REQUIREMENT	7.70			7.70			7.70			7.70			7.70						39
X SIM INCREMENT	.44			.45			.44			.45			.44						
• SIMULATOR REQUIREMENT	3.52			3.6			3.52			3.6			3.52						18
T-1 LOCAL AIRCRAFT	3/2	3/2	1	3/2	3/2	1	2	2	2	2	1		1	1	0				23
T-1 OUT AND BACKS	1			1			1			1									8
T-1 CROSS COUNTRIES														4					16
T-3 AIRCRAFT							1			1									2
T-3 REMARKS						T-3 CHECK PREPS FOR CAPT HAVERKAMP												

SIMULATORS	MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY			TOTAL
SIMULATORS REQUESTED	3/2	1	1	3/2	1	1	2	1	2	2	1								18
PHYSICAL TRAINING																			

REMARKS

SORTIES	ACFT	SIMS
REQUESTED	47	20
- REQUIRED	39	18
• ☒ GAIN / ☐ LOSS 0.21	8	2
ESTIMATED POSITION	2.15	3.4

SIGNATURE OF FLIGHT COMMANDER
Jn. R. Smith

SIGNATURE OF SECTION COMMANDER
Pxx — D. Huse

RANDOLPH TW FORM 44 (00)   PREVIOUS EDITION IS OBSOLETE   HQ ATC, RANDOLPH AFB TX

INSTRUCTOR PILOTS	MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY			FLIGHT
Collins	-	1	-	T	1	class		mtg	sof	S		1		1	-				B
Goldsmith	1	1	Pop	1	1	1	1	1	class		1	PSU	1	1	1				
Brown	1	1	1	1	1	RSU	1	1	1	P	r	1	1	1	1				WEEK OF
Richard	1	1	1	1	1	class	1	1	1	I	1	clent							
Call	1	M1	1		Sos	1		1	1	N	1	1	Sm						24 Feb
Gray	1	T	1	1	Sm	1	1	RSU	1	N	1	1	1	1	1				X-C REMARKS
Willis	1	1	1	1	1	-	1	1	-	S E M I N A R	1	1	1	1					

IPs AVAILABLE	-	6	6	6	5	4	6	5	5	-	6	5					
TEAM CAPABILITY			1			1			1			1			1		
NUMBER OF TRAINEES	11			11			11			11			11				
X ACFT INCREMENT	.69			.67			.68			.68			.68				
÷ ATTRITION FACTOR	.769			769			.769			.769			.769				TOTALS
AIRCRAFT REQUIREMENT	10			10			10			10			9				49
SIM INCREMENT	.45			.46			.46			.46			.46				
SIMULATOR REQUIREMENT	5			5			5			5			5				25
T-1 LOCAL AIRCRAFT	4	3	4	4	4	4	4	4		4	4	4	8				52 49
T-1 OUT AND BACKS																	
T-1 CROSS COUNTRIES																	
T-3 AIRCRAFT		ORT 2															ORT 2

T-3 REMARKS: 1 'POP' sim

SIMULATORS	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY		SATURDAY		TOTAL
SIMULATORS REQUESTED	2	2	2	1	1	2	2	2	2	2			20 23
PHYSICAL TRAINING													

REMARKS

Ordering 2 ORTS on Monday

Planning on 5 team sims (10 Trainees) in the 120xf blk

Request light turn on Monday to give adequate time for letho seminar and a test first period

Planning on flying a 'POP' sim 3rd period Monday

	SORTIES	ACFT	SIMS
REQUESTED		52	27
- REQUIRED		49	25
		49	25
☑ GAIN ☐ LOSS		+3	+4
ESTIMATED POSITION		1.0	1.0

SIGNATURE OF FLIGHT COMMANDER

SIGNATURE OF SECTION COMMANDER

WEEKLY SCHEDULING REQUEST

INSTRUCTOR PILOTS	MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY			FLIGHT
KING	O	1	O	1	SoF	1	MTG O	O	1	O	1	O	SoF	O	1				86-11
HARRIS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				C
TRUE	1	1	1	1	1	1	RSU 1	1	1	1	1	1	1	1	1				WEEK OF
LOVELADY	1	1	1	RSU	1	1	1	1	1	RSU	1	1	1	1	1				24-28
CURRAN	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				FEB
LYDA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
HAY	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				X-C REMARKS
																			(7) 4 HOP
																			X-C'S
																			SATURDAY
																			RETURN

GUEST HELP																			
GUEST + I'S	O	1	1	O	1	1	O	1	1	O	1	1	O	1	1			

	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY		SATURDAY		TOTALS
IPs AVAILABLE	6	8 7	7 6	6 6	7 7	6 7	6	6 7	9				
TEAM CAPABILITY	1	1 0	1	O O	O 2	2 O	1	1 O	O O				
NUMBER OF TRAINEES	13		13		13		13		13				
X ACFT INCREMENT	.77		.77		.77		.77		.76				
+ ATTRITION FACTOR	.764		.764		.764		.769		.768				TOTALS
AIRCRAFT REQUIREMENT	13.02		13.02		13.02		13.02		12.86				65
SIM INCREMENT	.44		.43		.44		.43		.44				
SIMULATOR REQUIREMENT	5.72		5.59		5.72		5.59		5.72				29
T-1 LOCAL AIRCRAFT	Y 2	1	2 1	1	3 4	5	3 4	O	O O	O			27
T-1 OUT AND BACKS	4		3		2		1						20
T-1 CROSS COUNTRIES									7				28
T-3 AIRCRAFT													

T-3 REMARKS

SIMULATORS	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY		SATURDAY		TOTAL
SIMULATORS REQUESTED	2 3	2	3 2	2	3 3	2	3 3	O	O O	1			29
PHYSICAL TRAINING													

