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AN APPROACH TO WORKLOAD ASSIGNMENT AND SCHEDULING OF ENGINEERING AND INSTALLATION ACTIVITIES FOR AIR FORCE COMMUNICATIONS COMMAND (AFCC)

Scott A. Hammell, Captain, USAF

LSSR 85-80

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The thesis offers two models which are applied sequentially to first the assignment and then the scheduling of workload. Each job has characteristics of estimated man-hours, personnel skills required, and scheduling milestones. Units have man-hours and personnel skills available. The workload assignment model makes one to one assignments of jobs to units; however, units may be assigned more than one job provided available man-hour rim conditions are satisfied. Using the Honeywell LP6000 software package, right hand side values of available man-hours were uniformly reduced in successive solutions. The scheduling model employed a version of the zero-one, multiproject scheduling problem by Pritsker, Watters and Wolfe (1968). For a list of fifteen jobs assigned to one unit, a four month planning horizon was treated as a "project" with fifteen basically parallel activities. Sequencing and concurrency of performance were discussed. Using a schedule effectiveness measure of throughput time, the level of a critical skill was ranged and the effects noted in the results from the LP6000 package. The thesis concluded that strictly uniform levels of tasking would result in many additional miles traveled and that as skills are reduced, schedules become extended or are infeasible.

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AN APPROACH TO WORKLOAD ASSIGNMENT AND SCHEDULING OF ENGINEERING AND INSTALLATION ACTIVITIES FOR AIR FORCE COMMUNICATIONS COMMAND (AFCC)

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

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This thesis, written by

Captain Scott A. Hammell

and approved in oral examination, has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS MANAGEMENT

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James M. Masters
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OVERVIEW

Introduction

A significant mission responsibility of the Air Force Communications Command (AFCC)[1] is to engineer, install and maintain newly acquired and modernized ground Communications-Electronics (C-E) equipment and systems Air Force-wide. Because of the pervasive nature of communications in AF missions, virtually every activity, large and small, has derived its communicative capability from an AFCC Engineering and Installation (E-I) effort. As the reliance on technology increases and new systems are needed to replace the old, it becomes increasingly important to translate fixed, ground C-E requirements into operational facilities in the most effective manner possible.

The C-E programming process is the framework in which the translation of requirements into capabilities takes place. It is a complex process characterized by long lead times of from three to five years and which involves nine major procedural steps and ten AF organizational

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[1]Effective 15 November 1979, Air Force Communications Service (AFCS) was redesignated as Air Force Communications Command (AFCC).

elements (24:1). Such lengthy delays clearly reduce the responsiveness of communications systems to rapidly changing AF needs. While significant reductions in the process duration might be realized by large scale changes in C-E programming procedures themselves, an alternative first action is to pursue efficiencies within steps of the process. The purpose of this thesis is to investigate certain portions of the process for which AFCC E-I elements are responsible and to recommend alternative approaches to the assignment and scheduling of E-I workload.

Statement of the Problem

Top management in AFCC has expressed its interest in improving overall E-I management (13:Atch 1). One of the specific topics identified has been in the area of E-I workload assignment and scheduling. There has been considerable research and literature on the topics of assignment (9), scheduling (4; 12; 20), multiproject management (18; 22), and project management with resource constraints (16; 37). However, none of the techniques described in the literature have been applied as aids to the workloading system.

There exists a need to investigate the field of management science for the techniques which support the type of workload assignment and scheduling faced by AFCC. Furthermore, the most promising methods need to be applied in a workable model.

Background

The purpose of this portion of the paper is to provide an understanding of the mission and organization of the Air Force Communications Command. This will not only provide a basis for later discussion, but also will place the E-I activities in perspective for the reader. The first discussion will present the command's mission areas with special attention given to the E-I mission as it supports the C-E programming process. Then, both the current command organizational structure and the planned reorganization will be presented.

AFCC mission. The mission of AFCC can be briefly stated as "providing communications, air traffic control, and standardized automated data processing support for the Air Force and other federal activities throughout the world [2:68]." What that statement does not do is convey the scope and magnitude of the command's responsibilities. Wherever the Air Force is, some element of AFCC is there as well. Over 48,000 personnel, including nearly 7,000 civilians, perform their important jobs at more than 550 locations ranging across the United States and 23 foreign countries. An additional 16,000 members of the Air National Guard and Air Force Reserves make a significant contribution to the AFCC mission which is as diverse as its personnel are dispersed (2:68). The six principle mission responsibilities are (2:68; 32:3):

1. on-base communications;
2. air traffic services;
3. long-line communications
4. combat communications;
5. data automation management; and
6. ground C-E Engineering and Installation.

Of the six principle services provided by the command, customers are probably most familiar with on-base communications. The common user systems are telephone systems, intercoms, the telecommunications center, and intra-base radios. Some of the special purpose systems include fire and crash alarms, intrusion detection and warning systems, and closed circuit television (2:68).

Another major function performed by a tenant operations and maintenance (O&M) communications unit for its host base is the operation of air traffic services. Personnel actively support flight operations from manned facilities such as the control tower, ground controlled approach van, or radar approach control building. Other navigational aids, including the radio beacon, direction finder, instrument landing system, glideslope and localizer, ground/air/ground transmitter/receiver sites, and TACAN, complete the traffic control and landing system (11:11). On a worldwide basis, AFCC operates a service known as the Notice to Airmen (NOTAM) system which maintains current status of airfields and facilities at fliers' enroute locations and ultimate destinations (2:69; 10:11).

Like the NOTAM system, the third service category of long line communications is a global rather than an individual base-oriented service. Operating and maintaining microwave, tropospheric scatter, and satellite systems, AFCC ties hundreds of Department of Defense (DoD) locations into the Defense Communications System (DCS), the common-user long distance voice and data network. Other elements of the DCS, such as global radio, round out the DoD's system for command and control. AFCC also serves as the Air Force manager for the Military Affiliate Radio System (MARS). This high frequency band radio system, composed of military radio operators and licensed volunteer amateurs called HAM's, is capable of supporting both military and humanitarian contingencies worldwide (2:68).

Because not all operations can be supported by fixed communications systems, AFCC has four combat communications groups to support the fourth mission area listed above. Taskings may range from assisting authorities with disaster relief to providing complete communications services to a tactical forward operating base. In any case, the command is equipped with "emergency mission support and combat facilities providing quick response mobile communications and transportable terminal navigational aids for any location in the world [32:3]."

AFCC has over 2,600 personnel and 154 computer systems involved in its mission of data automation management. Responsibilities include the acquisition, development, test, evaluation, and maintenance of computer systems and software. This function is not restricted to Air Force use alone. Other DoD and federal agencies receive design support from one of the direct reporting activities (2:69).

The final mission responsibility and the one which is the general subject area for this thesis is the Engineering and Installation (E-I) of fixed ground C-E equipment and systems. As the Air Force's single manager of C-E systems, AFCC E-I activities play a key role in turning communications requirements into operational capabilities. The scope of this responsibility is significant. In fiscal year 1979, over 2,200 separate jobs were completed (48). This involved more than 600 engineers and 350 E-I teams, a force of over 3,000 military and civilian personnel who were TDY 60 percent of the time doing their jobs at locations throughout the world (2:68; 33:2).

The E-I mission can be divided into four major activities: programming, engineering, installation, and maintenance. The first three relate directly to the C-E programming process, while the fourth activity represents a special tasking of E-I units. A limited discussion of the process will illustrate the E-I role.

C-E programming process. C-E program management is governed by AFR 100-18 which identifies the principle players in the process as the requiring command, the host organization and the implementing command. The requiring command is the command (such as MAC, SAC, or USAFE) that needs the service at one of its bases or operational locations. The host is the command or organization which is responsible for tenant support and has jurisdiction over the base and other real property. Overall responsibility for the management of an approved program, including engineering, installation and testing, is held by the implementing command. Except in programs involving nonstandard C-E systems, high costs and/or special modifications, AFCC is usually the implementing command (45:3-1,3-2).

As an illustration of this discussion, Figure 1-1 presents a bar chart representation of the relationship and time phasing of the C-E programming process and E-I activities.

The C-E programming process begins when a requiring command identifies a need for some C-E service. Such a service may require the installation of newly procured or off the shelf equipment, rehabilitation or relocation of existing facilities, or even removal of some systems no longer needed by the using organization. A job becomes programmed when the need is submitted for approval through the chain of command to HQ USAF (33:5). E-I personnel at

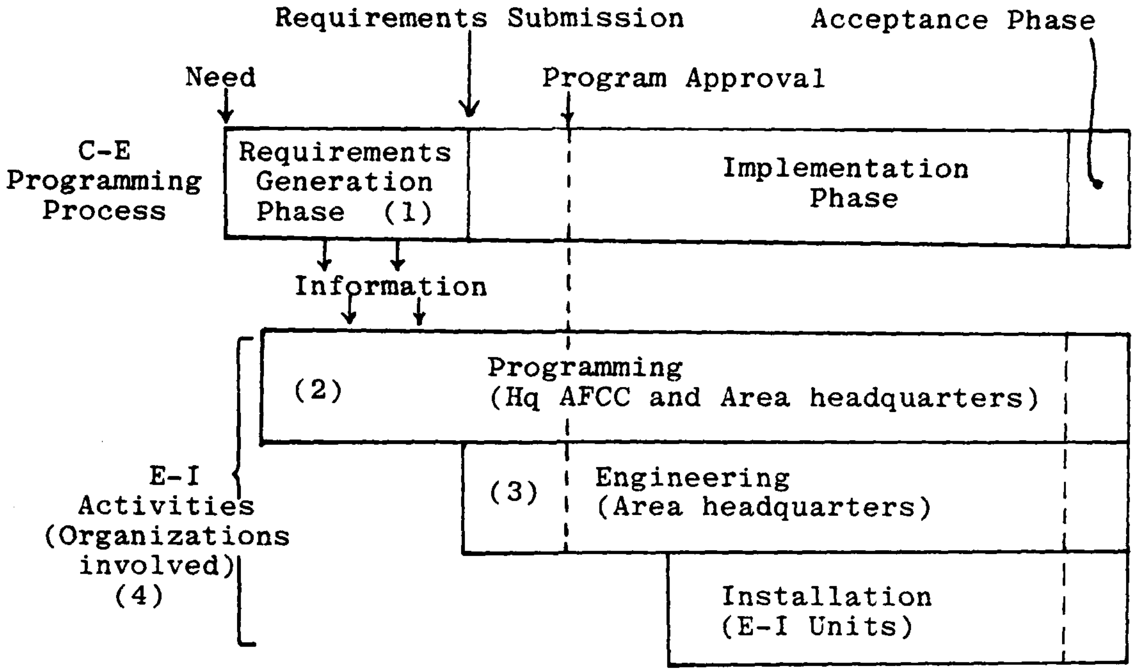

Figure 1-1

C-E Programming Process and E-I Activities

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(1) Acting in its role as a functional part of the host or requiring command's staff, the AFCC communications unit supporting the location needing the service will often perform many of the activities in this phase.

(2) Hq AFCC may assist the requiring command with guidance on generating the requirement.

(3) Engineers from the Area headquarters may perform preliminary surveys prior to program approval.

(4) The fourth E-I activity, maintenance, is not included in this relationship.

HQ AFCC and next lower echelon levels become aware of the action through the Base Communications-Electronics Plan (BCEP) process, the minutes of the host's Command Control Communications Requirements Board (C^3RB) meeting, or through a formal request for technical assistance to provide a statement of work for the job (42). This begins the implementation phase of the C-E process. For the purpose of this thesis, the term "programming" will be used to describe not only this early E-I activity of monitoring the requirements generation, but also establishing milestones and coordinating the activities of other program participants. Programming is performed for the duration of the process.

The implementation phase continues with the initiation of engineering activities. E-I personnel prepare a document called the Engineering Implementation Plan. Specifics of the statement of requirements are studied and consideration is given to what type of action is required (removal, installation, relocation, etc.), what equipment will best satisfy the requirement, how the equipment will be sited, and what the estimated costs will be (33:5; 24:35).

When the program receives USAF approval, it is assigned to a program manager at one of the Communications Area headquarters and the program code is changed from pending to approved status (42). This permits the next step in the engineering activity--scheme preparation. A scheme is the detailed formal planning document:

> . . . prepared by the implementing command that translates an approved programmed requirement into the engineering, supply, test, installation data and guidance necessary to establish, change, remove or relocate a C-E facility [46:1-1,1-2].

It is comprised of the list of materials, statement of work (installation instructions), authorization documents, drawings, and the site concurrence letter/support requirements letter (SCL/SRL). Prepared, in many cases, following an on-site engineering survey by the responsible AFCC E-I engineer, the scheme is the central document to E-I activities. In addition to establishing procedures for the E-I team which performs the work, it details logistical support requirements (potentially involving AFLC) and it specifies responsibilities of the host organization. The host's responsibilities, called allied support, are spelled out in the SCL/SRL, which is a committment by the host to AFCC E-I for construction and other base support (45:A4-2).

Concurrent with the monitoring of supply status of materials ordered for the scheme and the progress of allied support, the program manager assigns the scheme to one of 9 active duty or 19 ANG E-I units. This begins the installation phase of the program. The tasked unit reviews the scheme package for technical adequacy and feasibility, coordinating any necessary changes with the engineer. Once the allied support is completed and all materials are on site, a team is deployed to complete the job. Following the installation, testing and acceptance, the facility is commissioned and the C-E process is complete.

Although it is not related to the C-E programming process, the fourth E-I activity, maintenance, is important to this thesis because it competes with scheme work for the allocation of E-I workload. AFCC is responsible for the performance of depot level maintenance (DLM) on certain C-E facilities. Since many equipment items cannot be transported to the responsible Air Logistics Center for DLM, E-I teams travel to the operating locations. In addition to performing scheduled DLM, teams are also available for other functions. They provide emergency assistance when a maintenance task is beyond the O&M communications unit's capability. They are periodically called upon to provide temporary manning assistance to other units. Finally, E-I personnel can be tasked to augment combat communications units deployed on military exercises (48).

The point to be made is that E-I workload entails a wide variety of activities. The resources of time, money, equipment, materials, and personnel are allocated to other organizations (for manning assistance and augmentation), to work orders (for DLM), and to job orders (for engineering assistance and consultation), as well as to schemes. As a means of simplifying references to these diverse functions, this thesis will hereafter use the term "job" to describe any distinct E-I activity of the types discussed.

AFCC organizational structure. The purpose of this portion of the background is to acquaint the reader with two abbreviated AFCC organizational structures. The first structure will depict the present organization of the command. As of this writing, AFCC is planning to reorganize in an effort to more effectively carry out its mission and concept of operations. Therefore, the second structure will depict the command as it will be organized once HQ USAF approval is received. In neither case will the complete command mission structure be presented. Discussion will be limited to those elements pertinent to this thesis: HQ AFCC, the intermediate subcommands, and the O&M and E-I units.

AFCC's present command structure is shown in Figure 1-2. Despite numerous changes and expansion of the command's mission, it is not significantly different, in concept, from the structure established in July 1961 when AFCC (then AFCS) was activated as a major command and later in July 1970 when the E-I mission was assumed from the Ground Electronics Engineering and Installation Agency (GEEIA) (24:3).

