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Master's thesis

A COMPUTER BASED SCHEDULING SYSTEM FOR USE BY BASE LEVEL CIVIL ENGINEERING IN DEVELOPMENT OF THE IN-SERVICE WORK PLAN.

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Captain John E. Kuhn, USAF

AFIT-LSSR-47-80

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Austere funding, reduced manning, and scarce resources make it important for Air Force Civil Engineering managers to take advantage of the most current and efficient technology available to accomplish routine and repetitive tasks. The requirement to allocate limited manhours among competing requirements in the In-Service Work Plan is becoming increasingly important. The authors of this thesis have developed a computer based scheduling system that constructs the first future month In-Service Work Plan as effectively as currently existing manual methods. The system uses a payoff matrix to determine the value of completing a specific work order and a linear programming model to determine the best mix of work orders to schedule from the pool of backlogged work orders. Use of the payoff matrix concept provides the flexibility for each Civil Engineering Organization to determine the factors to consider and their relative weights in arriving at a benefit value for each work order. The conclusion reached in the thesis is that the computer based scheduling system will construct the In-Service Work Plan as effectively as currently existing manual methods and that the system is feasible for use at any Civil Engineering Organization, provided adequate computer capability is available.

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A COMPUTER BASED SCHEDULING SYSTEM FOR USE BY BASE LEVEL CIVIL ENGINEERING IN DEVELOPMENT OF THE IN-SERVICE WORK PLAN

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Facilities Management

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Finally, we dedicate this thesis to our wives, Glenda and Lorraine, and our families, for their loyalty and devotion throughout this demanding year.

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CHAPTER I

PROBLEM

Introduction

Planning and scheduling problems arise in almost every area of human endeavor. These problems may range from proper phasing of activities and funding in the acquisition of a multi-billion dollar weapons system to preparation of a multi-course dinner. Exact algorithms or procedures do not exist for developing highly efficient schedules that will work for every given situation. Seemingly logical methods of scheduling may work well in one situation and poorly in another (7:124).

Scheduling has been defined "as a problem of sequencing [7:124]." This definition has been further refined by other authors to distinguish between the terms. Sequencing is defined as the determination of the order in which tasks wait at a work center to be performed. Scheduling is the specification of a clock time for the beginning and ending of the task (3:205). These definitions for scheduling and sequencing will be used throughout this research effort and the two terms will be considered as separate functions.

Planning will be considered as the process of determining in advance specifically what should be done in order to accomplish a particular task, how it should be done, where it should be done, and who should do it (1:99).

The need for planning and scheduling becomes exceedingly more important as funding and manning become increasingly scarce. The requirement for advanced planning and scheduling continues to receive increased emphasis as commanders at all levels stress the necessity to do more with less (2:63). Certainly the Base Civil Engineering (BCE) organization, by virtue of the nature of the work it does and its dependence upon manpower, material, and equipment, must avail itself of the most current scheduling techniques in order to continue to accomplish its mission. Major General Robert C. Thompson (Ret.), former Director of Engineering and Services, Headquarters USAF, acknowledged the requirement for innovation when he described "a good boss." He stated, "They sought new and better ways to do the job--and they encouraged those who worked for them to do the same thing [11:1]."

Background

Role of Base Civil Engineering. The primary mission of Air Force Civil Engineering activities is to "acquire, construct, maintain, and operate real property facilities, and provide related management, engineering, and other support work and services [13:p.2]." All of the activities of BCE are in support of the base's assigned mission. In actuality the BCE organization is strictly a service organization with a strong commitment to provide its customers the best possible support.

The primary means employed by BCE in providing work and services are through the use of in-service forces or contracted forces (13:p.4). This research effort is concerned only with the scheduling system for the in-service work forces. The entire in-service work force falls within the purview of the Operations Branch of the organization and the planning, scheduling, sequencing, and performing of in-service work is their primary function. Figure 1 depicts the organizational structure for a typical BCE organization (13:p.19).

Planning and scheduling of work is a major effort in any BCE organization. The In-Service Work Plan (IWP) is the mechanism used by the BCE organization to schedule work orders. As a support organization, every BCE squadron has the goal of satisfactory and timely accomplishment of work requirements. In order to realize this goal, BCE must use the resources at its disposal in the most efficient and effective manner possible. If the work force does the most important work first and does it right, it is successfully supporting the base's mission. It should be noted that the objectives associated with