REMARKS

SORTIES	ACFT	SIMS
REQUESTED	75	29
– REQUIRED	65	29
☑ GAIN ☐ LOSS	.77	Ø
ESTIMATED POSITION	+.6	+2.6

SIGNATURE OF FLIGHT COMMANDER

SIGNATURE OF SECTION COMMANDER
Byron D. Huse

WEEKLY SCHEDULING REQUEST

INSTRUCTOR PILOTS	MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY			FLIGHT
Meyer	I	I	I				I	MTG	I	I	I	OFF	I	I	I				**D**
Ward	T	D	Y	→															
Embrey	RSU	I	I	RSU	I	I	I	I	I	RSU	I	RSU	I	I	I				WEEK OF
Merkle	I	I		I	I		I	I		I	I		I	I					
Samels	I	I		I	I	I	H	H	G's	I	I		I	I					24 Feb
Hartman	I	I		I	I	I	I	I	I	I	I		I	I					
Ridnour	I	I	I	I	I	I	I	I	I	I	I		I	I					X-C REMARKS
McMurry	I	I	I	I	I	I	I	I	I	I	I		I	I					
GUEST HELP																			
Cliett		I						I			I			I					
Cunningham		I			I			I			I			I					
Duke		I			I			I			I								

	MON			TUE			WED			THU			FRI			SAT			TOTALS
IPs AVAILABLE	6	8	9	6	9	8	6	7	7	6	9	I	6	8	8				
TEAM CAPABILITY	1			1			1			2			2	2	1				
NUMBER OF TRAINEES	15			15			15			15			15						
X ACFT INCREMENT	.77			.77			.77			.77			.77						
+ ATTRITION FACTOR	.769			.769			.769			.769			.769						
= AIRCRAFT REQUIREMENT	15			15			15			15			15						**75**
X SIM INCREMENT	.47			.47			.47			.47			.47						
= SIMULATOR REQUIREMENT	7			7			7			7			7						**35**
T-1 LOCAL AIRCRAFT	3	7	5	3	7	7	3	5	6	4	8		4	8					**70**
T-1 OUT AND BACKS																			
T-1 CROSS COUNTRIES																			
T-3 AIRCRAFT		2*																	

T-3 REMARKS: *ORTS

SIMULATORS	MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY			TOTAL
SIMULATORS REQUESTED	4	2	2	4	2	2	4	2	2	4	2		4	2					**36**
PHYSICAL TRAINING																			

REMARKS

SORTIES	ACFT	SIMS
REQUESTED	70	36
− REQUIRED	75	35
= GAIN/LOSS	−0.2	+0.1
ESTIMATED POSITION	+0.3	+1.0

SIGNATURE OF FLIGHT COMMANDER

SIGNATURE OF SECTION COMMANDER

INSTRUCTOR PILOTS	MONDAY		TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY		FLIGHT
Collins			—SOF—							LV								E
Cannon	-ins																	
KARMANN	- RSU -						-RQ-					-RSU						WEEK OF 24-28 Feb
O'Brien																		
Richardson																		
Hoagcamp																		X-C REMARKS
Wojkowski																		
GUEST HELP																	
Lt Col NEGLEY																	
CAPT BERGEZ				1						1			1				
CAPT Bruning	1						1										
CAPT Willie																	
CAPT Hughes	1	1		1			1			1			1				
IPs AVAILABLE	7	7	7	6	6	6	7	6	6	7	7	6	7	6	6		
TEAM CAPABILITY	—	0	—	—	0	—	—	0	—	—	0	—	—	0	—		
NUMBER OF TRAINEES	8			8			8			8			8				
X ACFT INCREMENT	.68			.68			.68			.69			.68				
ATTRITION FACTOR	.769			.769			.769			.769			.769				**TOTALS**
AIRCRAFT REQUIREMENT	7.1			7.1			7.1			7.1			7.1				35.5
X SIM INCREMENT	.47			.47			.47			.47			.47				
SIMULATOR REQUIREMENT	3.76			3.76			3.76			3.76			3.76				18.8
T-1 LOCAL AIRCRAFT	4	3		4	4		4	4		4	4		4	4			41 [43*]
T-1 OUT AND BACKS																	0
T-1 CROSS COUNTRIES																	0
T-3 AIRCRAFT		2 ORT											1				2 ORT / 1

T-3 REMARKS

SIMULATORS	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY		SATURDAY		TOTAL
SIMULATORS REQUESTED	3	3	3	3	3	3	3	3	3	2			29

PHYSICAL TRAINING

REMARKS

* orientation AFA

SORTIES	ACFT	SIMS
REQUESTED	41	29
— REQUIRED	35.5	18.8
☑ GAIN ☐ LOSS	.8	2.7
ESTIMATED POSITION	2.3	3.7

SIGNATURE OF FLIGHT COMMANDER   _James W. Collins_

SIGNATURE OF SECTION COMMANDER

WEEKLY SCHEDULING REQUEST

INSTRUCTOR PILOTS	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	FLIGHT
HAMILTON		3015				Janet	**F**
ZIMMERMAN		RSU					
RICE	RSU			S			WEEK OF
BOTING				P			
REAGAN	ORT			I N			24-28
NICHOLS							FEB
MILLER				S E M			X-C REMARKS
				I N A R			

GUEST HELP							
WINKER							
BURKE							
WILLIAM							

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	TOTALS
IPs AVAILABLE	7 7 6 8	7 6	9 9 9	9 8 8	7 7		
TEAM CAPABILITY	2 2	2 2		3 2	2 2		
NUMBER OF TRAINEES	9	8	7	6	5		
X ACFT INCREMENT	1.11	1.11	1.11	1.11	1.11		
÷ ATTRITION FACTOR	.769	.769	.769	.769	.769		
• AIRCRAFT REQUIREMENT	12	11	10	9	7		49
X SIM INCREMENT	.44	.43	.44	.43	.44		
• SIMULATOR REQUIREMENT	4	3	3	3	2		15
T-1 LOCAL AIRCRAFT	4 4	4 4	4 4	2 2	2 2		36
T-1 OUT AND BACKS	1	2	2	2	2		9
T-1 CROSS COUNTRIES							
T-3 AIRCRAFT	2*	1					3 LCLs
T-3 REMARKS	*2 ORTS	#1 NIGHT TUES					

SIMULATORS	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	TOTAL
SIMULATORS REQUESTED	2 2	2 2	1 1	2 2			20
PHYSICAL TRAINING							

REMARKS

SORTIES	ACFT	SIMS
REQUESTED	54	20
– REQUIRED	49	15
• ☑ GAIN ☐ LOSS	+5	+.6
ESTIMATED POSITION	+4.5	+.0

SIGNATURE OF FLIGHT COMMANDER
Mark W. Hammet

SIGNATURE OF SECTION COMMANDER

APPENDIX C

This appendix contains the student preference lists for units A, B, and C. The lists display each student's name on the right and a listing of instructors to the right. The assigned instructor is circled. The unit scheduler uses the list to determine proper matchings of students the the instructors assigned by the squadron scheduler.