With its headquarters at Scott AFB, Illinois, AFCC is organized to provide responsive support to its customers (32:3). Six intermediate subcommands called "communications areas" are located in the United States and overseas. As operational headquarters equivalent in size and mission to numbered Air Force level organizations, the Areas provide operations, maintenance, planning, and programming guidance

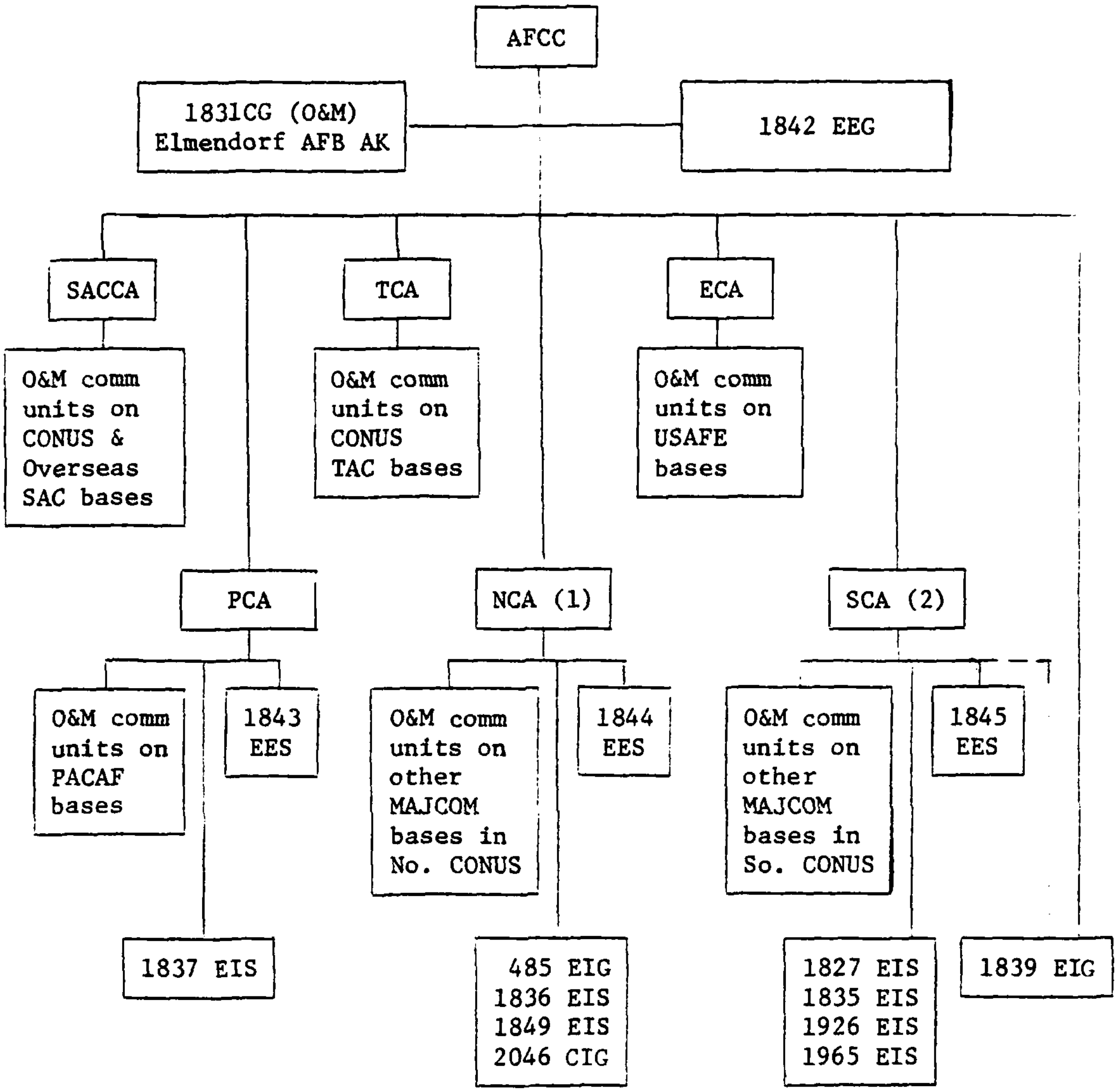

Figure 1-2

AFCC Present Organization

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(1) NCA regional responsibilities include Canada, Greenland, Iceland, the Azores, Grand Bahama Islands, and Eastern Test Range locations.

(2) SCA regional responsibilities include Alaska (E-I only) and the Canal Zone.

to their subordinate O&M units. In addition to these functions, three of the Areas (NCA, SCA, and PCA) also have E-I responsibilities. Their electronic engineering squadrons (EES), located at the Area headquarters, are comprised primarily of program managers and engineers who perform the roles described in the previous section. Tasking of one Area versus another is based on the location of the job. Subordinate E-I units perform the other two E-I mission activities of installation and depot level maintenance. E-I units are assigned jobs on the basis of both the organic capability (having the people to do the job) and the proximity of the job to the unit (42). Thus, the current concept of E-I workloading for both the Area and unit levels is based primarily on regional boundaries.

In an effort to improve its E-I mission performance, AFCC is planning a significant change in its E-I alignment as one part of a larger command reorganization. Figure 1-3 contains a schematic of that new structure. The most notable changes are the redesignation of the Area level headquarters, the abolishment of north-south CONUS boundaries, and the realignment of E-I organizations.

In the new AFCC structure, the Area headquarters are redesignated as "communications divisions." The purpose of the change is to more accurately reflect the truly operational versus managerial missions of those headquarters (29).

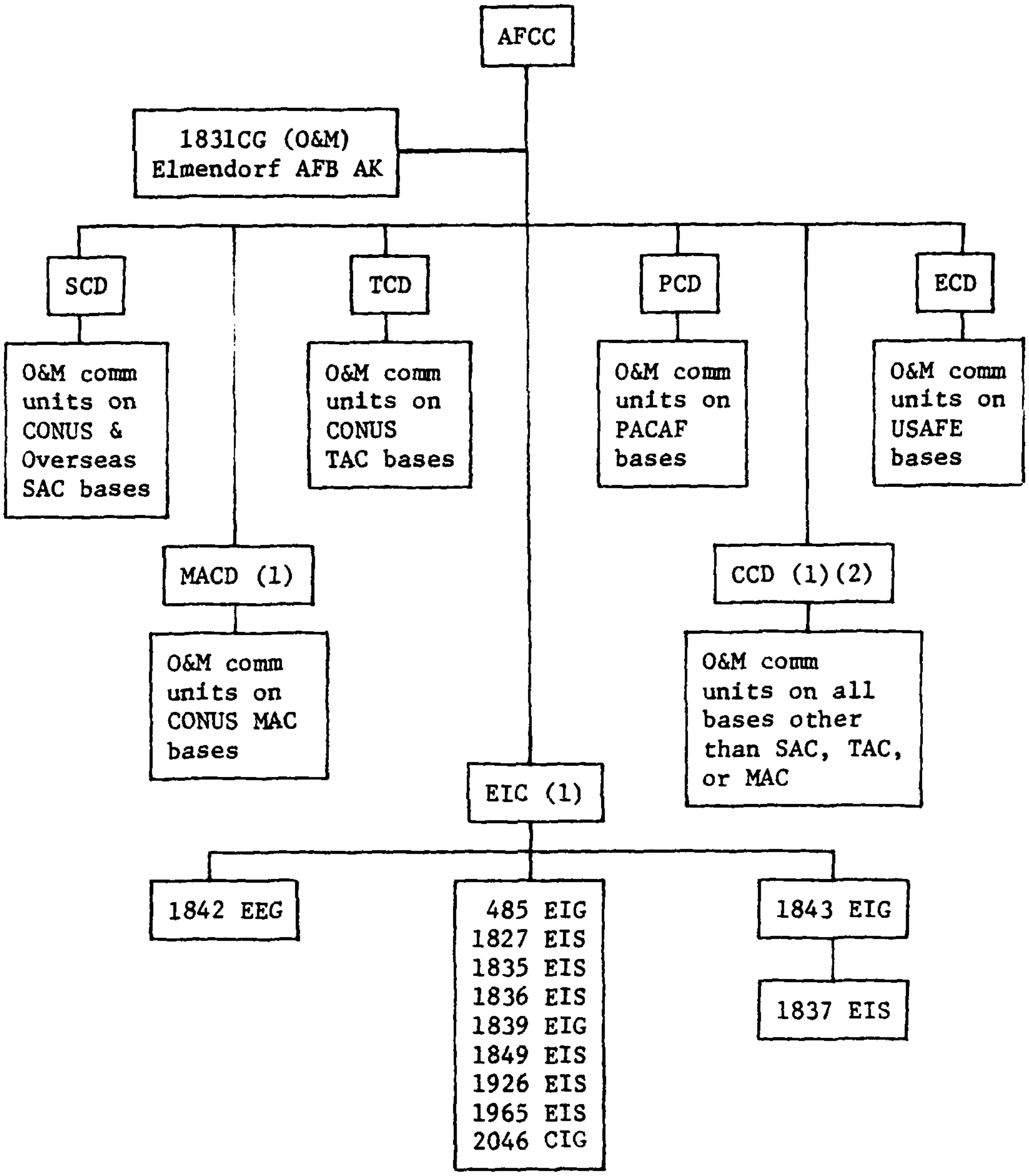

Figure 1-3
AFCC Planned Organization

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(1) New organizational elements.

(2) CCD regional responsibilities include Greenland, Iceland, Azores, Grand Bahama Islands, Eastern Test Range, and Canal Zone.

Military Airlift Communications Division (MACD) will be established with its headquarters at Scott AFB, Illinois. Like the Strategic and Tactical Communications Divisions (SCD and TCD), MACD will provide specialized service to its host major command, Military Airlift Command (MAC). It will be the headquarters for all CONUS O&M communications units which are tenants on MAC bases (6).

Coupled with the establishment of MACD is the abolishment of the north-south CONUS boundaries observed by Northern and Southern Communications Areas (NCA and SCA). In their place, Continental Communications Division (CCD) will assume the headquarters role for O&M units which are tenants on bases other than those operated by SAC, TAC or MAC. CCD will be located at NCA's current facility at Griffis AFB, New York (6).

The final change affects E-I organization. Where previously E-I functions were administered and performed on a regional basis under NCA, SCA, and PCA, the new structure establishes centralized management under the Engineering Installation Center (EIC). With its headquarters at Oklahoma City AFS , Oklahoma, the EIC will assume jurisdiction over all E-I activities in AFCC. As Figure 1-3 indicates, all but one of the E-I units will come under direct EIC control. Although obscured by their absorption by other organizational elements, the engineering and programming functions performed by the 1843, 1844 and 1845 EES will continue to operate in place at Wheeler AFB, Hawaii (1843 EIG); Griffiss AFB, New York (485 EIG); and Oklahoma City AFS, Oklahoma (EIC), respectively. The 1842 EEG at Scott AFB Illinois, will continue to support HQ AFCC in its current mission of assisting requiring commands with expressing and determining requirements, supporting the DoD Electromagnetic Compatibility Program, and providing technical assistance to procuring agencies, among others (29).

Justification

The justification for this thesis is based on four elements: the general need for efficient management of Air Force resources; the recommendation for a follow-on study to an AFIT thesis; the formulation of a new concept in E-I workloading developed in conjunction with the AFCC reorganization; and the timing of plans to expand the capabilities of the command's data management system. Each of these elements will be discussed in the succeeding paragraphs.

A fundamental challenge to all managers is to perform their function of using people or things to produce some end item or result in the most efficient manner possible. In the business community, the degree to which a manager is successful at this task determines the significance of his contribution to company profits. In the government sector, where the profit motive is lacking, a no less challenging relationship exists; that is, getting the maximum return from every tax dollar spent. As the former Assistant Secretary of the Air Force for Financial Management, John A. Hewitt, recently said:

> . . . along with the cost of energy, the cost of missiles, airplanes, bombs, guns (and yes, even butter) is expected to increase. Sacrifice and increased productivity from each American--not just those in the Department of Defense, but across the land--are required if we are to keep those costs under control. Most citizens help by paying taxes. [A DOD manager's] job is to ensure that the money allocated to defense results in maximum combat power. You do that by ensuring the Air Force has the best possible management [47:1].

These remarks apply not only to the combat forces themselves, but also to the multitude of support elements in the Air Force. Managers of AFCC E-I activities are provided with the resources to apply in their jobs: personnel, materials, equipment, facilities, funds, and time. How they put these resources to use affects the level of support they give to their customers. This thesis is intended to provide a management science method for workload assignment and scheduling, thereby making good use of limited resources. Such was the recommendation of an earlier thesis effort.

In mid-1979, HQ AFCS sponsored an AFIT thesis by Nauseef, Tahir, and Zidenberg (33). Its purpose was to define the factors which influence and measure E-I performance and to identify a series of meaningful performance indicators useful to the HQ staff in managing the engineering and installation of C-E systems. While fulfilling their research objectives, the researchers recognized that their effort was only one phase of the study needed to satisfy the command's overall goal of improved E-I management. They concluded that some techniques of management science applied to the E-I environment would put their results to practical use. This recommendation was an incentive to investigate the subject of the current thesis (33).

Motivation for the specific area of E-I workload assignment and scheduling came from contacts in November 1979 with personnel at HQ AFCC/EPC; Deputy Chief of Staff (DCS) for Engineering, Programs, and Acquisition; Directorate of Program Control. Discussing their sponsorship of the Nauseef, et. al. thesis, they alluded to the proposed reorganization of AFCC as previously described (5). Furthermore, in March 1980, the DCS/EP formulated an overall concept for E-I workload assignment with centralized management under the proposed EIC (13:Atch 1). Subsequent contacts with AFCC/EPC personnel established the topic as one worthy of study. Although directed mainly at the emergence of the EIC and its need for a workload assignment and scheduling tool, the research was considered to be potentially useful to any centralized tasking group, regardless of the organizational arrangement (48).

Finally, the research effort is justified by the recent expansion of the capability of the Engineering and Installation Management System (EIMS). EIMS is the data management system which AFCS inherited from GEEIA.

Maintaining 134 records on each E-I scheme, work order, or job order, it has been expanded to provide a real-time retrieval capability to the Communications Areas and active duty E-I units as well (48). This thesis will serve as a basis for establishing software capability requirements when the data automation request for the workload assignment system is submitted in FY 1981 (5).

Research Questions

The overall objective of this research effort was to investigate the field of management science for promising approaches to the AFCC function of assigning and scheduling E-I workload. In forming this objective, a series of research questions were developed for consideration.

1. What is the nature of the E-I workload assignment and scheduling problem?

2. What is the relationship between job assignments and the level of E-I unit tasking?

3. Can a computer programmed scheduling model be formulated to identify the optimum start and completion dates within a planning horizon for a series of jobs with given characteristics?

4. What is the relationship between schedule dates and the level of available resources?

The final section of this chapter presents a brief overview of the approach taken to answer these questions and achieve the research objective.

Approach

The earliest activities in the performance of this thesis involved the identification and delimitization of the topic. Contacts were made at each level of command within AFCC to understand its plans, policies, organizational structure, and current procedures as they related to the E-I mission.

With the subject in mind, an extensive search of management science literature pertaining to topics such as project management and scheduling methods was performed. The literature review resulted in the identification of assignment and scheduling models which supported the nature of the AFCC E-I problem. Using actual milestones and other data extracted from the EIMS, sample problems involving several jobs and multiple, constrained resources were solved using the models.

As the research progressed, questions arose on the AFCC interpretation of level resource tasking under the new workloading concept. Contacts with staff and unit personnel produced responses which established the type of examinations to which the models would be submitted.

Final work on the thesis involved the full scale tests of each model. Developed from the insight gained in the preliminary (sample) runs and the contacts made with command personnel, the tests produced valuable results.

The chapters which follow will present the review of the literature, the research methodology, the model formulations, the results, and finally, the conclusions and recommendations.

Chapter 2

LITERATURE REVIEW

Work on this thesis began with the gathering of the elements of justification discussed in the previous chapter. AFCC managers of E-I activities wanted to improve on the way things were being done (13:Atch 1), but the problem had not even been addressed beyond conceptualization. Realizing that the scope of the thesis topic would not include the entire range of management science disciplines, it was necessary to place limits on the search. Consideration was given to the desired results of the new concept.

AFCC's first objective was to minimize travel mileage as a means of reducing funds expenditure for travel payments. Second, command personnel wanted to overcome the effects of the existing practice of assigning jobs on a regional basis which caused uneven unit tasking and skill utilization. Finally, it was desired to meet required operational dates within the constraints of time, resources and priorities (13:Atch 1). Based on an analysis of these objectives, a set of three subject areas was selected for investigation. Following a brief discussion of management science, in general, the topics of workload assignment, scheduling, and resource allocation will be examined.

Management science (also known by other labels such as operations research and decision science) is the interdisciplinary field of study and application which establishes

> . . . mathematical or other explicit relationships that describe the key elements of some actual or administrative process with reasonable fidelity, and draws useful conclusions about the actual process through analysis of these relationships [7:2].

Put simply, it is using quantitative methods to model and explain a specific problem situation. With its roots in the mathematical programming works of Quesnay in the Tableau economique and later sophisticated models of Walras (14:5), management science has only emerged as a discipline in the past fifty years (1:1). It received extensive use during World War II, the Korean War, and the Vietnam War, but its utility was not, and is not, limited to military applications (7 :5). Industry made good use of management science as it developed, and now a multitude of applications exist: forecasting, accounting and finance, marketing, human resource management, aggregate production planning, inventory control, computer and information systems, facilities location and layout, scheduling and sequencing, project selection, reliability, maintenance, urban and health services, education and transportation systems, and electric utilities to name several (31:xv-xviii). An in-depth treatment of the origin and influences of linear programming is found in Dantzig (14:Chapter 2).

The next three sections will review the literature in the areas of workload assignment, scheduling, and resource allocation.

<u>Workload Assignment</u>

In the field of E-I activities, workload assignment is the act of tasking a unit i with the performance of job j. Because the E-I teams which perform the work come from a single unit,[1] the act has the characteristics of the classical assignment problem found in management science literature.