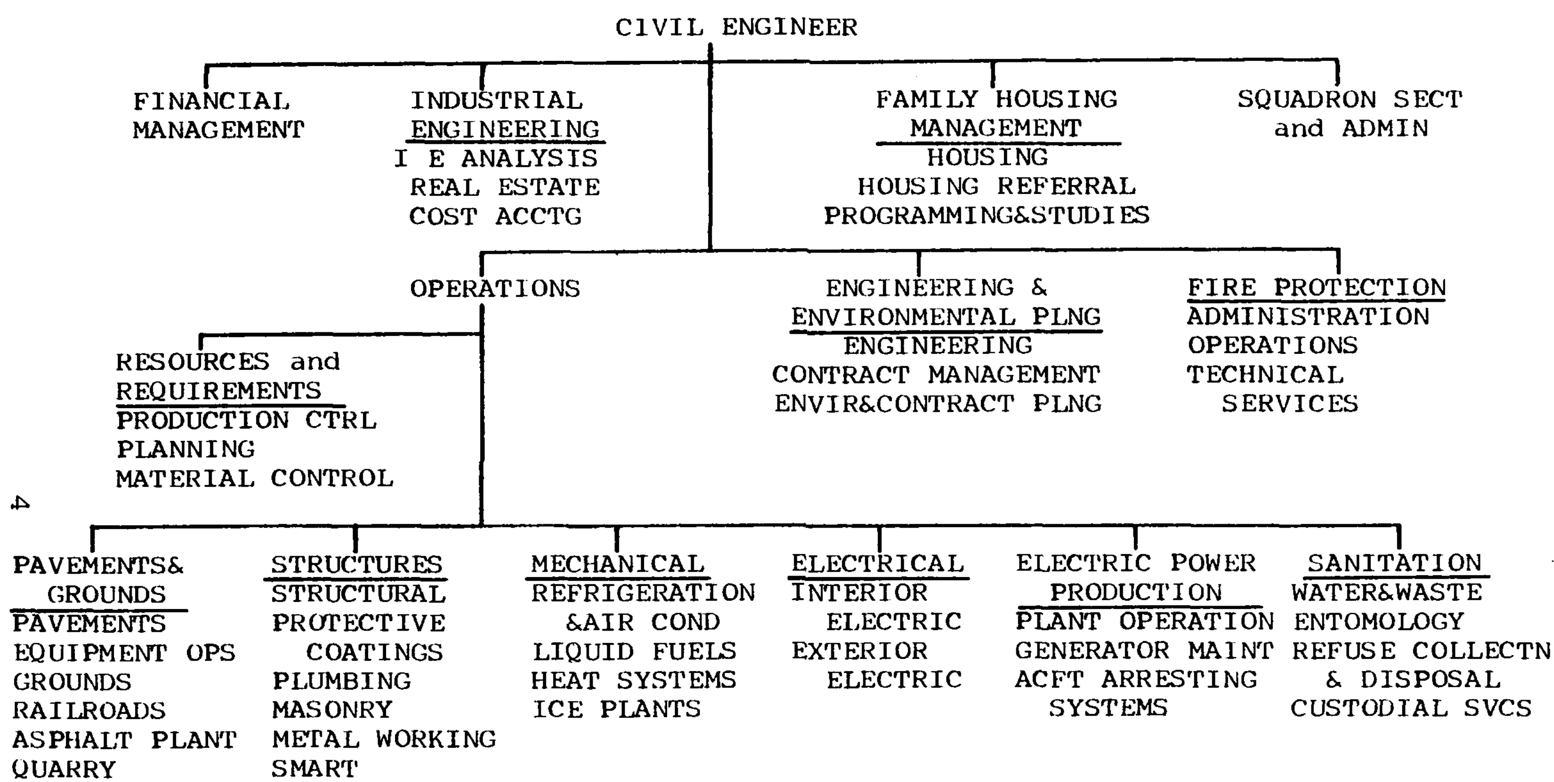

Fig. 1 Organizational Structure for a Typical Base Civil Engineering Organization. (AFR 85-10[C3], Operation and Maintenance of Real Property. 22 September 1978)

mission accomplishment are universal to Air Force Civil Engineers throughout the world (10:34).