COURSE FV5AAO CLASS 8813 SECTION: O
INSTRUCTOR NAMES AND FLIGHT CATEGORIES LISTED IN ORDER OF OCCURENCE (LATEST FIRST)

STUDENT						OVER TWELVE
CLARDY WI	HARTMAN 8 -F	MEYER FRA -IC	EMBREY ST -CI	CLIATT CH -C	MEYER FRA -C	
DE LA PEN	MERKLE WI -FCI	BROOKS RO -I	KARMANN D -CF	MEYER FRA -C		
DEDET ROY	MEYER FRA -FCI	MCMURRY J -C	WARD SCOT -IFC			
HANSEN DU	EMBREY ST -C	HOGANCAMP -F	MERKLE WI -C	REDNOUR R -CF	SAMELS OL -CFI	BROOKS RO -I
HUGENBERG	SAMELS OL -FIC	MCMURRY J -CI	WAGNER RO -I	MERKLE WI -C		
JENSEN DA	SAMELS OL -F	MEYER FRA -C	MCMURRY J -I	WARD SCOT -ICF	CLIATT CH -C	
KIRNAK MI	EMBREY ST -C	REDNOUR R -F	MERKLE WI -ICF	MEYER FRA -I	CLIATT CH -I	
KNOX DAVI	HARTMAN S -CF	LUKE THOM -I	MCMURRY J -FCI	SAMELS OL -F	REDNOUR R -C	WARD SCOT -C
LEIMER JE	HARTMAN S -FIC	MERKLE WI -C	SHAMBLIN -F			
MOHAMMED	HARTMAN S -ICF	MEYER FRA -C	MCMURRY J -C			
MURPHY SA	MEYER FRA -I	EMBREY ST -ICF	REDNOUR R -I	HARTMAN S -F	CLIATT CH -C	CUNNINGHA -C
OSTROSKI	CUNNINGHA -CIF	EMBREY ST -FI	SAMELS OL -C	WAGNER RO -C		
PRYOR PAU	SAMELS OL -IC	RICHARDSO -F	CLIATT CH -C	HARTMAN S -I		
TANK DANI	REDNOUR R -FIC	HARTMAN S -F	LUKE THOM -C	MEYER FRA -F	SAMELS OL -C	CLIATT CH -F
WHITNEY R	MERKLE WI -FC	REDNOUR R -FCI	MCMURRY J -I	MEYER FRA -C		

-120-

charged P is circled

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(00;11;26)

COURSE FV5AAO CLASS 8814 SECTION: O

STUDENT	INSTRUCTOR NAMES AND FLIGHT CATEGORIES LISTED IN ORDER OF OCCURENCE (LATEST FIRST)			OVER TWELVE STUDENT
BONDS JAM	GOLDSMITH -IC	WILLIS DA -C	CALL WILL -C	
BORN RICH	BRAY TOM -C	BILLIS JU -C	BRAY KENN -IC	BEARD MIK -C
CRAVEN RA	GRAY TOM -C	NEILAN MI -C		
HOADLEY W	BRAY TOM -I	WILLIS DA -C	CALL WILL -C	GOLDSMITH -C
MACDOUGAL	SHAMBLIN -C	COLLINS J -C	COLLINS J -C	GOLDSMITH -C
CONRAD JO	BRAY KENN -C	BEARD MIK -I	GOLDSMITH -C	RICHARD J -C
PARKHURST	WILLIS DA -IFC	BRAY KENN -C	WILMOT DA -C	CALL WILL -C
RANDOLPH	BRAY KENN -C	CALL WILL -CI	NEILAN MI -C	
SCHMEI 1?	GRAY TOM -IC	GOLDSMITH -I	BEARD MIK -C	
SMITH	RICHARD J -IC	BEARD MIK -C	CALL WILL -C	
VIGNAROL	BILLIS JU -C	BRAY KENN -FIC		

Assigned IP is circled

PAGE 5

(00111126)

COURSE FV5AAO CLASS 8618 SECTION: O
(INSTRUCTOR NAMES AND FLIGHT CATEGORIES LISTED IN ORDER OF OCCURENCE (LATEST FIRST)
STUDENT

MERLONG C   BERGER ST -C

LUNDQUIST   OBRIEN JE -O   (USPICH)   (TARROW)

MATTISON   KARMANN D -C   BRUNING S -C

FAZZEI RO   COLLINS J -C   RICHARDSON -C

PEPPER DA   HOGANCAMP -C

PRICE JEF   CANNON RO -C

REITMEIST   OBRIEN JE -C   CANNON RO -C   (ODRIEN)

STEWART U   COLLINS J -C   RACKOWSKI -C   (WACKOWSKI)

(23,58(37))

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PCN UE038DL01

APPENDIX D

This appendix contains the programs used to solve the Level 1 and Level 2 problems. In it we briefly explain how to structure input data, run the programs. Both programs are in Fortran 77 and were compiled and executed on an IBM PC/XT.