The assignment problem is generally considered to be a special case of the more general transportation problem, although it has been shown that they actually are equivalent problems, being special cases of each other (14:319). In his historical summary of the development of the classical transportation problem, Dantzig (14:299) reports that one of the earliest descriptions of problems related to this class was offered by L. V. Kantorovich in his 1939 paper (27). Soon after, Frank L. Hitchcock developed a constructive solution (25) which surpassed Kantorovich's incomplete algorithm and formulated the problem in the form now considered standard (14:299-300). While these two authors

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[1]The exception to this situation is when a team from one unit is augmented with personnel from some other active duty or ANG E-I unit.

failed to attract very much attention when they published their papers, T. C. Koopmans enjoyed greater visibility with his application of transportation problem solutions to the cargo ship shortage experienced during World War II (14:300). His postwar efforts in the use of linear programming produced an historic paper entitled "Optimum Utilization of the Transportation Problem" (14:300). Since that time, many adaptations of the problem have been made. Examples include Orden's transshipment problem, Beale's caterer problem (3:7), and Kuhn's Hungarian method (27). The latter is of particular interest.

In 1931, a Hungarian mathematician, E. Egervary, presented a paper which "considered the problem of finding a permutation of ones in a matrix composed of zero and one elements [14:300]" as a proof for a linear graph theorem of Konig (14:404). H. W. Kuhn based his 1955 combinatorial solution to a specialized assignment problem on that paper (28). This is the problem formulation which is referred to as the Hungarian method. Kuhn coined the name "hungarian" because his solution was an offshoot of the work done by Konig and Egervary, both from Hungary, and because the foundation they provided preceded other discussion of the assignment problem by 15 years (28:83).

Considering the basic characteristics of the E-I workload assignment problem mentioned earlier, it is possible to use the classical assignment problem formulation and

Hungarian solution method. However, for reasons which will be discussed in detail in Chapter 3 , a modification of a transportation model is selected for use.

Scheduling

Scheduling is the act of stipulating when a job or task will be performed. Much of the literature treats this topic along with sequencing which is "the mere ordering of a collection of jobs or tasks to be performed [40:268]." Because of the nature of C-E schemes and other jobs, and their performance in more or less a single operation by a single E-I unit, it was determined early in the research effort that E-I activities are scheduled rather than sequenced. Discussion in this section will be oriented toward the former category.

The foundation upon which the concepts of scheduling have been developed is the job-shop process. Conway, et. al., published a thorough treatment of the process in their 1967 textbook, Theory of Scheduling (12), which established some basic assumptions, problem classifications, and schedule evaluation criteria (40:270-272). As a lead-in to the assumptions, the job-shop process elements are defined. One or more operations, the basic activity unit, make up a job which is processed on a machine. Several machines make up a job-shop. The job-shop process is:

> . . . the machine, jobs, operations and a statement of the disciplines or physical constraints that restrict the manner in which an operation can be assigned to the corresponding machine [40:270].

Although the nomenclature just presented suggests a factory production activity, it should be understood that they apply equally well to other environments (40:271). In E-I activities, the operations would be the actions taken in accordance with a job's statement of work, the job in a job-shop relates directly to the E-I job, and the machine would be the E-I team and their tools and equipment. Continuing this example, the job-shop would be the organizational combination of E-I units and the process would be all of the aforementioned elements plus the scheduling policies of the command.

The assumptions offered by Conway, et. al., for the job-shop scheduling problem are in the form of "restrictions which are placed on the definitions of the job set and the machines as well as on the manner in which a schedule may be constructed [12:5]." Examples include specifications of continuous machine availability, operation sequences, singularity of machine type, and no-break operation (12:5-6). Because these restrictions are frequently violated in practice, additional constraints and definitions are added to move the problem from the idealized situation to a more realistic environment (40:270).

It is possible to draw distinctions between different scheduling problems. Salvador offers the classification scheme found in Figure 2-1 (40:272). It is easy to see that problem elements may be known with certainty (Deterministic) or may be partly or completely unknown (Probabilistic), and can be of the single or multiple machine category. Additional subdivision is possible. The E-I scheduling problem classifications which apply are identified in the figure by the arrows. Because the time required to carry out a scheme's statement of work is not known with certainty, the E-I problem is at least probabilistic. The fact that there are nine active duty E-I units identifies the problem as a multiple machine case. Finally, because the units work independently and are not exactly alike, the problem is classified as single staged (machines in parallel) with different machines. Conway, et. al., state that:

> . . . a specific scheduling problem is described by four types of information:
> 1. The jobs and operations to be processed.
> 2. The number and types of machines that comprise the shop.
> 3. Disciplines that restrict the manner in which assignments are made.
> 4. The criteria by which a schedule is evaluated [12:6].

Day and Hottenstein present a slightly different format for classification upon which they base their excellent review of sequencing research:

1. Number of component parts comprising a job.
    a. Single component jobs.
    b. Multi-component jobs which require assembly and/or subassembly operations.

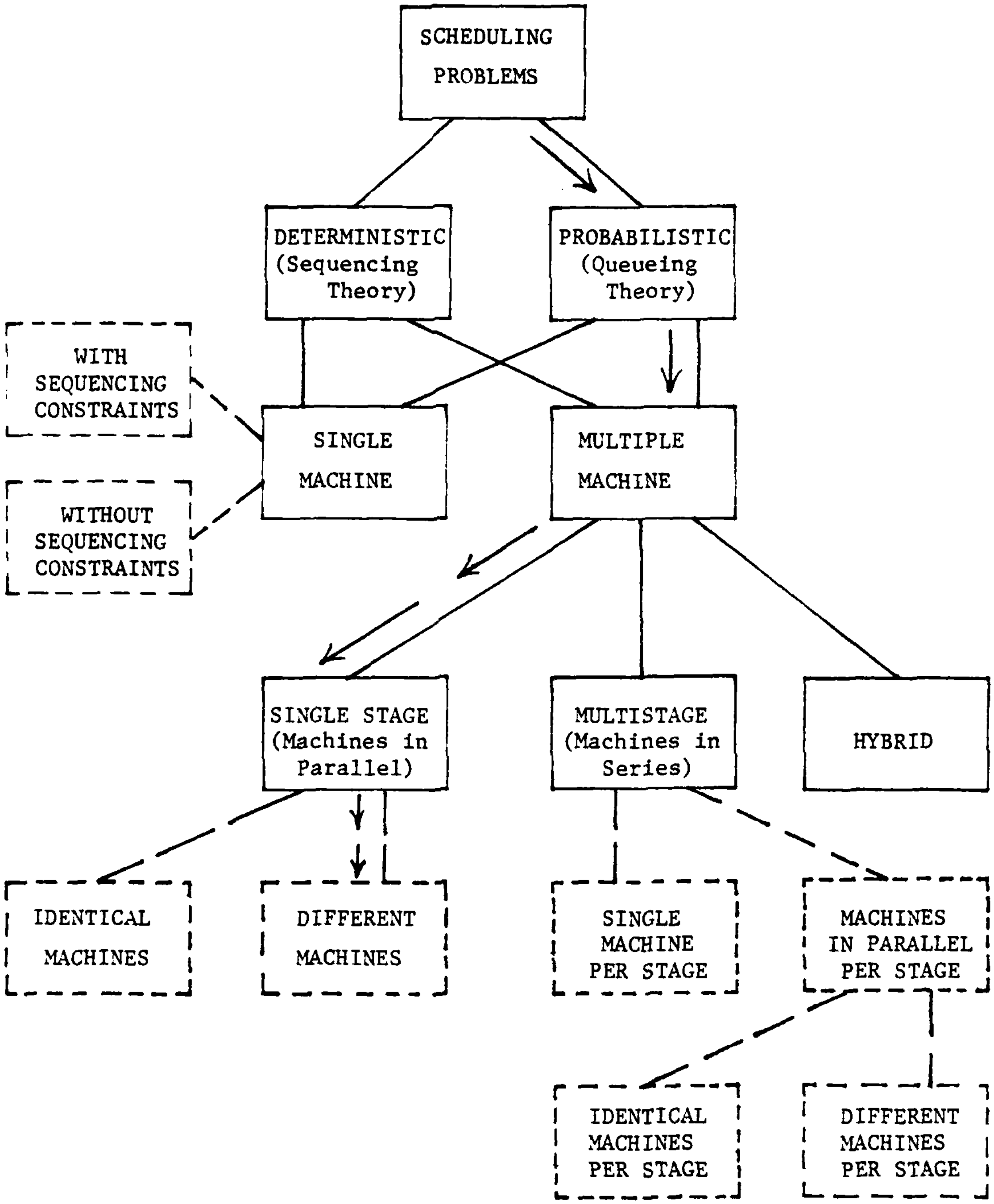


Figure 2-1

A Classification Scheme for Scheduling Problems (40:272)

2. Production factors possessed by the shop.
   a. Machines.
   b. Labor and machines.
3. Jobs available for processing.
   a. N jobs to be scheduled, or sequenced, where N is finite . . .
   b. An undetermined (literally infinite) number of jobs arrive continuously, but randomly, at the shop for service . . . [20:11].

Providing 162 references, their discussion reviews sequencing literature by classifying an article as a (1a-2a-3a) or (1a-2a-3b) variety, for example (20:11). The E-I scheduling problem would be classified as (1a-2b-3b).

Finally, because the value of a scheduling decision must be measurable, schedule evaluation criteria have been established. Using such variables as completion time, flow time, waiting time, lateness, utilization (40:273), makespan (time until last job is complete) and throughput time (37:3), a number of writings exist presenting and comparing the different techniques (11; 19; 22; 30; 34; 41). Regardless of the variable used, the value of a schedule is determined using a format basic to management science problem solution. Randle reports that a common series of characteristics among scheduling problems are: an objective function; a set of decision rules; and a structure of resources and requirements (38:10). As a measure of effectiveness, the objective function will maximize or minimize the equation which relates one or more of the variables mentioned above. The decision rules are equivalent in purpose to the assumptions offered by Conway, et. al. The structure of resources and requirements are found both in the additional assumptions necessary to make the problem realistic, and in the class of problem as depicted by Figure 2-1.

Another area in which scheduling has been important and which is well documented is project management. Because one of the principle tasks of project scheduling is the coordination of resources (9:302), discussion will be deferred to the next section which deals with resource allocation.

Resource Allocation

When a machine[1] is scheduled to perform a task at a certain time, resources are allocated. Raw materials, personnel, equipment, facilities, time, and money may be required to accomplish the task. In an age when resources are becoming more scarce, efficient allocation becomes more important. A common situation in which competition for resources exists is in project management.

Project network models are very frequently used to manage complex projects. A project is composed of a series of related jobs or operations. Having parallel and/or series work flows with precedence relationships among certain operations, project network models were initially proposed

[1]The term "machine" should be considered as a general term in the vein of earlier discussion on the job-shop process.

in techniques such as the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM) (9:302). Their emphasis, though, was focused on time management more than on resource allocation. In his frequently referenced paper, "Resource Allocation in Project Network Models--A Survey," Davis indicates that although many proposals for extension of PERT/CPM techniques into other areas have been made, they have only limited usefulness to the resource allocation problem (17:177-178). Applications of networking techniques which <u>have</u> proven useful are categorized as:

1. Resource leveling
2. Scheduling to satisfy stated resource constraints (17:183).

Resource leveling within a project attempts to reschedule jobs or operations such that the utilization of resources is as level as possible across and between the project time periods. One study by Burgess and Killebrew measures the effectiveness of a schedule by comparing the sum of the squares of the resource requirements. Davis also reviews other resource leveling works by Dewitte; Levy, et. al.; Wilson; and Black. While the approaches to the problem vary, it is noted that none of the authors provide solutions which have realistic assumptions and are computationally efficient (17:185).

The second category of networking techniques is similar to the first in that stating resource constraints places an artificial resource leveling target on the problem. Instead of reaching level utilization (if feasible) through some procedure, the resource constraint forces the utilization peaks below the threshold, often at the expense of the project duration. In addition to the resource leveling techniques, several other procedures have been developed for the constrained resource case. Kelly and Brooks each have developed algorithms to deal with the problem (17:185).

The basic criticism of constrained resource scheduling methods is that none can provide optimum results for large or complex problems. Heuristic scheduling rules are widely used because they can solve large problems, but they only provide a "good," not a "best (optimal)," solution. Various heuristic scheduling rules and comparisons between them are found in Weist (48), Minh (30), Patterson (34), Conway (11), Davis and Heidorn (19), Fendley (22), and Shaffer, et. al. (41). Optimal approaches to scheduling problems make use of linear programming, enumerative procedures, and other mathematical techniques. Although yielding a "best" solution, such approaches quickly exceed reasonable computational limits as the problem size increases. Davis reports that improvements have been made on Weist's original formulation (48) and that optimal techniques are growing in number. Burton (8), Fisher (23), Johnson (26), Davis (15), Bennington and McGinnis (4), and Pritsker, et. al. (37) have all advanced study in the field (18).

Of particular interest to this thesis is the linear programming formulation by Pritsker, Watters and Wolfe (37). Using binary variables (0,1) to depict the completion or noncompletion of an activity, it is possible to obtain an optimal schedule for a multiproject situation. Realities of the project environment are incorporated through a series of constraint equations reflecting job completion requirements, precedence relationships, and resource limitations. Such a formulation permits solution to the scheduling problem using existing zero-one integer programming algorithms (3:9).

Summary

This chapter has presented a review of three areas of management science literature. Selection of the subject areas was accomplished through consideration of the objectives established by AFCC in its new concept of E-I workloading.

Workload assignment writings were investigated because the act of tasking E-I units with the performance of jobs had the characteristics of the classical assignment problem. It was noted that assignment problems and transportation problems shared common historical development, being special cases of each other. Making use of this point, discussion indicated that a modified version of a transportation model could be used to assign E-I workload.

The lengthy discussion of scheduling literature was based on AFCC desires to perform the assigned jobs so that required operational dates could be met. The E-I scheduling problem was compared to the job-shop process and other classification routines. In a related area, the subject of resource allocation was examined. This third subject was motivated by AFCC's stated objective of leveling the tasking and skill utilization among E-I units. The literature review concluded with the identification of a feasible scheduling model formulation which considered resource limitations and other constraints.

In the chapter which follows, the methodology used in the research effort will be presented.

Chapter 3

METHODOLOGY

This chapter presents an expanded discussion of the research approach offered at the close of Chapter 1. It describes the E-I environment, the information required to establish the workload assignment and scheduling models, and the EIMS data base.

E-I Environment

Before any treatment of management science techniques could be accomplished, it was first necessary to examine and define the environment of E-I activities. To support their portion of the worldwide AFCC mission, E-I units are dispersed around the CONUS and overseas. The map of the CONUS in Figure 3-1 illustrates the locations of seven active duty E-I units. The exploded map format identifies the regions in which each unit does a predominant portion of its work. It should be understood that these boundaries are not absolute. Augmentation and skill specialization by certain units regularly call for crossing into other areas. The unlabeled points scattered across the map represent many of the facilities which receive E-I unit support. A majority are major Air Force installations, but

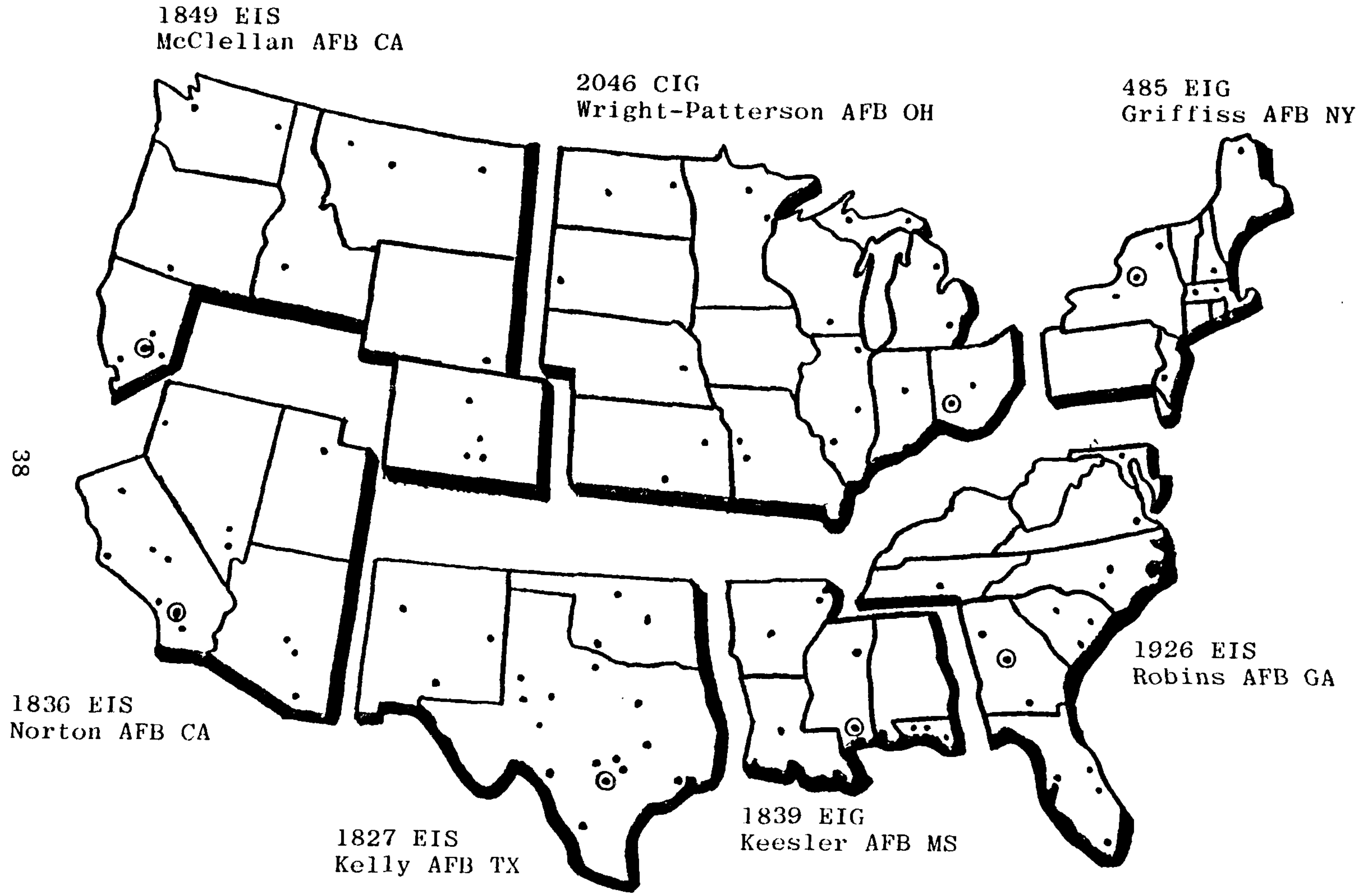


Figure 3-1

CONUS Active Duty E-I Units and Their Primary Areas of Responsibility (43) some are small operational facilities. A similar situation exists in the overseas areas; however, no map is offered here.