Flow of work requirements. The BCE organization primarily supports the other base organizations by accomplishing work on real property facilities. The flow of work requests through the Operations Branch is a straightforward process which begins with a verbal or written request for accomplishing some specific work. Figure 2 is a diagram of the work order flow through the Operations Branch. The first action is for the Production Control Unit to determine if the work is a BCE responsibility. If the work is accepted, the next action is to establish the priority and classification of the work. The priority ranges from one to four with one being the highest priority (12:p.4-2). The work is then classified either as maintenance, repair, or construction. This determination is based on the definitions provided in AFM 86-1, Programming Civil Engineer Resources (14:pp.2-1 to 2-3). The next action is to decide whether the work is appropriate for in-service or contract accomplishment. This decision is made by the Chief of the Resources and Requirements Section. If the work request is to be accomplished by in-service work forces, the work must be authorized by either a job order or a work order. In AFR 85-1, Resources and Work Force Management, a work order is

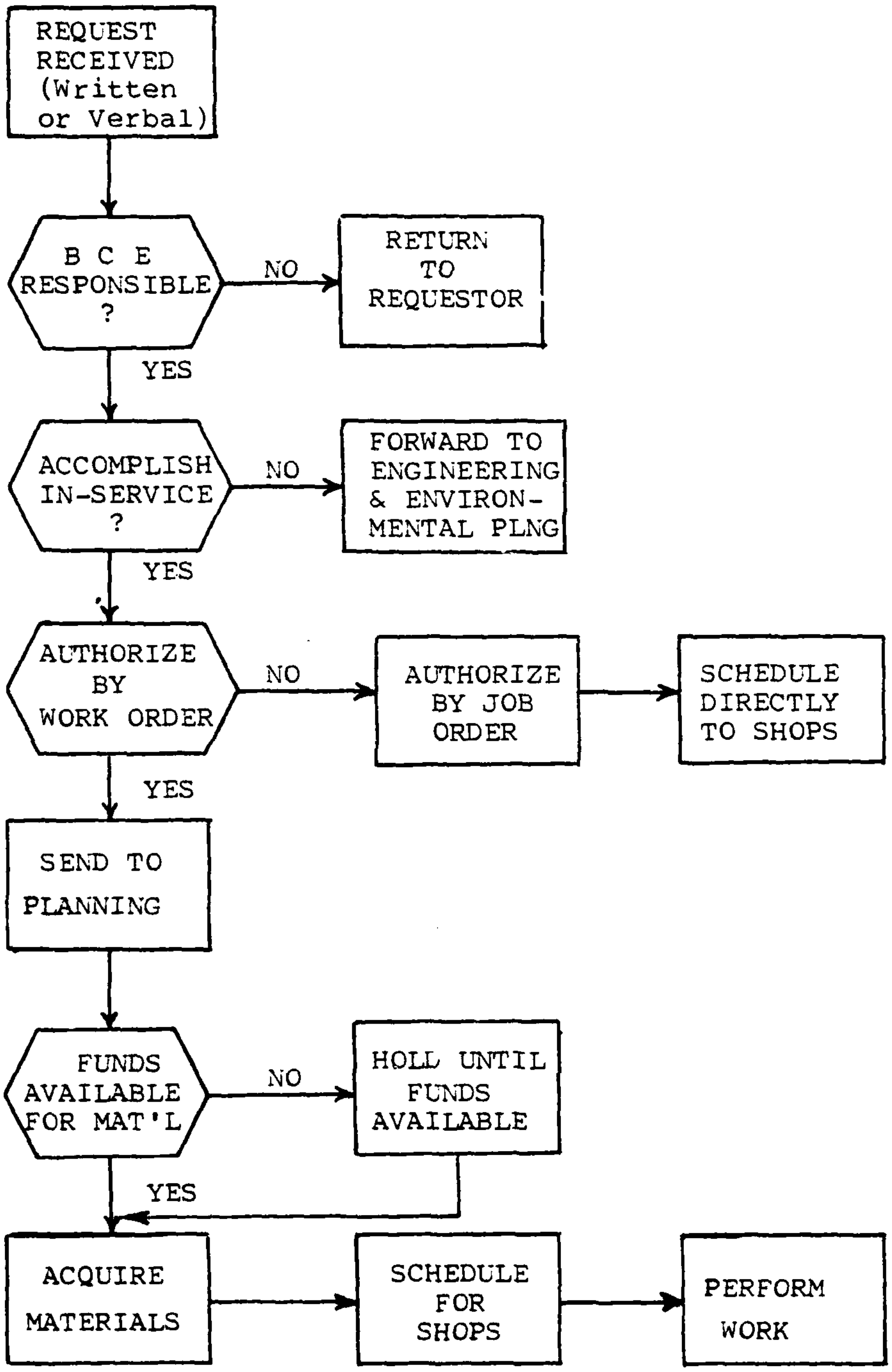

Fig. 2 Work Order Flow Through the Operations Branch

described as:

> A way to control large or complex jobs. The decision to use a work order is based on the need for detailed planning, capitalization of real property records, collecting reimbursements, and gathering data for review and analysis [12:p.8-1].

All other types of in-service work are authorized by job order, which is a "fast way to authorize work that does not require detailed planning (12:p.6-1)."