D.1 - LEVEL 1 PROGRAM

Both the Level 1 and Level 2 use two input files DATA.MST and SCHED.MST. DATA.MST is the file containing the master data for the programs. It contains the following five items: 1) the total number of tasks in the schedule, 2) the number of instructors available for the day, 3) the number of local aircraft tasks, 4) the number of simulator tasks, and 5) the number of cross-country/out & back tasks. Each entry is a 3 digit number and occupies a separate line. SCHED.MST contains the start times for all tasks in the daily schedule. The order of entry is 1) all local aircraft tasks, 2) simulator tasks, 3) cross country tasks, 4) other tasks. Task start times need not be in order within a block but the block order must be maintained (e.g. all simulator tasks must be in block 2). Entries are in the 4 digit 24 hour clock (e.g. 1315 for 1:15 p.m.) and each entry occupies a separate line. Due to the variable nature of the "other" tasks both the start and end times for these tasks are required. Enter them as an 8 digit number (e.g. 10061421 for a task starting at 10:06 a.m. and ending at 2:21 p.m.). Examples of DATA.MST and

SCHED.MST are included with the Level 1 program. With this input data the Level 1 program will run with the prompt DLWTH15. Output will consist of an infeasibility check and task strings similar to those in figure 5.1. Also, an output file STRTEND is created by the program which contains the start and end times of all tasks in minutes.

data.wed
099
035
057
030
005

sched.wed
0655
0702
0711
0717
0741
0750
0756
0806
0812
0821
0827
0836
0845
0851
0901
0916
0922
0931
0940
0946
0955
1002
1011
1017
1026
1035
1041
1050
1056
1106
1212
1130
1136
1216
1125
1231
1240
1255
1302
1311
1320
1325
1350
1415
1421