The concept of E-I workloading had been based primarily on these regional boundaries. E-I units with the skills necessary to perform a job were tasked to do so if the job was located in their region. The problem this created was that workload was often unevenly assigned. Furthermore, as the weather turned colder, northern based "outside" installation skilled personnel were virtually idled between December and March. Development of the new E-I workloading concept by AFCC is designed to eliminate parochial boundaries, allowing the assignment of jobs to units on the basis of travel considerations, resource utilization, and other conditions (13:Atch 1).

The conclusion drawn from this examination of the E-I environment was that the elements of both an assignment problem and a scheduling problem were present. Jobs had to be assigned to capable units according to some criteria. Once assigned, the series of jobs for which a particular unit was responsible during some time period had to be scheduled. The next two sections will discuss the development of the models for each situation.

Workload Assignment Model

The problem facing E-I managers once a job has received USAF approval and the early stages of the C-E process have begun is that it must be assigned for performance to one of the E-I units. Likewise, for the other types of E-I workload, once a job has been identified, it must be assigned for performance. Discussions with a program manager at Southern Communications Area revealed that this was normally accomplished six to eight months prior to the expected start of actual job performance activities (42). This was the lead time assumed in the problem formulation.

Assignment model. The workload assignment model initially selected for use was in the form of the classical assignment problem previously discussed. Selecting a series of jobs with potential performance times which fall within the two or three month planning horizon, the jobs and E-I units would be arranged in the format shown in Figure 3-2.

i \ j	JOB 1	JOB 2	JOB 3	...	JOB N
UNIT 1	845	48	300	...	1800
UNIT 2	420	1000	M	...	2080
UNIT 3	M	M	1230	...	169
...	...	...	...	...	...
UNIT M	1580	184	120	...	832

Figure 3-2

Assignment Tableau

This is the typical tableau used in the classical assignment problem. The column positions contain the job designations and the rows represent units. Within each cell is the distance which a team from unit i would travel to reach job location j. An "M", representing a very large distance, is entered in a cell if an E-I unit does not have all of the skill types required to do the job. This insures that such a unit will not be assigned to the task. The Hungarian solution method is then applied (9:312):

Step 1. List the matrix m x m . If short of square, add dummy sources or destinations with zero cost.

Step 2. Subtract the smallest number in each row from itself and others in row.

Step 3. Subtract the smallest number in each column from itself and others in column.

Step 4. Draw the minimum number of lines, n , which will cover all the zeros. If n=m then you have optimum solution. If n>m , continue.

Step 5. Subtract the smallest uncovered number in the matrix from itself and all other uncovered numbers. Add this value to the intersection of lines.

Step 6. Repeat step 4.

The result is an assignment of one job to each unit. If the number of jobs exceeded the number of units and dummy rows (units) were added, the technique can be extended by reforming the matrix with all of the units and the remaining jobs, and assigning again. Because the assignment of a job to a unit does not render that unit unavailable for any other assignments, the procedure is carried out until all jobs have been assigned. The mathematical formulation of this problem is (40:105):

$$\text{Minimize} \quad \sum_{i=1}^{M} \sum_{j=1}^{N} C_{ij} \, x_{ij} \tag{3.1}$$

$$\text{Subject to} \quad \sum_{i=1}^{M} x_{ij} = 1 \quad \text{for all } j \, . \tag{3.2}$$

$$\sum_{j=1}^{N} x_{ij} = 1 \quad \text{for all } i \, . \tag{3.3}$$

$$x_{ij} \in \{0,1\} \quad \text{for all } i \text{ and } j \, . \tag{3.4}$$

where C_{ij} = the distance between job j and unit i . It was noted, though, that this treatment gave no consideration to the question of resource leveling, that is, AFCC wanted to task units evenly. Therefore, another formulation was needed to take resource availability and unit tasking into account.

Transportation model. The next formulation took the form of a transportation model. As discussed in Chapter 2, the assignment and transportation problems are equivalent. The difference comes in the formulation of the mathematical model. The transportation problem tableau is similar to the assignment tableau but it adds rim conditions. In this case, the rim conditions used are man-hours. Each job has a demand and each unit has a supply. The transportation tableau is shown in Figure 3-3. The mathematical formulation for this problem is:

$$\text{Minimize} \quad \sum_{i=1}^{M} \sum_{j=1}^{N} C_{ij}\ x_{ij} \tag{3.5}$$

$$\text{Subject to} \quad \sum_{i=1}^{M} x_{ij} = D_i \quad \text{for all} \quad j\ . \tag{3.6}$$

$$\sum_{j=1}^{N} x_{ij} = S_j \quad \text{for all} \quad i\ . \tag{3.7}$$

$$\sum_{i=1}^{M} D_i = \sum_{j=1}^{N} S_j \tag{3.8}$$

where

$$x_{ij} \geq 0 \tag{3.9}$$

Note that where the assignment problem has $\sum_{i=1}^{M} x_{ij} = 1$ for all i and all j, the transportation problem has $\sum_{i=1}^{M} x_{ij} = D_i$ for all j and $\sum_{j=1}^{N} x_{ij} = S_j$ for all i.

That is, where the assignment model makes a one to one assignment of jobs to units, the transportation problem only

i \ j	JOB 1	JOB 2	JOB 3	...	JOB N	SUPPLY (Man-hours)
UNIT 1	845	48	300	...	1800	23,000
UNIT 2	420	1000	M	...	2080	19,500
UNIT 3	M	M	1230	...	169	21,500
...	...	...	...	...	...	...
UNIT M	1580	184	120	...	832	29,200
DEMAND (Man-hours)	617	2420	290	...	700	

Figure 3-3

Transportation Tableau

ensures that the sum of man-hours assigned from each unit equals the requirement for the job and the sum of man-hours for each job equals the number available from each unit. In the transportation problem, x_{ij} would represent the portion of man-hours supplied to job j by unit i. This could allow a violation of the E-I workloading concept. Team integrity (that is, all members of an installation team come from the same E-I unit) is not maintained if portions of the man-hours required by a particular job are furnished by two or more units. In the classic transportation problem, any source can serve multiple destinations and any destination can be served by multiple sources. Thus, for application to the E-I workload assignment problem, still another formulation had to be sought.

Modified transportation model. The challenge in the third iteration of model formulation for workload assignment was to correct the portion of the transportation model which failed to support the E-I concept. Some combination of the one to one pairing feature of the classical assignment model and the resource availability feature of the transportation model was needed.

The solution was found in a modification of the transportation model formulation. Rather than allowing the variable x_{ij} to take on any values greater than or equal to zero (Eq (3.9)), it is restricted to binary values, (0,1), as in the assignment model. To insure that a job was assigned to at most one unit, Eq (3.6) was modified to include the required man-hours, D_j, as a coefficient of x_{ij}. Thus,

$$\sum_{i=1}^{N} D_j x_{ij} = D_j \quad \text{for all } j \text{ which can be reduced to}$$

$$\sum_{i=1}^{N} x_{ij} = 1 \quad \text{for all } j \;.$$

To satisfy the right-hand side rim conditions for available man-hours, S_i, a D_j coefficient of x_{ij} was also inserted into Eq (3.7).

Therefore, the modified transportation model formulation becomes:

$$\text{Minimize} \quad \sum_{i=1}^{M} \sum_{j=1}^{N} C_{ij} x_{ij} \tag{3.10}$$

$$\text{Subject to} \quad \sum_{j=1}^{N} D_j x_{ij} \le S_i \quad \text{for all } i \;. \tag{3.11}$$

$$\sum_{i=1}^{M} x_{ij} = 1 \quad \text{for all } j \;. \tag{3.12}$$

$$x_{ij} = \begin{cases} 1 & \text{if job } j \text{ is assigned to unit } i \,, \\ 0 & \text{otherwise.} \end{cases} \tag{3.13}$$

This formulation satisfied the requirements for a workload assignment model.

Scheduling Model

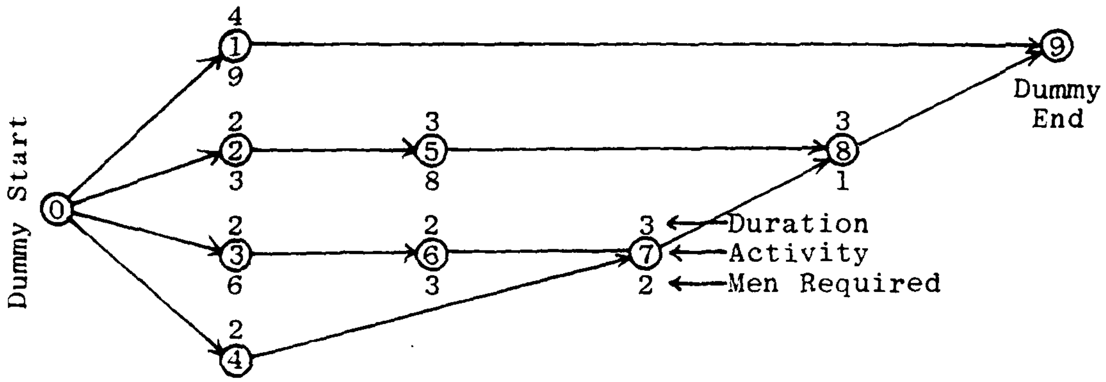
Once the set of jobs from a given planning horizon had been assigned to various E-I units, the task was to separately establish a schedule for each unit which makes the best use of the available skills. The literature review initially looked at PERT techniques but later produced a linear program scheduling model which was capable of handling the problem.

Because some previous studies of the C-E Process (24) and E-I activities (33) made good use of PERT, the initial search for a scheduling model examined this topic for feasibility. Contacts with personnel in the Aeronautical Systems Division at Wright-Patterson AFB, Ohio, revealed several points. First, PERT/CPM techniques had application in their System Program Office environment, but that they were used on individual projects rather than for overall, multiproject control and scheduling. Second, the commercially packaged project management programs such as Mark III and Concorde II were used primarily as automated status reporting, a "what if" forum, and as Gantt chart plotting devices. Finally, no special techniques were being employed to schedule activities of a project so as to level the use of resources (39).

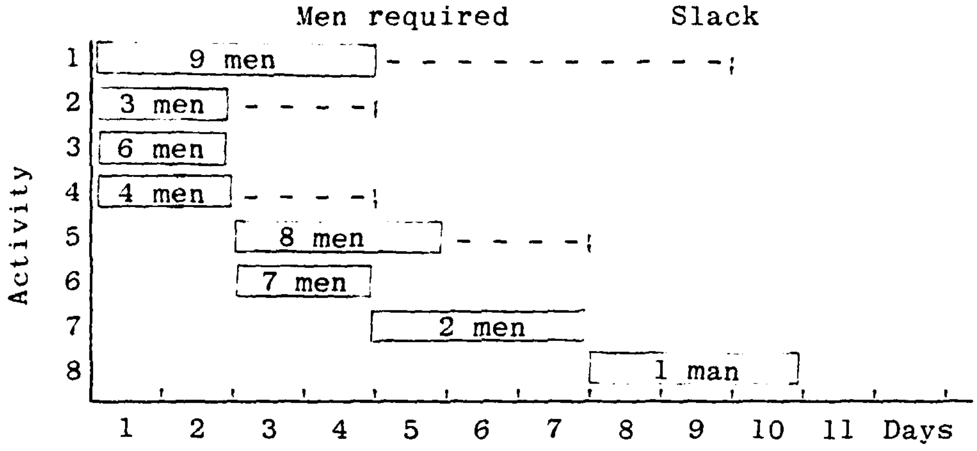
Although the use of PERT/CPM as a scheduling method was discarded, the notion that C-E jobs could be treated by some type of network model was retained. The monograph of project management literature edited by Davis indicated that a number of techniques were available which scheduled activities of a single project or multiple projects while attempting to level the utilization of resources (19). Davis' own article in that collection contained an illustration of a technique which became the basis for examination of the job scheduling problem (16).

Considering the project network shown in Figure 3-4(a), it is possible to develop the bar chart and manpower profile for the project shown in Figures 3-4(b) and (c). If less than the peak requirement of 25 men are available or if level utilization of manpower is desired, the activities must be rescheduled from their earliest start positions to some other arrangement. Permitting an eleven day schedule allows the resequencing results shown in Figure 3-5(a) and (b).

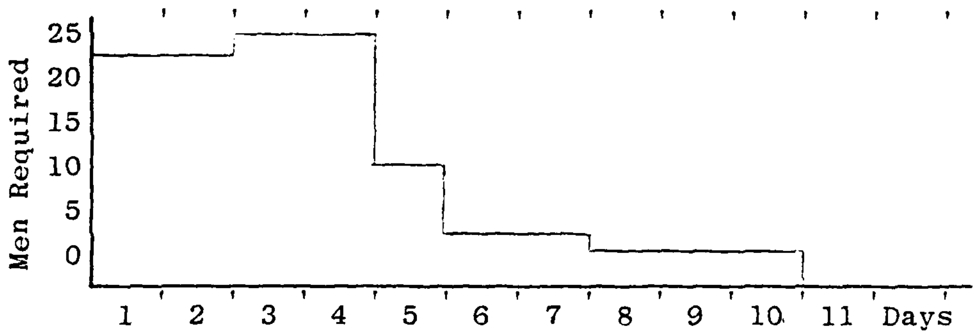
It is possible to portray the E-I scheduling problem in the framework of the above discussion. Consider a list of jobs assigned to a unit for a planning period as a series of activities within a larger project. Although most of these activities are independent and performed in parallel, some could have precedence relationships. Given the characteristics for each job (earliest start time, precedence relationships, duration, required completion time, and resource requirements), a bar chart and resource profile similar to Figures 3-4(b) and (c) can be constructed. Then using a heuristic or optimal technique, the activities can



(a) Project Network (16:119)



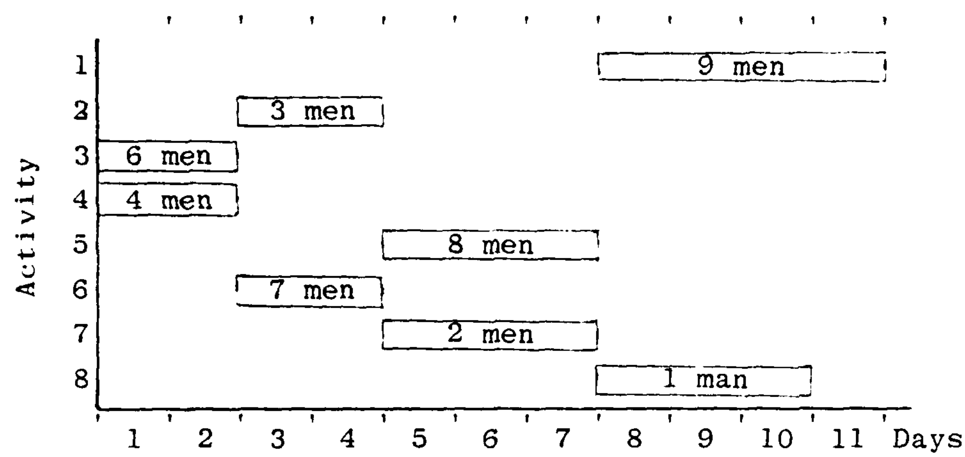
(b) Earliest Start Schedule (16:121)



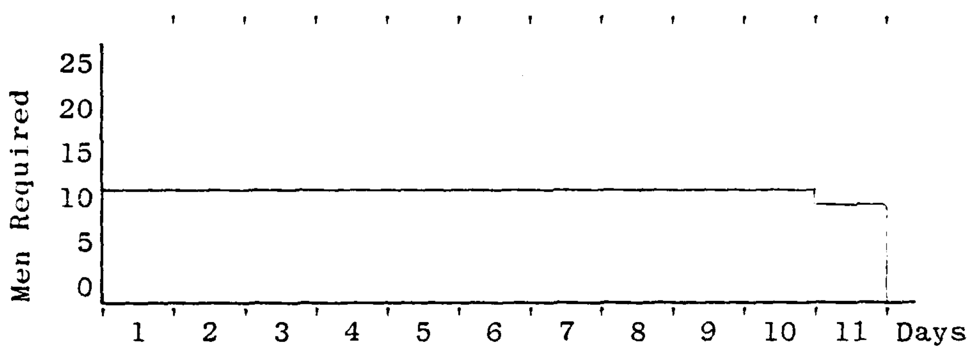
(c) Resource Profile (16:121)

Figure 3-4

Scheduling Example 1



(a) Optimum 11-day Schedule (16:122)



(b) Resource Profile (16:122)

Figure 3-5

Scheduling Example 2

be scheduled to level the resource requirements while achieving some objective such as minimizing throughput time.

The network based technique appeared to be feasible for application to the E-I scheduling problem. Further examination of the literature on network models revealed the zero-one integer programming model developed by Pritsker, Watters, and Wolfe in 1968 (37). This formulation was designed to determine "when a job should be processed, given limited availabilities of resources . . . [37:2]." It is capable of treating not only multiple projects, but also the jobs which make up each project. Although this thesis views each job (along with its subactivities) as a single task, conditions could exist in which two or more subactivities warrant special scheduling consideration. An example is the distinctly separate stages of activity (removal and reinstallation) which make up a radar relocation.

The model's objective function is composed of a series of decision variables which each represent the completion of a project j in period t. When the formulation focuses on throughput time, the objective is to minimize the function subject to the model constraints. The constraint equations establish the resource limitations, in the form of skill types demanded and available. Furthermore, they set job completion restrictions, any precedence relationships, and other model characteristics. Specifics of the model formulation will be presented in Chapter 4.

EIMS Data Base

The principle source for the input information used in the workload assignment (modified transportation) model and the scheduling (zero-one integer) model is the Engineering and Installation Management System (EIMS) data base. Maintained on a disc file for real time access, EIMS data is cataloged under 134 file records. These include milestones, priorities, workload identification numbers, anticipated resource requirements, and narrative job descriptions to name a few.

Since the EIMS data base was dedicated to E-I information, it was investigated for the items required as inputs to the two models. The workload assignment model required unit information (unit name and available man-hours), job information (workload identification number, and required man-hours), and cost information (in the form of distance between units and job locations). For each unit, the scheduling model required unit resource information (available skills) and job information (workload identification number, required skills, earliest start date, latest completion date, and duration).

The source for information on distances between a job location and each of the E-I units was obtained from the

Official Table of Distances, AFR 177-135 (44). Whenever listings were not found for a particular location, estimates were made using maps and the listings for the next closest location.

The remainder of information required by the models was obtained from the 2046 CIG in a product extracted from the EIMS data base. It listed the workload identification number, job location, estimated (required) man-hours, required skills, the assigned E-I unit, and milestones such as the team start and completion dates, allied support completion date, and material available date. Furthermore, it listed only those jobs which had not already started (installation, removal, or whatever) as of 5 August 1980, which were coded with a Required Operational Date/Programmed Operational Date in the first quarter of Fiscal Year 1981, and which were not already assigned to an ANG E-I unit.

One comment about the accuracy of information in the EIMS data base--a data system is only as good as the inputs made to it. It was apparent from several interviews and a recent report by the AFCC Inspector General that EIMS information is not always reliable. The problems range from an inability to make reliable milestone estimates except in the very short term, to uncertainty introduced by the supply system and the weather. In some cases, a general misunderstanding of the need for accurate EIMS information and its usefulness results in less than desirable care when making inputs to the system. Despite these problems and the errors which they could introduce, the EIMS remains the principle source of information for the models. It was decided that, for the purpose of this thesis, EIMS information would be considered accurate and up to date.

Many more than the 368 jobs finally used were originally listed in the EIMS printout. An extensive review of the listing revealed that not all of the entries would be suitable to include in the model. Therefore, a cull was performed. Examples of entries which were deleted are:

1. Amendments. When a job is amended, its workload identification number's eighth digit is increased by one. Unless other parameters in the line entry reflected a change, the original information was retained and the amendment line was deleted.

2. Associated jobs. Multiple entries which clearly were to be performed by the same team and during the same time frame were consolidated, as appropriate, into a single line entry.

3. Unknown location. In some cases, the location description carried the word "classified." Because the location is key to the model, these cases were deleted.

4. Overseas locations. Initially, workload assignment was to be conducted worldwide. However, the complexity of travel routes and the lack of accurate mileages in the

overseas area made this impossible. Therefore, these jobs were deleted and only seven E-I units were considered in the models.

The result of the cull was a listing of 368 jobs. In many cases, the required information was incomplete. On the basis of jobs with similar characteristics such as team skill composition, required man-hours and team start (completion dates), missing information was inserted. This was warranted by the need for a representatively sized data base, but one in which the accuracy relative to the real world was not as important. Information was required to test the models only. No comparison with actual assignments and scheduling was to be attempted.

Summary

Overall, the methodology of this thesis was to investigate management science literature for applicable models for workload assignment and scheduling. Consideration was given to the E-I environment as a model was developed for each case. A data base was established from an admittedly incomplete source, the EIMS data base. Finally, models were run with the data base. The sequence of activities for running the models is shown in Figure 3-6.

The next chapter presents the model formulations.

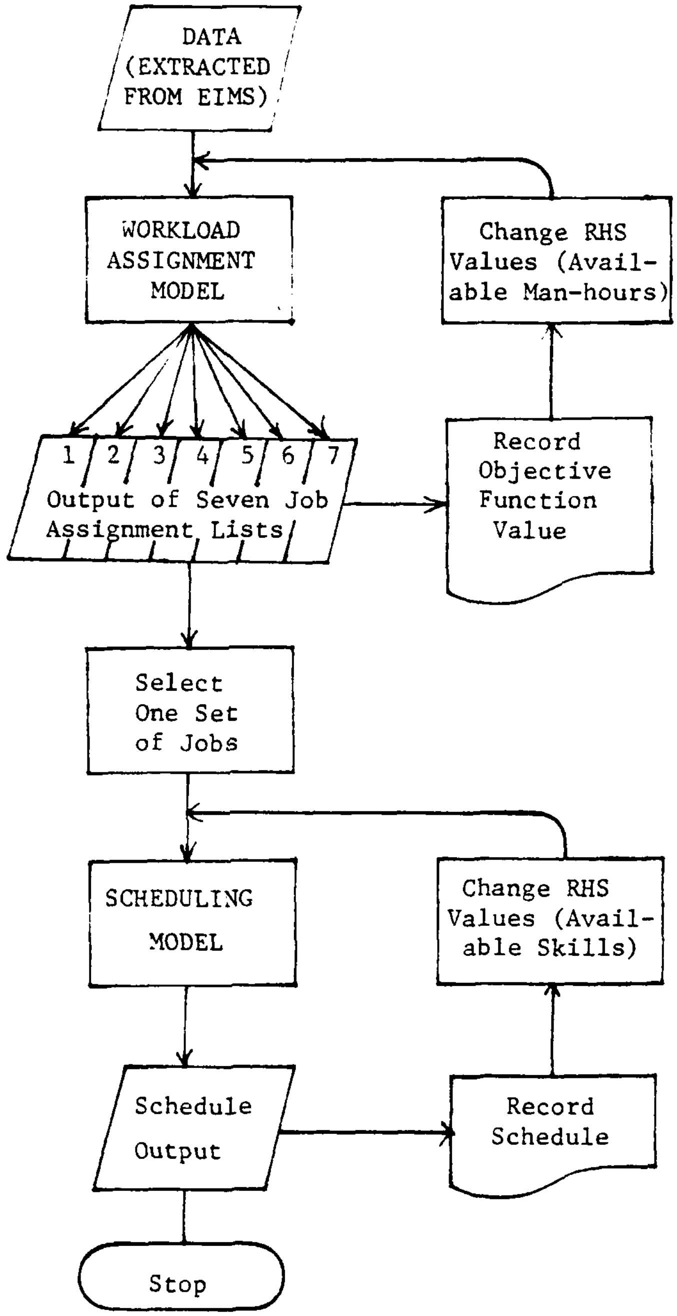


Figure 3-6

Full Scale Model Testing Sequence

Chapter 4

THE MODELS

This chapter presents the mathematical formulations of the workload assignment and scheduling models.

Workload Assignment Model

The workload assignment model is a linear program which minimizes the total one-way travel mileage resulting from the assignment of jobs to E-I units.

Objective function. The decision variables in this first model are the one-to-one pairings of each job with each E-I unit. Capable of only two values, a variable equals "one" if the job-unit pairing which it represents is selected, and "zero" if it is not selected. The variable coefficients are the one-way travel distances from the units' home bases to the job locations. An exception to this condition exists when a unit does not possess all of the skill authorizations[1] required by a job. Because the unit cannot legitimately perform the job, an extremely large distance coefficient is given to that variable. The model, in its attempt to

[1]Skill authorizations should be understood to mean the same as Air Force Specialty Code (AFSC) manpower authorizations. The term is used here because of its common usage in the E-I environment.

minimize the objective function, will ensure that this variable is not included in the final solution. Thus, the inappropriate assignment is avoided. The objective function takes on the following form:

$$\text{Minimize} \quad \sum_{i=1}^{M} \quad \sum_{j=1}^{N} \quad C_{ij}\, x_{ij} \qquad (4.1)$$

where

i = the index for identifying each of the M units.

j = the index for identifying each of the N jobs.

C_{ij} = the distance (one-way) in miles between the home base of unit i and job location j .

x_{ij} = the decision variable pairing unit i and job j .

<u>Constraints</u>. In the workload assignment model, there are three types of constraints: binary, man-hour, and job performance.

The first constraint type has already been implied by the definition of x_{ij} in the previous section. The binary constraint restricts the decision variable from taking on any values other than zero or one. Thus:

$$x_{ij} = \begin{cases} 1, \text{ if job } j \text{ is assigned to unit } j \\ 0, \text{ otherwise} \qquad \text{for all } i,j \end{cases} \qquad (4.2)$$

The man-hour constraint appears as:

$$\sum_{j=1}^{N} D_j x_{ij} \leq S_i \qquad \text{for all } i \tag{4.3}$$

where

D_j = the man-hours estimated to be required to perform job j .

S_i = the total man-hours available during the planning horizon for unit i .

The function of this constraint is to insure that the sum of the man-hours for all of the jobs assigned to unit i does not exceed the number of man-hours the unit has available. As discussed in Chapter 3, one of the reasons for selecting this form of linear program was to exploit the uses of these man-hour values which are the rim conditions of the transportation tableau given in Figure 3-3. Although the D_j values are fixed quantities, the S_i values may be changed to reflect the effects which various levels of resource availability (man-hours) will have on the assignment of jobs.

The last restriction is the job performance constraint. If the problem were not constrained in any way, the optimum result to the minimization of distance traveled would assign all $x_{ij}=0$. Thus the objective function would have a value of zero as well. But all $x_{ij}=0$ would mean no jobs were assigned to E-I units at all. The job performance constraint remedies this situation by requiring every job to be assigned. It further restricts the problem by requiring the assignment to be exclusively made. Consider its form:

$$\sum_{i=1}^{M} x_{ij} = 1 \qquad \text{for all } j \tag{4.4}$$

Summing over the index i , the constraint allows only one unit to be paired with each job j . No split assignments are possible.

Scheduling Model Formulation

Like the workload assignment model, the scheduling model is also a linear program. This application was derived from the basic model originally developed by Pritsker, Watters, and Wolfe (37). It was designed for multiproject scheduling with limited resources. The projects consisted of one or more jobs which may or may not have precedence requirements, multiple resource constraints, resource substitutability, job splitting capability, due dates, and/or concurrency of performance requirements (37:3).

Although the Pritsker, et. al., model had a wide variety of capabilities, it was determined that a more simple version would better serve this thesis effort. The basic formulation was reduced to the treatment of multiple projects each without any subactivities. This required several of the original equations to be altered. The reader is directed to References 21, 30, 35, and 36 for several discussions of the original model. One other point which must be emphasized is that in addition to certain modifications of the model, it was convenient to make several changes in variables and parameters to simplify use of the model during this research effort. This should be kept in mind if any comparison is made between the models.

Objective function. The objective function is composed of bivalent decision variables which indicate whether or not a job j has been completed in or before period t. The form for the model which uses "throughput time" as a schedule effectiveness measure is:

$$\text{Maximize} \quad \sum_{j=1}^{N} \sum_{t=e_j}^{G_j} t \, y_{jt} \tag{4.5}$$

where

j = the index for identifying each of the N jobs.

t = the index for identifying time periods.

e_j = the earliest time period in which job j can be completed.

G_j = the latest time period in which job j can be completed.

y_{jt} = the decision variable indicating the completion of job j in period t.

Throughput time for a job is the elapsed time between its earliest start and actual completion dates (37:7). Although this objective function does not specifically compute this difference, it does provide a relative measure of throughput time. For each job that has an earliest start a_j after period 1, there will be a "fixed cost" contribution of (a_j-1) to the objective function value. To remove this effect, the quantity $\sum_{j=1}^{N} (a_j-1)$ would be subtracted from the original result and the actual throughput time would be obtained. This was unnecessary for the purposes of this thesis.

Constraints. The scheduling model has binary, job completion, and resource constraints. Depending on the nature of the set of jobs being scheduled, it may also have sequencing, concurrency and/or nonconcurrency constraints.

Like the workload assignment model, the scheduling model's decision variables are binary. This first constraint takes on the following form:

$$y_{jt} = \begin{cases} 1, & \text{if job } j \text{ is completed in period } t, \\ 0, & \text{otherwise.} \end{cases} \quad \text{for all } j \text{ and for } t=\min a_j, \ldots, \max G_j \,. \tag{4.6}$$

Job completion constraints are required to ensure that a job is completed only once. For a given job j, $y_{jt}=1$ for a unique period t. In equation form, this becomes:

$$\sum_{t=e_j}^{G_j} y_{jt} = 1 \qquad \text{for all } i \,. \tag{4.7}$$

The third type of constraint, related to resource requirements and availability, represents the primary influence on the model. Recall from the Chapter 3 discussion of resource leveling that if an absolute or desired level of resource utilization is set, projects may not be able to be scheduled at their earliest start times. Instead, some shuffling of projects within their available slack time may be required to avoid resource demands during any one time period exceeding the absolute or desired level. The resource constraint examines each time period during the planning horizon for the resource requirements. It is written as:

$$\sum_{j=1}^{N} \sum_{q=t}^{t+d_j-1} r_{jk}\, y_{jq} \leq R_{kt} \quad \text{for } k=1,2,\ldots,K \text{ and for all } t=\min a_j,\ldots,\max G_j \quad . \tag{4.8}$$

where

q = a dummy index used for time periods.

k = the index for identifying each of the k resource types.

d_j = the duration, in periods, of job j .

r_{jk} = the number of resources of type k required by job j .

R_{kt} = the number of resources of type k available in period t .

In the linear program formulation, this constraint produces (at a maximum) K equations for each time period in the planning horizon.

The remaining constraint types--sequencing, concurrency and nonconcurrency--represent optional extensions of the basic model discussed thus far. The basic model assumes that the jobs are independent, whereas, the inclusion of any of these other constraints does not.

Sequencing establishes an order of precedence for job performance. Clearly, not all jobs to be scheduled in a planning horizon would have such a requirement. But, to produce a realistic schedule for E-I activities, the few jobs with preceding or following activities must be considered. A sequencing constraint where job m must precede job n has the form:

$$\sum_{t=e_m}^{G_m} ty_{mt} + d_m \leq \sum_{t=e_n}^{G_n} ty_{nt} \qquad (4.9)$$

where

m = a subscript identifying a unique job m .

n = a subscript identifying a unique job n .