1436
1445
1451
1501
1510
1516
1525
1546
1555
1706
1715
1721
0600
0600
0630
0630
0725
0725
0755
0755
0850
0850
0920
0920
1015
1015
1045
1045
1140
1210
1210
1305
1305
1335
1335
1430
1430
1500
1500
1555
1625
1625
1121
1145
1246
1326
1341
05581046
10311530
15152015
06371000
09451313
12581620
16001915

```fortran
C      ***** FINDING THE MINIMUM # OF INSTRUCTORS*****
C
       PROGRAM DILWORTH
       REAL*8 TCOST
       INTEGER C(1800),X(1800),U(1800),RC(1800),B(200)
       INTEGER STARTN(1800),ENDN(1800),CAP(1800)
       INTEGER I1(200),I2(200),FOU(200),NXTOU(1800),FIN(200)
       INTEGER NXTIN(1800),I7(1800),LARGE,TOT,COUNT
       INTEGER STK(1800),STKH(1800),STKM(1800)
       INTEGER ETKH(1800),ETKM(1800),ETK(1800)
       LOGICAL*2 L1(200),L2(200),REPEAT
       COMMON /ARRAYS/STARTN/ARRAYE/ENDN/ARRAYU/U/ARRAYX/X
       COMMON /ARRAY9/RC/ARRAYB/B/BLK1/I1/BLK2/I2/BLK3/FOU
       COMMON /BLK4/NXTOU/BLK5/FIN/BLK6/NXTIN/BLK7/I7
       COMMON /L/N,NA,LARGE
       COMMON /BLK8/L1
       COMMON /BLK9/L2/BLKR/REPEAT
C
C      ***** INPUTTING THE DATA *******
C
       OPEN(5,FILE = 'DUMP')
       OPEN(33,FILE = 'DATA.MST')
       READ(33,10)NT
10     FORMAT(I3)
       READ(33,11)NIP
11     FORMAT(I3)
       READ(33,12)NACFT
12     FORMAT(I3)
       READ(33,17)NSIMS
17     FORMAT(I3)
       READ(33,18)NOB
18     FORMAT(I3)
       CLOSE(33)
C
       OPEN(15,FILE = 'SCHED.MST')
       DO 15 I = 1,NACFT
        READ(15,14)STKH(I),STKM(I)
14      FORMAT(2I2)
        STK(I) = STKH(I)*60 + STKM(I)-60
        ETK(I) = STK(I) + 180
15     CONTINUE
C
       DO 20 I = NACFT + 1,NACFT + NSIMS
        READ(15,19)STKH(I),STKM(I)
19      FORMAT(2I2)
        STK(I) = STKH(I)*60 + STKM(I)-30
        ETK(I) = STK(I) + 135
20     CONTINUE
C
       DO 24 I = NACFT + NSIMS + 1,NACFT + NSIMS + NOB
        READ(15,21)STKH(I),STKM(I)
21      FORMAT(2I2)
        STK(I) = 0000
        ETK(I) = 1400
```

```fortran
24    CONTINUE
C
      DO 23 I = NACFT + NSIMS + NOB + 1,NT
       READ(15,22)STKH(I),STKM(I),ETKH(I),ETKM(I)
22     FORMAT(4I2)
      STK(I) = STKH(I)*60 + STKM(I)
      ETK(I) = ETKH(I)*60 + ETKM(I)
23    CONTINUE
      CLOSE(15)
C
C    ***** OUTPUTTING START AND END TIMES IN MINUTES *****
C
      OPEN(90,FILE = 'STRTEND')
      DO 27 I = 1,NT
       WRITE(90,25) STK(I),ETK(I)
25     FORMAT(2I5)
27    CONTINUE
      CLOSE(90)
C
C    ***** CREATING DUMMY NODES *******
C
      DO 35 I = 1,NT
       STK(NT + I) = STK(I)
       ETK(NT + I) = ETK(I)
35    CONTINUE
C
C    ***** GENERATING NETWORK ARCS *****
C
      J = 0
      N = 2*NT + 2
      DO 40 I = 1,NT
       DO 45 L = NT + 1,2*NT
        IF((STK(L).LT.ETK(I)).OR.(STK(L).GT.ETK(I) + 180))GOTO 45
        J = J + 1
        STARTN(J) = I
        ENDN(J) = L
        U(J) = 1
        C(J) = 0
45     CONTINUE
40    CONTINUE
C
C    ***** GENERATING ARCS FROM s AND t *****
C
      DO 50 I = J + 1,J + NT
       STARTN(I) = N-1
       ENDN(I) = I-J
       U(I) = 1
       C(I) = 0
50    CONTINUE
C
      DO 55 I = J + NT + 1,J + 2*NT
       STARTN(I) = I-J
       ENDN(I) = N
       U(I) = 1
```

```
        C(I) = 0
55    CONTINUE
C
C     ***** CREATING s-t ARC *****
C
      NA = J + 2*NT + 1
      STARTN(NA) = N
      ENDN(NA) = N-1
      U(NA) = 1000000
      C(NA) = -1
C
C     ***** PLUGGING INTO RELAX *****
C
      LARGE = 20000000
      CALL INIDAT
      REPEAT = .FALSE.
      DO 60 I = 1,NA
       RC(I) = C(I)
60    CONTINUE
C
      DO 65 I = 1,N
       B(I) = 0
65    CONTINUE
C
      CALL RELAX
C
C     ***** CALCULATING NUMBER OF INSTRUCTORS *****
C
      MIN = NT-X(NA)
      IF(MIN.GT.NIP) THEN
       WRITE(*,67)NIP
67     FORMAT('0','NO FEASIBLE SOL. EXISTS FOR',I4,' INSTRUCTORS')
       WRITE(*,68)MIN
68      FORMAT(' ','THE LOWER BOUND ON THE # OF INSTRUCTORS IS:',I6)
       GO TO 192
      ENDIF
C
C     ***** DETERMINING THE MINIMUM COST ******
C     ***** (COST = TOTAL IDLE TIME) WAY *****
C     *****  OF USING THE MIN # OF I.P.'S *****
C
      B(N-1) = -MIN
      B(N) = -B(N-1)
      NA = NA-1
99     J = 0
C
C     ***** COLLAPSING THE NETWORK *****
C
      DO 110 I = 1,NT
       DO 105 L = 1,NT
        IF((STK(L).LT.ETK(I)).OR.(STK(L).GT.ETK(I) + 180))GO TO 105
        J = J + 1
        STARTN(J) = I
        ENDN(J) = L
```

```fortran
      U(J)=1
      C(J)=STK(L)-ETK(I)
      B(I)=0
105   CONTINUE