This form of the constraint reduces the number of equations from the larger of $(G_m - e_m)$ and $(G_n - e_n)$ to a single equation for each sequencing relationship (37:11-12). An example of a sequencing requirement is when job m is a radar antenna removal and job n is the reinstallation of the same antenna at another location.

The concurrency and nonconcurrency constraints are similar to the sequencing constraint. Concurrency requires that job m and job n be performed simultaneously. This condition is achieved by requiring

$$y_{mt} = y_{nt} \tag{4.10}$$

If the jobs are of equal duration, they will be performed simultaneously. If, however, they are of different duration, this equation will have them completed at the same time, but the shorter job will start later. To establish concurrent performance of unequal duration jobs which start at the same time, the following is used:

$$y_{m(t+d_m-d_n)} = y_{nt} \quad (\text{if } d_m < d_n) \tag{4.11}$$

Nonconcurrency of jobs m and n requires that they must not be performed simultaneously, but allows them to be scheduled in any order (37:17). This final constraint takes the form:

$$\sum_{q=t}^{t+d_m-1} y_{mq} + \sum_{q=t}^{t+d_n-1} y_{nq} \le 1 \quad \text{for } t=\max\{e_m, e_n\},\ldots,\min\{G_m, G_n\}$$

Summary

The models presented in this chapter are summarized below. The workload assignment model is formulated as:

$$\text{Minimize} \quad \sum_{i=j}^{M} \sum_{j=1}^{N} C_{ij}\, x_{ij} \tag{4.1}$$

Subject to

$$x_{ij} = \begin{cases} 1, & \text{if job } j \text{ is assigned to unit } i \,, \\ 0, & \text{otherwise.} \qquad \text{for all } i \,,\ j \,. \end{cases} \tag{4.2}$$

$$\sum_{j=1}^{N} D_j\, x_{ij} \le S_i \qquad \text{for all } i \,. \tag{4.3}$$

$$\sum_{i=1}^{M} x_{ij} = 1 \qquad \text{for all } j \,. \tag{4.4}$$

where

i = the index for identifying each of the M units.

j = the index for identifying each of the N jobs.

x_{ij} = the decision variable pairing unit i and job j.

C_{ij} = the distance (one way) in miles between the home base of unit i and the location of job j.

D_j = the man-hours estimated to be required to perform job j.

S_i = the total man-hours available during the planning horizon for unit i.

The scheduling model is formulated as:

$$\text{Minimize} \quad \sum_{j=1}^{N} \sum_{t=e_j}^{G_j} t\, y_{jt} \tag{4.5}$$

Subject to

$$y_{jt} = \begin{cases} 1, & \text{if job } j \text{ is completed in period } t, \\ 0, & \text{otherwise.} \end{cases} \quad \text{for all } j \text{ and for } t = \min a_j, \ldots, \max G_j \quad (4.6)$$

$$\sum_{j=1}^{N} \sum_{q=t}^{t+d_j-1} r_{jk}\, y_{jq} \le R_{kt} \quad \text{for } k=1,2,\ldots,K \text{ and for all } t=\min a_j, \ldots, \max G_j \quad (4.8)$$

$$\sum_{t=e_m}^{G_m} t\, y_{mt} + d_m \le \sum_{t=e_n}^{G_n} t\, y_{nt} \quad (4.9)^1$$

$$y_{mt} = y_{nt} \quad (4.10)^1$$

$$y_{m(t+d_m-d_n)} = y_{nt} \quad (\text{if } d_m < d_n) \quad (4.11)^1$$

$$\sum_{q=t}^{t+d_m-1} y_{mq} + \sum_{q=t}^{t+d_n-1} y_{nq} \le 1 \quad \text{for } t=\max\{e_m, e_n\}, \ldots, \min\{G_m, G_n\} \quad (4.12)^1$$

where

j = the index for identifying each of the N jobs.

k = the index for identifying each of the K resource types.

m = a subscript identifying a unique job m.

n = a subscript identifying a unique job n.

---

[1]This constraint is included only when required to capture special scheduling problem characteristics.

q = a dummy index used for time periods.

t = the index for identifying time periods.

y_{jt} = the decision variable indicating the completion of job j in period t.

a_j = the earliest time period in which job j can be started.

e_j = the earliest time period in which job j can be completed.

d_j = the duration, in periods, of job j.

G_j = the latest time period in which job j can be completed.

r_{jk} = the number of resources of type k required by job j.

R_{kt} = the number of resources of type k available in period t.

Chapter 5

RESULTS

The purpose of this chapter is to present the results of the research effort. Discussion will begin with the preliminary tests conducted on each of the models. After the test solutions are analyzed, the full scale model results will be presented.

Preliminary Tests

To be certain that the models were properly formulated and coded, preliminary tests were conducted on both of the models using a very small selection of input data. This technique allowed comparisons to be made between the models' solutions and expected solutions. Due to the very small problem size, the expected solutions could be obtained simply by observation.

Workload assignment model. The task in the first model test was to make the optimum assignment of four sample jobs to three E-I units. The only criteria used to select the jobs from the EIMS listing were that each one should have a different location and that, under the old workloading concept, each would have been assigned to one of the three units used in the test. The tableau for the test run is shown in

Figure 5-1. This translates into the linear program formulation shown in Figure 5-2. Note that no consideration was given to assigning a big "M" distance in a cell to prevent the related variable from entering the solution.

The solution to the initial workload assignment test produced the absolute minimum value for the objective function. The man-hours available from each unit were sufficient to allow jobs to be assigned to the nearest E-I unit. Thus, the jobs at Loring, KI Sawyer, and Andrews were all assigned to the 485 EIG, whereas the job at Offutt was assigned to the 1827 EIS.

A second test of the model was conducted to see if it would behave predictably. Reducing the man-hours available from the 485 EIG below the level necessary to perform the three jobs assigned to it in the first test produced a different, but expected result. Tasking for the job at KI sawyer changed from the 485 EIG to the 1839 EIG with an increase in the objective function value.

Results for the tests are summarized in Table 5-1. They are reasonable solutions to the sample problems and reflect the expected outcomes. As the available man-hours were reduced below the sensitivity range of a right hand side value, other variables were forced into the equation. Furthermore, the objective function showed an increase in value. These findings implied that a relationship between the level of tasking (measured in man-hours) and travel

E-1 UNIT \ JOB j	LORING AFB ME[1] 0109A6B0	OFFUTT AFB NB 0062T9B0	KI SAWYER AFB MI 0911A4B0	ANDREWS AFB VA 4902R0D0	AVAILABLE MAN-HOURS
485 EIG GRIFFISS AFB NY	x_{11} 660	x_{12} 1182	x_{13} 862	x_{14} 388	(2) 4500
1839 EIG KEESLER AFB MS	x_{21} 1868	x_{22} 1009	x_{23} 1284	x_{24} 1029	(2) 4500
1827 EIS KELLY AFB TX	x_{31} 2428	x_{32} 925	x_{33} 1587	x_{34} 1606	(2) 4500
REQUIRED MAN-HOURS	617	2664	290	700	

Figure 5-1

Preliminary Workload Assignment Tableau

---

(1) Base names indicate the job location. The number shown is the workload identification number (WIN).

(2) These values were varied during the test.

ROWS \ COLUMNS	TYPE	LORING: 0109A6	OFFUTT: 0062T9	KISAWY: 0911A4	ANDREW: 4902R0	LORING: 0109A6	OFFUTT: 0062T9	KISAWY: 0911A4	ANDREW: 4902R0	LORING: 0199A6	OFFUTT: 0062T9	KISAWY 0911A4	ANDREW: 4902R0	Right Hand Side
		{------------------------(INTEGER=0,1)------------------------}												
MILES	(F)	660	1182	862	388	1168	1009	1284	1029	2428	925	1587	1606	
0485M4	(P)	617	2664	290	700									≤ 4500
1839C7	(P)					617	2664	290	700					≤ 4500
1827C6	(P)									617	2664	290	700	≤ 4500
LORING:0109A6	(Z)	1				1				1				= 1
OFFUTT:0062T9	(Z)		1				1				1			= 1
KISAWY:0911A4	(Z)			1				1				1		= 1
ANDREW:4902R0	(Z)				1				1				1	= 1

Figure 5-2

Preliminary Workload Assignment Model Linear Programming Tableau

Table 5-1

Preliminary Workload Assignment
Model Results

UNIT	485 EIG		1839 EIG		1827 EIS	
RUN	1	2	1	2	1	2
AVAILABLE MANHRS	4500	1500	4500	4500	4500	4500
LOCATION (RWMHRS)						
LORING (617)	***	***				
OFFUTT (2664)					***	***
KI SAWYER (290)	***			***		
ANDREWS (700)	***	***				
MHRS (TOTAL ASGD)	1607	907	0	700	2664	2664

RUN	1	2
Objective Function Value	2835 miles	3257 miles

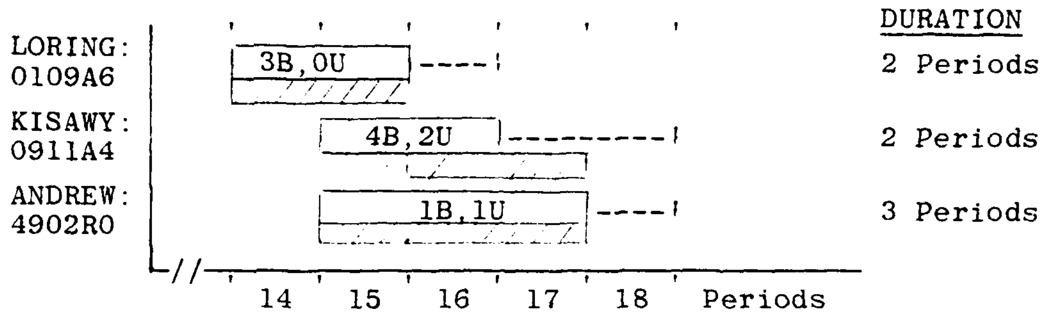
*** Indicates the job was assigned to the unit.

mileage could be established. It was recognized, however, that the test problem itself was too small to provide any valuable insight into the relationship.

Scheduling model. Preliminary testing of the scheduling model was conducted using contrived data. This was done to keep the test problem small. For the sake of continuity and only as an example, the three jobs assigned to the 485 EIG in the first workloading test just discussed were selected. All other information items were bogus. Time bar representation of the three jobs, their early start dates, duration, due dates, resource requirements, and possible schedules are all illustrated in Figure 5-3.

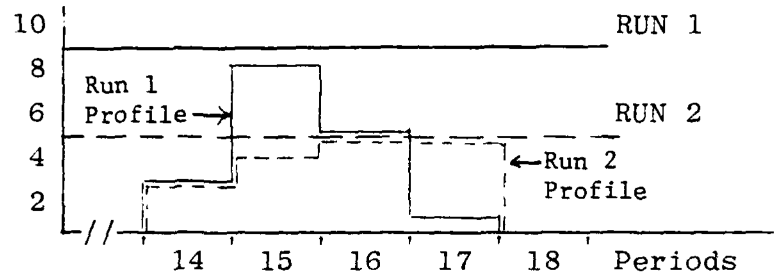
The scheduling model was formulated as described in Chapter 4 with the objective function which minimizes throughput time. It is subject to satisfying a series of job completion and resource constraints. No sequencing or concurrency/nonconcurrency constraints were included.

The first test supplied more than the number of skills of either type required in any one period by all of the jobs. As expected, this resulted in each job being scheduled at its earliest start position. Reducing the quantity of one skill type, the second test forced a different schedule. Had the schemes all been scheduled at their earliest starts, a resource shortage for skill B would have existed. The model properly sought the optimum feasible

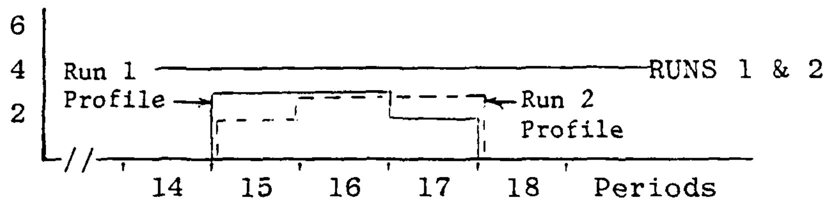


(a) Bar Chart

ESD = Early Start Date
--| = Due Date
= Run 1 Schedule (earliest start)
= Run 2 Schedule



(b) B Skill Resource Profile[1]



(c) U Skill Resource Profile[1]

Figure 5-3

Preliminary Scheduling Model Bar Chart and Profiles

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[1]"B" and "U" are used as shorthand notations to describe skill types for the Air Force Specialty Codes of 361X0 and 361X1.

schedule. The linear programming tableau for this problem is shown in Figure 5-4.

Analysis of these preliminary tests indicate that the scheduling model, like the workload assignment model, was properly formulated and performed as expected. Having established the validity of the models, they were applied to the larger data base.

Full Scale Workload Assignment Tests

The full scale model for workload assignment was initially run using the information on 368 jobs and seven CONUS E-I units.

Job information was obtained in the manner described in Chapter 3. The information required on the E-I units was the number of man-hours available during the planning horizon of four months, September through December 1980. This was obtained by counting the number of workdays in the period (holidays and weekends were excluded), then multiplying by an 8-hour workday. This product was itself multiplied by the total number of direct labor personnel assigned to each of the E-I units. Finally, the value of assigned man-hours computed thus far was multiplied by the direct labor factor of 0.635, a figure used by AFCC as a target for direct labor skill utilization. It allows 36.5 percent of indirect labor for activities such as administrative work, ordinary and sick leave, and additional duties (48).

ROWS \ COLUMNS	TYPE	LORING: DAY015	LORING: DAY016	KISAWY: DAY016	KISAWY: DAY017	KISAWY: DAY018	ANDREW: DAY017	ANDREW: DAY018	Right Hand Side — SKILLS REQUIRED: RUN 1	RUN 2
		{----------			(INTEGER=0,1)			---------}		
PERIOD	(F)	1	1	1	1	1	1	1		
LORING: 0109A6	(Z)	1	1						= 1	= 1
KISAWY: 0062T9	(Z)			1	1	1			= 1	= 1
ANDREW: 4902A4	(Z)						1	1	= 1	= 1
DAY014: SKIL-B	(P)	3							≤ 9	≤ 5
DAY014: SKIL-U	(P)	0							≤ 4	≤ 4
DAY015: SKIL-B	(P)	3	3	4			1		≤ 9	≤ 5
DAY015: SKIL-U	(P)	0	0	2			1		≤ 4	≤ 4
DAY016: SKIL-B	(P)		3	4	4		1	1	≤ 9	≤ 5
DAY016: SKIL-U	(P)		0	2	2		1	1	≤ 4	≤ 4
DAY017: SKIL-B	(P)				4	4	1	1	≤ 9	≤ 5
DAY017: SKTL-U	(P)				2	2	1	1	≤ 4	≤ 4
DAY018: SKIL-B	(P)							1	≤ 9	≤ 5
DAY018: SKIL-U	(P)							1	≤ 4	≤ 4

Figure 5-4

Preliminary Scheduling Model Linear Programming Tableau

For example, there are 82 workdays (21, 21, 18, and 22 workdays in September, October, November, and December 1980, respectively). With 656 hours available and based on the strength figures as of 30 June 1980, the 271 direct labor personnel from the 1849 EIS at McClellan AFB CA have 177,776 man-hours assigned. Applying the direct labor factor, the unit has 112,888 man-hours available for E-I jobs.

Severe difficulties with the initial run of the full scale model were experienced. It was not possible for the computer to reach an optimum solution within reasonable limits of core memory and computational time. Considering the size of the linear programming (LP) problem, this was not altogether surprising. Recall that the tableau for the preliminary workload assignment test involved only M=3 units and N=4 jobs. This translated into an LP formulation with 12 variables in the objective function (M x N) plus seven constraint equations (M + N) . The full scale tableau for workload assignment expands to M=7 units and N=368 jobs. Thus the full scale LP formulation contains an objective function with 2,576 variables and there are 375 constraint equations.

In an effort to determine the size problem which could be run, the number of jobs included in the problem was progressively reduced as repeat tests were performed. It was found that 150 jobs provided a problem whose size was workable within reasonable limits and yet, represented a large enough data base to still provide meaningful results. Using an arbitrary selection routine, 218 jobs were deleted from the 368 job data base, leaving 150 jobs to be assigned.

The goal of the full scale workload assignment model was to examine the relationship between job assignments and the level of E-I tasking. The former was to manifest itself in the measure of distance traveled to perform the job. The latter was identified in terms of the expended versus available direct labor hours. If the available hours during the planning horizon totalled 173,919 man-hours and all 150 jobs were performed, the utilization or tasking level would be 100 percent. Likewise, if the figure was 231,892 man-hours, 75 percent utilization (173,919÷231,892) would be reported.