110   CONTINUE
C
C     ***** MOVING "ARCS TO t" TO COLLAPSED NETWORK *****
C
      DO 120 I=J+NT+1,NA
      STARTN(I)=I-J-NT
      ENDN(I)=N
      U(I)=1
      C(I)=0
120   CONTINUE
C
C     ***** PLUGGING NEW NETWORK INTO RELAX *****
C
      CALL INIDAT
      DO 125 I=1,NA
      RC(I)=C(I)
      CAP(I)=U(I)
125   CONTINUE
      WRITE(*,85)MIN
85    FORMAT('0','THE LOWER BOUND ON THE # OF INSTRUCTORS IS:',I6)
      WRITE(*,100)NT
100   FORMAT('0','THE TOTAL NUMBER OF TASKS SCHEDULED IS:',I5)
      WRITE(*,101)J
101   FORMAT('0','THE TOTAL NUMBER OF ARCS GENERATED IS:',I6)
999   CALL RELAX
      IF(REPEAT) WRITE(*,1000)TOT
1000  FORMAT('0','THE PREVIOUS UPPER BOUND ON COST =',I7)
C
C     ***** CALCULATING THE COST *****
C
      TOT=0
      DO 140 I=1,J
      IF(X(I).NE.1) GO TO 140
      TOT=TOT+C(I)
140   CONTINUE
C
C     ***** OUTPUT *****
C
      WRITE(*,102)
102   FORMAT('0','A POSSIBLE SET OF TASK ASSIGNMENTS IS:')
      COUNT=0
      DO 500 I=1,NT
      DO 600 K=1,J
      IF(X(K).NE.1) GO TO 600
      IF((I.EQ.STARTN(K)).OR.(I.EQ.ENDN(K))) GO TO 500
600   CONTINUE
      WRITE(*,400)I
400   FORMAT(I6)
      COUNT=COUNT+1
500   CONTINUE
```

```
C
C     ***** THIS IS THE HEURISTIC WHICH LIMITS *****
C     ***** INSTRUCTORS TO 3 TASKS OR LESS    *****
C
      NV=0
      DO 800 I=1,J
       IF(X(I).NE.1) GO TO 800
       DO 700 K=1,J
        IF(X(K).NE.1) GO TO 700
        IF(STARTN(K).NE.ENDN(I)) GO TO 700
         WRITE(*,300)STARTN(I),ENDN(I),ENDN(K)
300       FORMAT(3I6)
         COUNT=COUNT+1
C
C     ******** DUTY DAY CHECK ***********
C
         IF(ETK(ENDN(K)).GT.STK(STARTN(I))+720) THEN
          WRITE(*,320)
320        FORMAT(' ','DUTY DAY VIOLATION')
          NV=NV+1
         END IF
C
         X(I)=0
         X(K)=0
          DO 750 M=1,J
           IF(X(M).NE.1) GO TO 750
           IF(STARTN(M).EQ.ENDN(K)) THEN
            WRITE(*,755) ENDN(M)
755          FORMAT(I6)
            COUNT=COUNT+1
            X(M)=0
           ELSE IF(ENDN(M).EQ.STARTN(I)) THEN
            WRITE(*,760) STARTN(M)
760          FORMAT(I6)
            COUNT=COUNT+1
            X(M)=0
           END IF
750       CONTINUE
         GO TO 800
700   CONTINUE
800   CONTINUE
      DO 130 I=1,J
       IF(X(I).NE.1) GO TO 130
       WRITE(*,127) STARTN(I),ENDN(I)
127    FORMAT(2I6)
       COUNT=COUNT+1
C
C     ******* DUTY DAY CHECK **********
C
       IF(ETK(ENDN(I)).GT.STK(STARTN(I))+720) THEN
        NV=NV+1
        WRITE(*,880)
880     FORMAT(' ','DUTY DAY VIOLATION')
       END IF
```

```fortran
C
130   CONTINUE
C
C
C     ******** OUTPUT *************
C
      WRITE(*,888) NV
888   FORMAT('0','THE NUMBER OF DUTY DAY VIOLATIONS =',I4)
C
      L=COUNT+NV
      WRITE(*,890)
890   FORMAT('0','THE SCHEDULE ABOVE IS FEASIBLE')
      WRITE(*,895) L
895   FORMAT(' ','FOR ',I3,'  INSTRUCTOR PILOTS')
      GO TO 9999
C
      IF((COUNT.EQ.B(N)).AND.(NV.EQ.0)) THEN
      WRITE(*,160)
160   FORMAT('0','THE SCHEDULE ABOVE IS OPTIMAL')
      WRITE(*,170) L
170   FORMAT(' ','FOR ',I3,'  INSTRUCTORS')
      WRITE(*,175)TOT
175   FORMAT(' ','THE OPTIMAL COST =',I7)
      GO TO 192
      END IF
C
C
      IF(L.GT.NIP) THEN
      WRITE(*,70)
70    FORMAT('0','THE SCHEDULE ABOVE IS INFEASIBLE')
      WRITE(*,71) L
71    FORMAT(' ','SINCE IT REQUIRES',I3,'  INSTRUCTORS')
      WRITE(*,72)NIP
72    FORMAT(' ','AND ONLY ',I2,'  ARE AVAILABLE')
      GO TO 192
      END IF
C
C
      IF(L.GT.B(N)) THEN
      WRITE(*,180)
180   FORMAT(' ','THE SCHEDULE ABOVE FEASIBLE')
      WRITE(*,185) L
185   FORMAT(' ','FOR',I3,'  INSTRUCTORS')
      WRITE(*,190)TOT
190   FORMAT(' ','THE UPPER BOUND ON COST(IDLE TIME) =',I7)
      ENDIF
C
C
192   WRITE(*,193)
193   FORMAT('0','DO YOU WISH TO MODIFY THE SCHEDULE?')
194   WRITE(*,195)
195   FORMAT(' ','TYPE IN 1 FOR YES --- 0 FOR NO')
      READ(*,197)ISENS
197   FORMAT(I1)
```

```
      IF(ISENS.EQ.1) THEN
      REPEAT=.TRUE.
199      WRITE(*,200)
200   FORMAT('0','ENTER THE DESIRED # OF INSTRUCTORS IN SCHEDULE')
      WRITE(*,201)MIN
201      FORMAT(' ','THE NUMBER MUST BE GREATER THAN OR EQUAL TO',I4)
      READ(*,202)INEW
202      FORMAT(I2)
      IF(INEW.LT.MIN) GO TO 199
      IF(INEW.GT.NIP) NIP=INEW
      B(N)=INEW
      B(N-1)=-INEW
C
C
      GO TO 99
      ENDIF
      IF(ISENS.NE.0) GO TO 194
9999  CLOSE(5)
      STOP
      END
```