It was necessary to scale the problem to the 150 jobs used. Therefore, each of the units' available man-hours were normalized to the required 173,919 man-hours as if those 150 jobs were the only ones to be performed during the planning horizon. The result was a set of right hand side values for the 100 percent utilization run of the model. To prepare for the tests, other right hand side value sets were calculated at decreasing, 5 percent step intervals down to 30 percent. These values and the objective function values resulting from the computer run are found in Appendix A.

Results. Figure 5-5 graphically depicts the results of the workload assignment model runs. The curve produced by the data points indicates that at very low levels (30 to 40 percent), the total one-way distance traveled was at its minimum of 59,770 miles. This represents the unconstrained problem condition. That is, no unit had an available man-hour value low enough to be exhausted, causing a job which would have been assigned to that unit to be assigned to another capable unit more distant from the job location. At somewhat higher levels of utilization or tasking (50 to 70 percent), the distance value begins to rise. Above 70 percent, the curve climbs very rapidly, reflecting the cost, in miles traveled, of limiting all units to the same percentage of man-hours expended.

Not all of the computer runs produced desired results. Figure 5-5 indicates that values for the 35 percent and 65 percent runs were not determined. Furthermore, all but one of the runs above 70 percent produced solutions to the linear program which were continuous rather than integer solutions. It is surmised that the reasons lie in the internal workings of the LP solution package used by the computer. While the continuous solution results cannot be fully accepted, they may properly represent the trend of objective function values. An integer solution obtained in a retest at 95 percent had a distance value of 1,082,191 miles compared to the 63,789 miles indicated by the

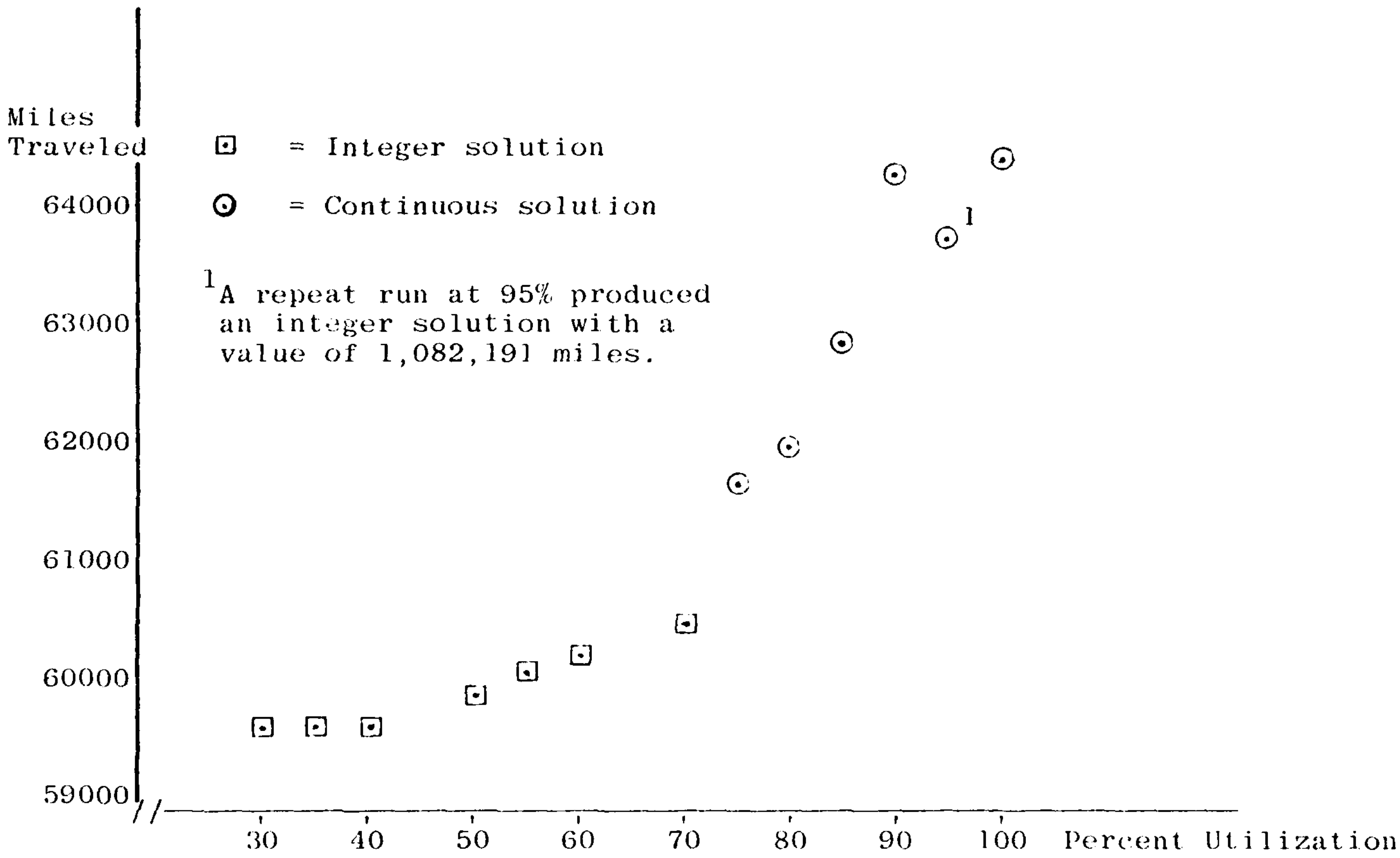

Figure 5-5

Relationship of Miles Traveled to Utilization

AD-A093 204 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 9/2
AN APPROACH TO WORKLOAD ASSIGNMENT AND SCHEDULING OF ENGINEERIN--ETC(U)
SEP 80 S A HAMMELL

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continuous solution. If this is a valid comparison, then the continuous solutions present a conservative version of the actual curve.

Full Scale Scheduling Tests

Tests on the full scale scheduling model were performed using the set of 15 jobs assigned to the 2046 CIG, Wright-Patterson AFB OH, by the 50 percent test of the workload assignment model.

As in the previous model, problem size posed computational difficulties. Even with the next to the fewest number of jobs assigned to any unit, the scheduling of jobs for the 2046 CIG produced a large LP formulation.

The key to the problem was in the number of periods between the completion of each job and the due date. For each slack period and earliest completion period, there was a variable in the objective function. With the earliest start, earliest completion, and latest completion dates, and the duration all registered in julian days, nearly 550 slack periods existed for this problem. Furthermore, there were 1,049 constraint equations. Considering that one goal of the scheduling model was to identify start and completion dates for a planning horizon six to eight months in the future, the precision of a schedule was determined not to be a critical factor. That is, reduction of all time values to a weekly versus daily basis would not adversely impact the model's application. The day to week time value adjustment significantly reduced the LP problem size to 120 variables in the objective function and 159 constraint equations.

The information from HQ AFCC which provided the total strength figures for the workload assignment model also detailed the number of personnel in each skill type for each unit. A routine for testing the relationship between schedule dates and resource availability was not as evident for this model as it was for the workload assignment model. Straightforward reductions in the number of personnel available in each skill type would not necessarily produce a smooth trend of increasing throughput time values. The reason for this is that there is an interdependence of skill types when more than just one type is required by a job. The testing routine finally established for the model was to select the most common skill type and to reduce its levels incrementally, observing the resulting objective function values.

Results. Figure 5-6 presents the results of the scheduling model test runs with various levels of B-type skills available. The first run of the scheduling model for the 15 jobs assigned to the 2046 CIG was the unconstrained case in which more than the maximum number of skills required during any period was available. This produced the expected result with all jobs scheduled at their earliest start position.

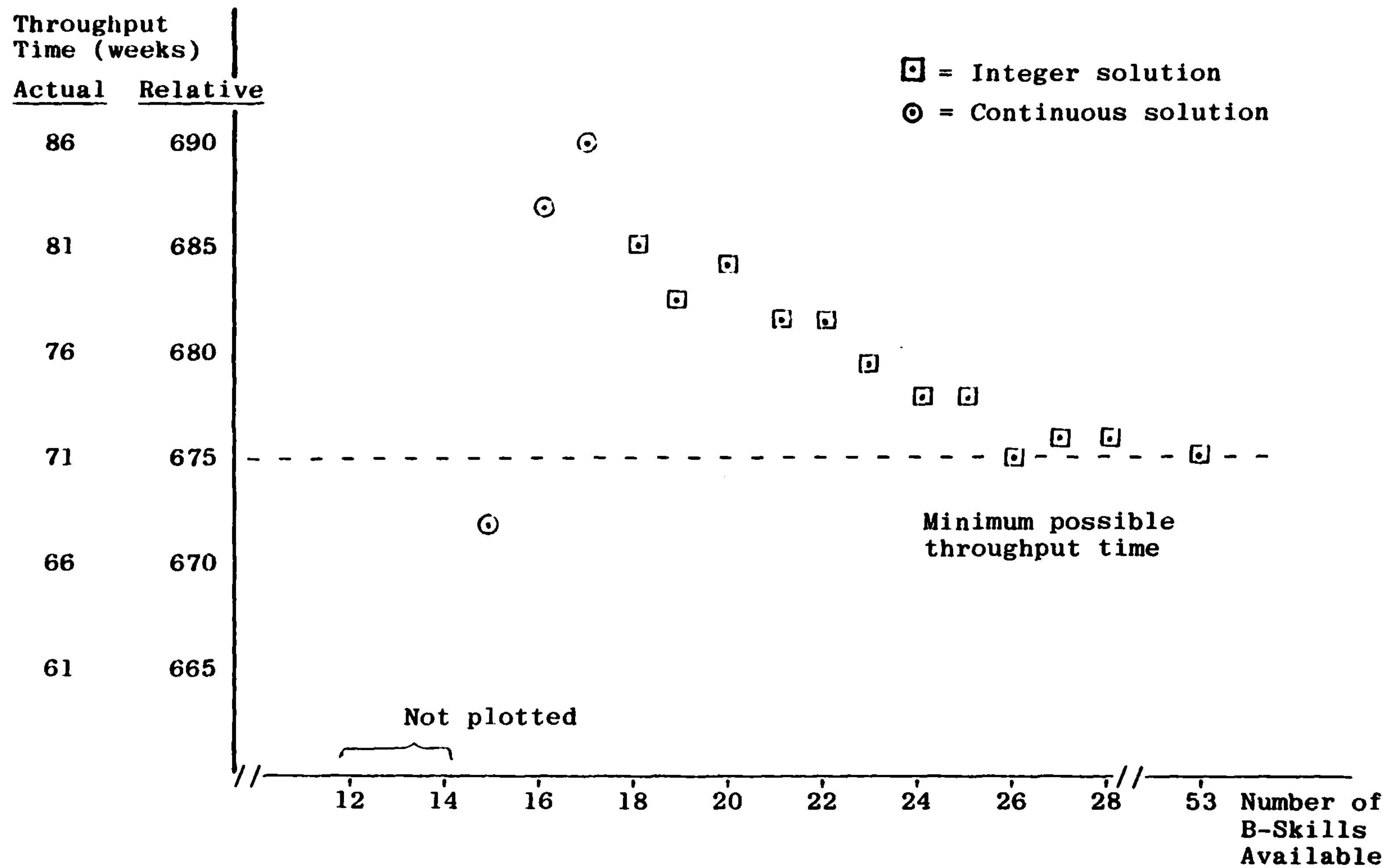

Figure 5-6

Relationship of Throughput Time to B-Skill Resource Availability

The objective function value was 675 weeks, which became 71 weeks of actual throughput time when the fixed component of 604 weeks was subtracted.

Successive reductions in the level of B-skills produced a trend of higher throughput times. Within four units of the calculated minimum thirteen units required to produce a feasible schedule in the planning horizon, the computer solutions again offered continuous rather than integer results. The conservative nature of the values obtained for twelve to fifteen units is evidenced by continuous solution throughput times which are well below the real minimum possible value of 71 weeks.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

The problem statement in Chapter 1 indicated that top management in AFCC had expressed an interest in improving the assignment and scheduling of E-I workload. While a considerable amount of research and literature which is applicable to the situation existed, none of the techniques offered by the field of study had been put to use as aids to the workloading system. Therefore, the purpose of this thesis was to investigate the workload assignment and scheduling problem for applications of appropriate management science techniques. While forming the research objectives, a series of four research questions was developed. Each will be restated and its conclusions separately discussed.

Research Question 1: What is the nature of the E-I workload assignment and scheduling problem?

The answer to this question was aptly presented by the discussion in both the Background of Chapter 1 and the Methodology, Chapter 3. Communications is a key to successful mission performance at all levels of the Air Force. Having a place in virtually every AF activity, it is imperative that existing capabilities are well supported and new requirements are expeditiously turned into operational systems. For most systems, this is accomplished by AFCC E-I activities throughout the world.

The basic task facing AFCC is to determine which of its dispersed units will perform a job and when it will be accomplished. Under the current AFCC workloading concept, jobs are assigned to communications areas and E-I units on a regional basis. The new concept eliminates these boundaries and seeks to minimize travel while leveling unit tasking and making effective use of personnel resources.

The conclusions drawn from this examination are that, first, the separable problems of assigning E-I jobs and then scheduling them each display the characteristics of problems commonly found in management science literature. Second, adaptations of existing problem solution formulations to these characteristics is possible. And finally, the techniques can be of some benefit to the command regardless of the organizational structure in which E-I activities are being carried out.

Research Question 2: What is the relationship between job assignments and the level of E-I unit tasking?

Development of a modified transportation model and its application to a linear programming solution package permitted this question to be addressed. Using man-hours as the rim conditions on the model formulation, it was determined that at low levels of utilization or tasking, the minimum possible distances would be traveled by E-I personnel.

However, once the uniform level of tasking began to increase toward the AFCC goal of 100 percent available skill utilization (available skills in hours = 63.5 percent of the assigned man-hours), the distance traveled also increases. At the highest percentage levels, this value climbs drastically.

These results were, of course, produced under a set of controlled conditions. The number of jobs considered was less than the total extracted from the EIMS and some information was estimated to fill gaps encountered. Nevertheless, the tradeoff curve in Figure 5-4 is characteristic of what would be produced by other job sets. The conclusion drawn from this is that AFCC goals under the new workloading concept are in conflict. Furthermore, even when a tasking or utilization level is set and the additional travel it forces is considered acceptable, units may not be worked at that level. This is because the jobs reassigned from other fully tasked units may not exhaust the number of man-hours which could be provided by the unit receiving the reassignment, a condition which would vary with each job set. E-I managers should consider these factors when reviewing job performance indicators under this concept.

Research Question 3: Can a computer programmed model be formulated to identify the optimum start and completion dates within a planning horizon for a series of jobs with given characteristics?

This question can be answered in the affirmative. The concept of automated scheduling based on an effectiveness measure such as throughput time was well documented and was, in fact, demonstrated by a sequence of tests scheduling fifteen jobs over a four month time frame. Although not specifically offered in the discussion of results, each integer LP model solution indicated which variables had a value of one. This identified the completion period t for each job j . Using the job duration, the start date could be calculated. Thus, the program and problem formulation are capable of setting optimum schedule dates for the planning horizon.

Research Question 4: What is the relationship between schedule dates and the level of available resources?

As stated in the Results, Chapter 5, the approach for examining this relationship was complicated by the interrelationship of skills which exists when more than one skill type is required by a job. To remove this influence of additional skill types on the schedules, the tests were run using a single constraining skill. The results demonstrated that for progressively lower skill levels, jobs had to be shifted within their slack time toward the due date, thus increasing the throughput time.

Once again, these results should be viewed as indicating the characteristics of the relationship between schedules and skill availability rather than the absolute relationship for all problems. The benefit derived is a potential for applying the model to a given set of jobs in a fixed planning horizon and being able to identify delays or exceeded due dates caused by skill availability.

Overall, this thesis has successfully achieved its purpose of examining the management science field and recommending an approach to the assignment and scheduling of E-I workload. It is noted that several simplifying assumptions made during the research moved the effort away from the real world environment toward the conceptual world. Consideration was not given to many of the E-I environment characteristics such as team chief availability; variability in the modes and costs of travel to and from job locations; and the stochastic nature of allied support performance, material availability, other milestones, and in job durations. Nevertheless, the research effort was of considerable scope and is expected to be of some benefit to AFCC. If not directly applicable, it will serve as an excellent basis for the data automation request for an automated workload assignment system to be submitted in the next fiscal year.

Recommendations

It is recommended that additional research be conducted as a follow-on to this thesis. It is necessary to expand this effort to incorporate some real world aspects in the models which had to be assumed away. Among these are the treatment of the stochastic nature of dates and performance times, the comparison of theoretical to actual assignments and schedules, and the examination of cost measures other than pure mileage for the workload assignment model. Additional study in these and other areas of E-I activity has potential benefits at all levels.