THE LOWER BOUND ON THE # OF INSTRUCTORS IS: 38

THE TOTAL NUMBER OF TASKS SCHEDULED IS: 95

THE TOTAL NUMBER OF ARCS GENERATED IS: 1203

THE PREVIOUS UPPER BOUND ON COST =   0

A POSSIBLE SET OF TASK ASSIGNMENTS IS:
```
     65
     66
     67
     82
     83
     84
     85
     86
     87
     89
     93
      1     23     46
      2     24     47
      3     25     48
      4     26     49
      5     27     50
      6     28     51
      7     29     52
      8     30     53
      9     31     54
     10     32     55
     11     33     70
     12     35     72
     13     36     73
     56
     14     37     74
     15     38     75
     57
     16     39     76
     17     40     77
     58
     18     41     78
     19     42     79
     59
     20     43     80
     89
     21     44     81
     60     34     71
     61     68     95
     64     94     91
     92     22     45
     62     69
     63     90
```

THE NUMBER OF DUTY DAY VIOLATIONS =   0

THE SCHEDULE ABOVE IS FEASIBLE
FOR   43   INSTRUCTOR PILOTS
Stop - Program terminated.

D.2 - LEVEL 2 PROGRAM

In addition to the input files for the Level 1 program the Level 2 program requires two additional input files which are unique to each unit. The first is the unit's Student preference matrix, called ARRAY, which ranks the instructors. The second file is the task assignments for the unit instructors. This file, called TASK, contains the mission number and assigned instructor number for each unit task. Examples of Assign and TASK are included with the Level 2 program. With these two additional input files the Level 2 program will run with the prompt UNIT6. Output will consist of a complete unit schedule including the mission number, instructor number, student number, and a brief description of each unit task as in table 5.6.

```
C       ***** DEVELOPING THE UNIT SCHEDULE *****
C
       PROGRAM UNIT
       REAL*8 TCOST
       CHARACTER*10 NM(20),NMS(40)
       INTEGER C(1600),X(1600),U(1600),RC(1600),B(80),ETKH(200)
       INTEGER STARTN(1600),ENDN(1600),IP(50),T(50),ETKM(200)
       INTEGER I1(80),I2(80),FOU(80),NXTOU(1600),FIN(80),F3(200)
       INTEGER NXTIN(1600),I7(1600),LARGE,TOT,S,R,MSN(50),D5(200)
       INTEGER COST(30,50),ASGN(30,6),ST(200),ET(200),F2(200)
       INTEGER MATE(50,50),ASGT(30,2),A(50),DATA(5),F1(200)
       INTEGER STK(50),ETK(50),D1(200),D2(200),D3(200),D4(200)
       LOGICAL*2 L1(80),L2(80),REPEAT
       COMMON /ARRAYS/STARTN/ARRAYE/ENDN/ARRAYU/U/ARRAYX/X
       COMMON /ARRAY9/RC/ARRAYB/B/BLK1/I1/BLK2/I2/BLK3/FOU
       COMMON /BLK4/NXTOU/BLK5/FIN/BLK6/NXTIN/BLK7/I7
       COMMON /L/N,NA,LARGE
       COMMON /BLK8/L1
       COMMON /BLK9/L2/BLKR/REPEAT
C
C      ***** INPUTTING THE DATA *******
C
       OPEN(60,FILE = 'DATA.MST')
       DO 8005 I = 1,5
        READ(60,8010) DATA(I)
8010    FORMAT(I3)
8005   CONTINUE
       CLOSE(60)
C
       NTOT = DATA(1)
       NACFT = DATA(3)
       NSIMS = DATA(4)
       NOB = DATA(5)
C
       WRITE(*,7777)
7777   FORMAT('0','INPUT THE NUMBER OF STUDENTS TO BE SCHEDULED:')
       READ(*,7778) NSTUD
7778   FORMAT(I2)
       WRITE(*,7779)
7779   FORMAT('0','INPUT THE NUMBER OF UNIT TASKS TO BE SCHEDULED:')
       READ(*,7780) NT
7780   FORMAT(I2)
C
C   ***** INPUTTING THE TASK ARRAY *****
C
       OPEN(10,FILE = 'TASK')
       DO 10 I = 1,NT
        READ(10,11) MSN(I),IP(I)
11      FORMAT(2I3)
10     CONTINUE
       CLOSE(10)
```

```
      WRITE(*,2000)
2000  FORMAT('0','INSTRUCTOR ASSIGNMENTS FROM DILWORTH RUN:')
      WRITE(*,2005)
2005  FORMAT(' ','TASK #  MISSION #   INSTRUCTOR #')
      DO 1610 I=1,NT
      WRITE(*,1611) I,MSN(I),IP(I)
1611  FORMAT(I4,I10,I15)
1610  CONTINUE
C
C     ********* INPUTTING THE UNIT TASK TIMES ********
C
      OPEN(80,FILE='SCHED.MST')
      WRITE(*,9003)
9003  FORMAT('0','MASTER SCHEDULE TIMES FOR UNIT ACTIVITIES:')
      DO 1 I=1,NTOT
      READ(80,2)D1(I),D2(I),D3(I)
2     FORMAT(I2,I1,I1)
1     CONTINUE
      CLOSE(80)
C
      DO 6 I=1,NT
      F1(I)=D1(MSN(I))
      F2(I)=D2(MSN(I))
      F3(I)=D3(MSN(I))
      WRITE(*,4)F1(I),F2(I),F3(I)
4     FORMAT(I4,I1,I1)
6     CONTINUE
C
C     ***** INPUTTING TASK START AND END TIMES (IN MINUTES)**
C
      OPEN(100,FILE='STRTEND')
      DO 8121 I=1,NTOT
      READ(100,8111) D4(I),D5(I)
8111  FORMAT(2I5)
8121  CONTINUE
      CLOSE(100)
      WRITE(*,6180)
6180  FORMAT('0','START AND END TIMES(IN MINUTES):')
      DO 6300 I=1,NT
      ST(I)=D4(MSN(I))
      ET(I)=D5(MSN(I))
      WRITE(*,6200)ST(I),ET(I)
6200  FORMAT(2I8)
6300  CONTINUE
C
C     ***** INPUTTING THE ASSIGNMENT ARRAY *****
C
      OPEN(20,FILE='ASSIGN')
      DO 20 I=1,NSTUD
      READ(20,12)(ASGN(I,J),J=1,4)
12    FORMAT(4I3)
20    CONTINUE
      CLOSE(20)
      WRITE(*,2001)
```

```
2001  FORMAT('0','STUDENT PREFERENCE MATRIX')
      WRITE(*,2011)
2011  FORMAT(' ','INSTRUCTOR #s')
      DO 1620 I=1,NSTUD
      WRITE(*,1613) (ASGN(I,J),J=1,4)
1613  FORMAT(4I3)
1620  CONTINUE
C
C    *****  CREATING FEASIBILITY MATRIX (MATE) *****
C
      DO 4000 I=1,NT
       DO 3900 J=1,NT
       IF((ST(J).GE.ET(I)).AND.(ST(J).LE.ET(I)+300))THEN
         MATE(I,J)=301-(ST(J)-ET(I))