APPENDIX A

TEST VALUES

Table A-1

Man-hour Values

	A ASSIGNED PERSONNEL Mil+Civ=TTL	B ASSIGNED MAN-HOURS (A x 656 Hrs)	C AVAILABLE MAN-HOURS (B x 0.635)	D NORMALIZED AVAILABLE MAN-HOURS
485 EIG Griffiss AFB NM	329+78=407	266,992	169,540	38,262
1839 EIG Keesler AFB MS	301+97=398	261,088	165,791	37,393
1827 EIS Kelly AFB TX	183+58=241	158,096	100,391	22,610
1849 EIS McClellan AFB CA	233+38=271	177,776	112,888	25,392
1835 EIS Norton AFB CA	141+18=159	104,304	66,233	14,957
1926 EIS Robins AFB GA	126+72=198	129,888	82,479	18,609
2046 CIG Wright-Patterson AFB OH	146+32=178	116,768	74,148	16,696
TOTAL	1,852	1,214,912	771,470	173,919

Table A-2

Full Scale Workload Assignment Test Results

Percent Utilization	Total Available Man-hours	Objective Function Value (miles)	Solution Integer	Solution Continuous
100	179,919	64,283.0		X
95	183,072	63,789.0		X
90	193,243	64,160.1		X
85	204,610	62,794.4		X
80	217,399	61,951.0		X
75	231,892	61,557.5		X
70	248,455	60,362	X	
65	267,569	--	No solution	
60	289,865	60,104	X	
55	216,217	60,037	X	
50	347,838	59,936	X	
45	386,487	--	No solution	
40	434,798	59,770	X	
35	496,911	59,770		
30	579,730	59,770	X	

Table A-3

Full Scale Scheduling Test Results

Number of B-Skills Available	Objective Function (OF) Value (weeks)	Actual Through-put Time (OF-604 weeks)	Solution Integer	Solution Continuous
12	616.66	12.36		X
13	636.00	32.00		X
14	615.19	11.19		X
15	672.00	68.00		X
16	686.83	82.83		X
17	689.75	85.75		X
18	685	81	X	
19	682	78	X	
20	684	80	X	
21	681	77	X	
22	681	77	X	
23	679	75	X	
24	678	74	X	
25	678	74	X	
26	675	71	X	
27	676	72	X	
28	676	72	X	
53	675	71	X	

APPENDIX B

SELECTED COMPUTER INFORMATION

CONTROL CARDS FOR LP6000 SOFTWARE PACKAGE

```
0010##STRIP R(SL);,8,16
0020$;IDENT;WP1189,80C007,CAPT HAMMELL,AFIT/LSA(GSM80S) 57432
0030$;PROGRAM;RLHS,NDUMP
0040$;LIMITS;15,20K,,3000
0050$;PRMFL;H*,R,R,AF.LIB/LP.PAC
0060$;FILE;A1,X1R,10R
0070$;FILE;A2,X2R,10R
0080$;FILE;A3,X3R,10R
0090$;FILE;A4,X4R,10R
0100$;FILE;A5,X5R,10R
0110$;REMOTE;SO
0120$;DATA;I*
0130;PREPRO
0140;TITLE;##### SCHEDULING MODEL #####
0150;CONVERT;SOURCE=TDATA/IN,IDENT=PROB
0160;SETUP;SOURCE=PROB
0170;SET;OBJ=PERIOD
0180;SET;RHS=SKILL
0190;INTEGER
0200;OUTPUT
0210;ENDLP
0220;EXECUTE
0230$;DATA;IN
0240$;SELECTA;SCHDATA
```

```
C SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
C     PROGRAM "SCHTEST" BUILDS THE LP6000 INPUT CARD
C             STREAM FOR THE PWW SCHEDULING MODEL.
C SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
C
 CHARACTER LOC*6(100),WIN*6(100),SKLNM*6(16)
 DIMENSION ROMHRS(100),SKILL(16),KK(100,16),RK(100,16)
 INTEGER MILESET(100),ESD(100),DUR(100),DUE(100),E(100)
&,T,MIN,MAX,AMIN,GMAX,WKDUR(100),ESDWK(100),DUEWK(100)
&,KL(16),SKSUM(16),TT
C
 DATA (SKLNM(K),K=1,16)/"Z SKIL","B SKIL","U SKIL","R SKIL",
&"A SKIL","N SKIL","J SKIL","K SKIL",
&"W SKIL","X SKIL","C SKIL","M SKIL",
&"V SKIL","D SKIL","G SKIL","H SKIL"/
C
 DATA (SKILL(K),K=1,16)/5.0,16.0,35.0,26.0,
&24.0,18.0,0.0,0.0,15.0,4.0,6*0.0/
C
 N=15
 L=16
C
 READ(10,70)(LOC(J),WIN(J),ROMHRS(J),MILESET(J),DUR(J)
&,ESD(J),DUE(J),(KK(J,K),K=1,16),J=1,N)
 70 FORMAT(V)
C
 DO 77 J=1,15
 WKDUR(J)=DUR(J)/7.0
 ESDWK(J)=ESD(J)/7.0
 DUEWK(J)=DUE(J)/7.0
 E(J)=ESDWK(J)+WKDUR(J)-1
 77 CONTINUE
C
 PRINT," J   JOB    WEEKS   ESTART EFINISH DUEDATE"
 DO 88 J=1,15
 PRINT 86,J,LOC(J),WKDUR(J),ESDWK(J),E(J),DUEWK(J)
 86 FORMAT(1X,I2,2X,A6,4(I6,2X))
 88 CONTINUE
C
 IF(WKDUR(J).LT.1) WKDUR(J)=1
 IF((DUEWK(J)-ESDWK(J)).LT.1)ESDWK(J)=ESDWK(J)-1
C
 DO 99 K=1,16
 SUM=0
 DO 99 J=1,15
 SKSUM(K)=SUM+KK(J,K)
 SUM=SKSUM(K)
 99 CONTINUE
C
```

```
PRINT,"          MAX REQD   AVAILABLE"
DO 98 K=1,16
IF (SKSUM(K).LT.1.)GO TO 97
IF (SKSUM(K).GT.SKILL(K)) KL(K)=K
97 PRINT 970, SKLNM(K),SKSUM(K),SKILL(K)
970 FORMAT(2X,A6,3X,I3,8X,F4.0)
98 CONTINUE
C
WRITE(9,1000)
1000 FORMAT(4HFILE,3X,5HTDATA)
C
C
DO 1111 J=1,15
MIN=E(J)
MAX=DUEWK(J)
WRITE(9,1500)(LOC(J),WIN(J),T,T=MIN,MAX)
1500 FORMAT(1HS,6X,A6,1H:,A6,1H:,3HPER,I3,1X,13H(INTEGER=0,1))
1111 CONTINUE
C
WRITE(9,2000)
2000 FORMAT(1HL,6X,6HPERIOD,2X,3H(F))
C
AMIN=500
C
DO 2200 J=1,15
IF(ESDWK(J).LT.AMIN)AMIN=ESDWK(J)
IF(DUEWK(J).GT.GMAX)GMAX=DUEWK(J)
WRITE(9,2210)(LOC(J),WIN(J))
2210 FORMAT(1HL,6X,A6,1H:,A6,2X,3H(Z))
2200 CONTINUE
PRINT,"  AMIN=",AMIN," GMAX=",GMAX
C
DO 4444 T=AMIN,GMAX
DO 4444 K=1,16
LK=KL(K)
IF(LK.NE.K) GO TO 4444
WRITE(9,3000)(T,SKLNM(LK))
3000 FORMAT(1HL,6X,8HPER   : ,I3,3H  :,A6,2X,3H(P))
4444 CONTINUE
C
DO 5555 J=1,15
MIN=E(J)
MAX=DUEWK(J)
DO 5555 T=MIN,MAX
WRITE(9,5000)(LOC(J),WIN(J),T,T)
5000 FORMAT(1HA,6X,7HPERIOD,,A6,1H:,A6,4H:PER,I3,1H=,I4,1H.)
5555 CONTINUE
C
DO 5155 J=1,15
MIN=E(J)
MAX=DUEWK(J)
```

```
DO 5155 TT=MIN,MAX
WRITE(9,5100)(LOC(J),WIN(J),LOC(J),WIN(J),TT)
5100 FORMAT(1HA,6X,A6,1H:,A6,1H,,2(A6,1H:),3HPER,I3,4H= 1.)
5155 CONTINUE
C
DO 6666 T=AMIN,GMAX
DO 6666 K=1,16
LK=KL(K)
DO 6666 J=1,15
MIN=E(J)
MAX=DUEWK(J)
C
DO 6666 TT=MIN,MAX
RK(J,LK)=KK(J,LK)
IF(T.GT.TT)GO TO 6666
IF (TT.GT.(T+WKDUR(J)-1)) GO TO 6666
IF ((T.LT.ESDWK(J)).OR.(T.GT.DUEWK(J))) RK(J,LK)=0.
IF(LK.NE.K)GO TO 6666
IF (RK(J,LK).LT.1.) GO TO 6666
WRITE(9,6000)(T,SKLNM(LK),LOC(J),WIN(J),TT,RK(J,LK))
6000 FORMAT(1HA,6X,8HPER   : ,I3,3H  :,A6,
&1H,,A6,1H:,A6,1H:,3HPER,I3,1H=,F4.0)
6666 CONTINUE
C
DO 7777 T=AMIN,GMAX
DO 7777 K=1,16
LK=KL(K)
IF(LK.NE.K)GO TO 7777
WRITE(9,7000)(T,SKLNM(LK),SKILL(LK))
7000 FORMAT(1HB,6X,8HPER   : ,I3,3H  :,A6,1H,,6HSKILL=,F5.0)
7777 CONTINUE
C
DO 8888 J=1,15
WRITE(9,9050)(LOC(J),WIN(J))
9050 FORMAT(1HB,6X,A6,1H:,A6,1H,,9HSKILL= 1.)
8888 CONTINUE
WRITE(9,9100)
9100 FORMAT(6HEND****)
C
STOP
END
```

LP6000 INPUT CARDS FOR UNCONSTRAINED
PRELIMINARY SCHEDULING MODEL TEST

```
0010FILE    TDATA
0020S       LORING:0109A6:PER 15 (INTEGER=0,1)
0030S       LORING:0109A6:PER 16 (INTEGER=0,1)
0040S       KISAWY:0062T9:PER 16 (INTEGER=0,1)
0050S       KISAWY:0062T9:PER 17 (INTEGER=0,1)
0060S       KISAWY:0062T9:PER 18 (INTEGER=0,1)
0070S       ANDREW:4902R0:PER 17 (INTEGER=0,1)
0080S       ANDREW:4902R0:PER 18 (INTEGER=0,1)
0090L       PERIOD  (F)
0100L       LORING:0109A6  (Z)
0110L       KISAWY:0062T9  (Z)
0120L       ANDREW:4902R0  (Z)
0130A       PERIOD,LORING:0109A6:PER 15=  15.
0140A       PERIOD,LORING:0109A6:PER 16=  16.
0150A       PERIOD,KISAWY:0062T9:PER 16=  16.
0160A       PERIOD,KISAWY:0062T9:PER 17=  17.
0170A       PERIOD,KISAWY:0062T9:PER 18=  18.
0180A       PERIOD,ANDREW:4902R0:PER 17=  17.
0190A       PERIOD,ANDREW:4902R0:PER 18=  18.
0200A       LORING:0109A6,LORING:0109A6:PER 15= 1.
0210A       LORING:0109A6,LORING:0109A6:PER 16= 1.
0220A       KISAWY:0062T9,KISAWY:0062T9:PER 16= 1.
0230A       KISAWY:0062T9,KISAWY:0062T9:PER 17= 1.
0240A       KISAWY:0062T9,KISAWY:0062T9:PER 18= 1.
0250A       ANDREW:4902R0,ANDREW:4902R0:PER 17= 1.
0260A       ANDREW:4902R0,ANDREW:4902R0:PER 18= 1.
0270B       LORING:0109A6,SKILL= 1.
0280B       KISAWY:0062T9,SKILL= 1.
0290B       ANDREW:4902R0,SKILL= 1.
0300END***
```

LP6000 INPUT CARDS FOR CONSTRAINED
PRELIMINARY SCHEDULING MODEL TEST

```
0010FILE   TDATA
0020S      LORING:0109A6:PER 15 (INTEGER=0,1)
0030S      LORING:0109A6:PER 16 (INTEGER=0,1)
0040S      KISAWY:0062T9:PER 16 (INTEGER=0,1)
0050S      KISAWY:0062T9:PER 17 (INTEGER=0,1)
0060S      KISAWY:0062T9:PER 18 (INTEGER=0,1)
0070S      ANDREW:4902R0:PER 17 (INTEGER=0,1)
0080S      ANDREW:4902R0:PER 18 (INTEGER=0,1)
0090L      PERIOD  (F)
0100L      LORING:0109A6  (Z)
0110L      KISAWY:0062T9  (Z)
0120L      ANDREW:4902R0  (Z)
0130L      PER   :  14  :B SKIL  (P)
0140L      PER   :  15  :B SKIL  (P)
0150L      PER   :  16  :B SKIL  (P)
0160L      PER   :  17  :B SKIL  (P)
0170L      PER   :  18  :B SKIL  (P)
0180A      PERIOD,LORING:0109A6:PER 15=  15.
0190A      PERIOD,LORING:0109A6:PER 16=  16.
0200A      PERIOD,KISAWY:0062T9:PER 16=  16.
0210A      PERIOD,KISAWY:0062T9:PER 17=  17.
0220A      PERIOD,KISAWY:0062T9:PER 18=  18.
0230A      PERIOD,ANDREW:4902R0:PER 17=  17.
0240A      PERIOD,ANDREW:4902R0:PER 18=  18.
0250A      LORING:0109A6,LORING:0109A6:PER 15= 1.
0260A      LORING:0109A6,LORING:0109A6:PER 16= 1.
0270A      KISAWY:0062T9,KISAWY:0062T9:PER 16= 1.
0280A      KISAWY:0062T9,KISAWY:0062T9:PER 17= 1.
0290A      KISAWY:0062T9,KISAWY:0062T9:PER 18= 1.
0300A      ANDREW:4902R0,ANDREW:4902R0:PER 17= 1.
0310A      ANDREW:4902R0,ANDREW:4902R0:PER 18= 1.
0320A      PER   :  14  :B SKIL,LORING:0109A6:PER 15=  3.
0330A      PER   :  15  :B SKIL,LORING:0109A6:PER 15=  3.
0340A      PER   :  15  :B SKIL,LORING:0109A6:PER 16=  3.
0350A      PER   :  15  :B SKIL,KISAWY:0062T9:PER 16=  4.
0360A      PER   :  15  :B SKIL,ANDREW:4902R0:PER 17=  1.
0370A      PER   :  16  :B SKIL,LORING:0109A6:PER 16=  3.
```

```
0380A      PER    :  16  :B SKIL,KISAWY:0062T9:PER 16=  4.
0390A      PER    :  16  :B SKIL,KISAWY:0062T9:PER 17=  4.
0400A      PER    :  16  :B SKIL,ANDREW:4902R0:PER 17=  1.
0410A      PER    :  16  :B SKIL,ANDREW:4902R0:PER 18=  1.
0420A      PER    :  17  :B SKIL,KISAWY:0062T9:PER 17=  4.
0430A      PER    :  17  :B SKIL,KISAWY:0062T9:PER 18=  4.
0440A      PER    :  17  :B SKIL,ANDREW:4902R0:PER 17=  1.
0450A      PER    :  17  :B SKIL,ANDREW:4902R0:PER 18=  1.
0460A      PER    :  18  :B SKIL,KISAWY:0062T9:PER 18=  4.
0470A      PER    :  18  :B SKIL,ANDREW:4902R0:PER 18=  1.
0480B      PER    :  14  :B SKIL,SKILL=   5.
0490B      PER    :  15  :B SKIL,SKILL=   5.
0500B      PER    :  16  :B SKIL,SKILL=   5.
0510B      PER    :  17  :B SKIL,SKILL=   5.
0520B      PER    :  18  :B SKIL,SKILL=   5.
0530B      LORING:0109A6,SKILL= 1.
0540B      KISAWY:0062T9,SKILL= 1.
0550B      ANDREW:4902R0,SKILL= 1.
0560END***
```

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BIOGRAPHICAL SKETCH

Captain Scott A. Hammell was born in Great Falls, Montana, and grew up in the Minneapolis suburb of Golden Valley, Minnesota. A distinguished graduate of the AFROTC, he received his Bachelor of Science degree in Electrical Engineering from Montana State University in 1973. As a communications-electronics engineer, Captain Hammell has served in an engineering role at HQ Southern Communications Area, as a remote communications detachment commander at Monte Nardello, Italy, and as a site liaison officer with the 2187th Communications Group at Aviano, Italy, prior to coming to AFIT. His next assignment will be to the Management Studies Division, Directorate of Studies and Analysis, HQ Air Force Communications Command, Scott AFB IL.