        ELSE
         MATE(I,J)=7777
        END IF
3900    CONTINUE
4000  CONTINUE
C
C    *****  WRITE OUT MATE *****
C
      WRITE(*,4050)
4050  FORMAT('0','MATE MATRIX BASED ON FEAS. OF TASK MATCHINGS')
      DO 4200 I=1,NT
       WRITE(*,4100) (MATE(I,J),J=1,NT)
4100    FORMAT(16I5)
4200  CONTINUE
C
C    *****  INITILIZING COST ARRAY ELEMENTS TO 8888 *****
C
      DO 100 I=1,NSTUD
       DO 50 J=1,NT
        COST(I,J)=8888
50     CONTINUE
100   CONTINUE
C
C    *****  UPDATING COST ARRAY ELEMENTS *****
C
      DO 1000 I=1,NSTUD
       DO 500 J=1,4
        DO 250 L=1,NT
        IF (ASGN(I,J).EQ.IP(L)) THEN
          COST(I,L)=J
          COUNT=COUNT+1
        END IF
250      CONTINUE
C
500     CONTINUE
C
1000  CONTINUE
C
C    *****  GENERATING ASSIGNMENT ARCS *****
C
```

```
          R=0
          N=2*NT
1001   J=0
          M=0
          R=R+1
C
          DO 1100 I=1,NSTUD
            DO 1050 K=1,NT
            J=J+1
            STARTN(J)=I
            ENDN(J)=K+NSTUD
            U(J)=1
            C(J)=COST(I,K)
            IF(C(J).LT.5000) M=M+1
1050      CONTINUE
1100   CONTINUE
          IF(M.EQ.0) GO TO 9990
C
C
C      ***** DUMMY NODES AND ARCS *****
C
          DO 1200 I=NSTUD+NT+1,N
            DO 1150 K=1,NT
            J=J+1
            STARTN(J)=I
            ENDN(J)=K+NSTUD
            C(J)=8888
            U(J)=1
1150      CONTINUE
C
1200   CONTINUE
C
          NA=J
C
C      ***** CHECKING # ARCS EQUALS # NODES SQUARED ****
C
          NACHK=NT*NT
          IF(NACHK.NE.NA) THEN
            WRITE(*,101)
101       FORMAT(' ','WE HAVE A PROBLEM BOB')
            WRITE(*,102) NA
102       FORMAT(' ','THE NUMBER OF ARCS IS:',I8)
            WRITE(*,103) NACHK
103       FORMAT(' ','IT SHOULD BE: ',I8)
          GO TO 9999
          END IF
C
C      ***** NODAL SUPPLY AND DEMAND *****
C
          DO 1300 I=1,NSTUD
            B(I)=-1
1300   CONTINUE
          DO 1400 I=NSTUD+1,NSTUD+NT
            B(I)=1
```

```fortran
1400  CONTINUE
      DO 1500 I = NSTUD + NT + 1,N
      B(I) = -1
1500  CONTINUE
C
C   ***** REDUCED COSTS ******
C
      DO 1600 I = 1,NA
      RC(I) = C(I)
1600  CONTINUE
C
C    ***** OUTPUTTING DATA *******
C
      WRITE(*,1612)NA
1612  FORMAT('0','NUM ARCS:  ',I8)
      WRITE(*,2002) R
2002  FORMAT('0','COST MATRIX',I4)
      R = R + 1
      DO 1630 I = 1,NSTUD
      WRITE(*,1627)(COST(I,J),J = 1,NT)
1627     FORMAT(16I5)
1630  CONTINUE
C
      LARGE = 2000000
      CALL INIDAT
      REPEAT = .FALSE.
C
C
      CALL RELAX
C
      DO 1800 L = 1,NSTUD
      DO 1700 I = 1,NA
      IF(X(I).NE.1) GO TO 1700
      IF(STARTN(I).EQ.L) THEN
       ASGT(L,1) = STARTN(I)
       ASGT(L,2) = ENDN(I)-NSTUD
      END IF
1700  CONTINUE
1800    CONTINUE
C
C   ***** STORING STUDENT ASSIGNMENTS *****
C
      DO 1810 J = 1,NA
      IF((X(J).EQ.1).AND.(C(J).LT.5000)) THEN
       A(ENDN(J)-NSTUD) = STARTN(J)
      END IF
1810  CONTINUE
C
C   ***** RAISING COST OF ASSIGNED TASKS *****
C
      DO 3000 I = 1,NSTUD
      K = ASGT(I,2)
      DO 2500 J = 1,NSTUD
      COST(J,K) = 8888
```

```fortran
2500    CONTINUE
3000    CONTINUE
C
C
      WRITE(*,2900) R
2900  FORMAT('0','COST MATRIX',I4)
      R=R+1
      DO 3100 I=1,NSTUD
      WRITE(*,3050)(COST(I,J),J=1,NT)
3050    FORMAT(16I5)
3100  CONTINUE
C
C     ***** UPDATING THE COST MATRIX BASED ******
C     ***** ON MATE VALUES AND PRIOR ASSIGNMENTS *
C
      DO 6000 I=1,NSTUD
      K=ASGT(I,2)
      DO 5000 J=1,NT
      IF(COST(I,J).GE.5000) GO TO 5000
      IF(MATE(K,J).LT.350) THEN
        COST(I,J)=COST(I,J)*MATE(K,J)
      ELSE
        COST(I,J)=COST(I,J)*MATE(J,K)
      END IF
5000    CONTINUE
C
6000  CONTINUE
C
C     ***** WRITING OUT COST MATRIX UPDATE *****
C
      WRITE(*,6050) R
6050  FORMAT('0','COST MATRIX',I4)
      DO 6100 I=1,NSTUD
      WRITE(*,6075) (COST(I,J),J=1,NT)
6075    FORMAT(16I5)
6100  CONTINUE
C
C     ***** LOOPING FOR NEXT ASSIGNMENT PASS *****
C
      GO TO 1001
C
C     ***** WRITING OUT RESULTS *****
C
      OPEN(200,FILE='INST')
      DO 6900 I=1,20
      READ(200,6910) NM(I)
6910    FORMAT(A10)
6900  CONTINUE
      OPEN(210,FILE='STUD')
      DO 6930 I=1,40
      READ(210,6920) NMS(I)
6920    FORMAT(A10)
6930  CONTINUE
C
```

```
9990   WRITE(*,7000)
7000   FORMAT('1','THE ASSIGNMENTS ARE:')
       WRITE(*,7010)
7010   FORMAT('0','MISSION  INSTRUCTOR #   STUDENT #  TASK TYPE')
       DO 8000 I=1,NT
       IF(MSN(I).LE.NACFT) THEN
       WRITE(*,7050)MSN(I),IP(I),A(I),F1(I),F2(I),F3(I)
7050      FORMAT(' ',I4,I13,I15,I7,I1,I1,' AIRCRAFT')
          GO TO 8000
       ELSE IF(MSN(I).LE.NACFT+NSIMS) THEN
       WRITE(*,7075)MSN(I),IP(I),A(I),F1(I),F2(I),F3(I)
7075      FORMAT(' ',I4,I13,I15,I7,I1,I1,' SIMULATOR')
          GO TO 8000
       ELSE IF(MSN(I).LE.NACFT+NSIMS+NOB) THEN
       WRITE(*,7080)MSN(I),IP(I),A(I),F1(I),F2(I),F3(I)
7080      FORMAT(' ',I4,I13,I15,I7,I1,I1,' CROSS COUNTRY/ O&B')
          GO TO 8000
       ELSE
       WRITE(*,7085)MSN(I),IP(I),A(I),F1(I),F2(I),F3(I)
7085      FORMAT(' ',I4,I13,I15,I7,I1,I1,' SOF/RSU/OTHER')
       END IF
8000   CONTINUE
C
C
9999   STOP
       END
```

END

10 — 86

DTIC