Since this research effort is concerned only with the scheduling system for work orders, the processing of work orders will be examined in more detail. Once the work request has been authorized for accomplishment by work order, a control number is assigned by Production Control to the work request. Next the work order control number and other descriptive information about the work order are entered into the work control subsystem of the Base Engineer Automated Management System (BEAMS).

BEAMS is primarily an automated performance reporting system. There are eight subsystems of BEAMS, of which the work control subsystem is used in conjunction with work orders. The work control subsystem merely tracks the progress of the work order. Once the work actually begins, BEAMS accumulates the expended manhours and material costs and can provide performance information based on the original estimate of manhours and material costs. BEAMS has been described as the most comprehensive performance reporting system in use in the Air Force (6:70). Even so, prior to actually beginning the work, the work control subsystem of BEAMS is strictly passive in that it only records and stores information about the work order. The use of BEAMS in the scheduling of work orders is limited to generating lists of work orders by priority, class of work, requesting organization, date of request, or by any other common characteristic. BEAMS is unable to perform any of the scheduling function of determining the combination of work orders that will utilize all of the available manhours and also assure the higher priority work is accomplished first.

After it has been input into BEAMS, the work order is then forwarded to the Planning Unit for preparation of the sequenced work plan, material requirements list, and estimate of the manhours required to accomplish the work. When the Planning Unit is finished, the work order is returned to Production Control and BEAMS is again updated.

Production Control now determines the start date of the work based on the priority of the work, the manhours availability, the completion date the customer requested, and the material lead time (12:p.8-2). The customer is also notified of the estimated start date.

Next the Chief of the Resources and Requirements Section must decide whether or not to authorize the ordering of materials for the work order. This decision is predicated on the availability of funds. If funds are not available the work order is held until funds become available. When funds are available, the work order is sent to Material Control for the acquisition of materials.

When all the required materials are received, the work order is returned to Production Control, where the estimated start date is reviewed for attainability. If necessary the date is revised, the customer is notified, and BEAMS is updated. The work order now awaits scheduling to the specific shops for work accomplishment. The IWP Scheduler is responsible for selecting the specific work orders that will comprise the current and first future month of the In-service Work Plan.

<u>The In-Service Work Plan</u>. The overall procedure for processing approved work orders is called the In-Service Work Plan (IWP). AFR 85-1, <u>Resources and Work Force Management</u>, describes the IWP as follows:

> The IWP is the management tool used to match work requirements with available shop resources. It is used to make commitments to customers and time phase work to keep the shops productive [12:p.11-1].

The IWP consists of a written portion, an automated portion, and visual charts.

The written portion of the IWP consists of work sheets (AF Forms 919, BCE In-Service Work Plan Work Sheet) for the current and first future month showing how manhours are allocated for the work to be done. Also the projected available manhours for the second and third future months are shown on the same type of work sheet (12:p.13-1). Consequently, the actual planning horizon for the firm work order schedule is two months with the projected manhours known for two additional months.

The BEAMS work order backlog report (PCN: SF100-360) is the automated portion of the IWP. If work orders are entered in discrete groups, corresponding to the projected month of accomplishment, BEAMS can be used to show how the work orders will flow into the work order schedule (12:p.13-1).

The visual charts show the status of every work order currently in the system. Every work order is in one of the following categories:

1. Scheduled for the current or first future month.
2. In Job Stoppage status.
3. Materially complete.
4. In Material Control.
5. Awaiting Funds.
6. In Planning.

These charts give the BCE management a visual display of the information it needs to make decisions on the in-service work force (12:p.13-1).

The IWP Scheduling Process

The scheduling of work orders in a BCE organization is the purpose of the IWP. Materially supported work orders are grouped together based on the month that the actual physical work is expected to be started. The decision as to when to schedule a specific work order is made by the IWP scheduler based on many factors. The flow of work orders from materially supported to completion is the functional responsibility of the IWP scheduler. Figure 3 is a representation of how work orders flow through the scheduling process and the inputs the IWP scheduler normally considers are indicated. Essentially what the IWP scheduler is tasked to do is determine the best combination of the available work orders to be scheduled against the available IWP manhours.

It is clear from Figure 3 that work orders that are scheduled in the current month IWP can be removed and placed in job stoppage status. Typically, this occurs when projected manhours are not available, additional required material is unavailable, some unforseen site condition necessitates additional planning, required special equipment is not available, or the weather prevents the work from continuing. The only other ways a work order can leave the current month IWP are to be completed or carried over into the next month's IWP.

Work orders coming out of job stoppage status or being carried over into the next month are given first preference by the scheduler for the available IWP manhours. For example, a work order that is carried over from the previous month would be continued and completed

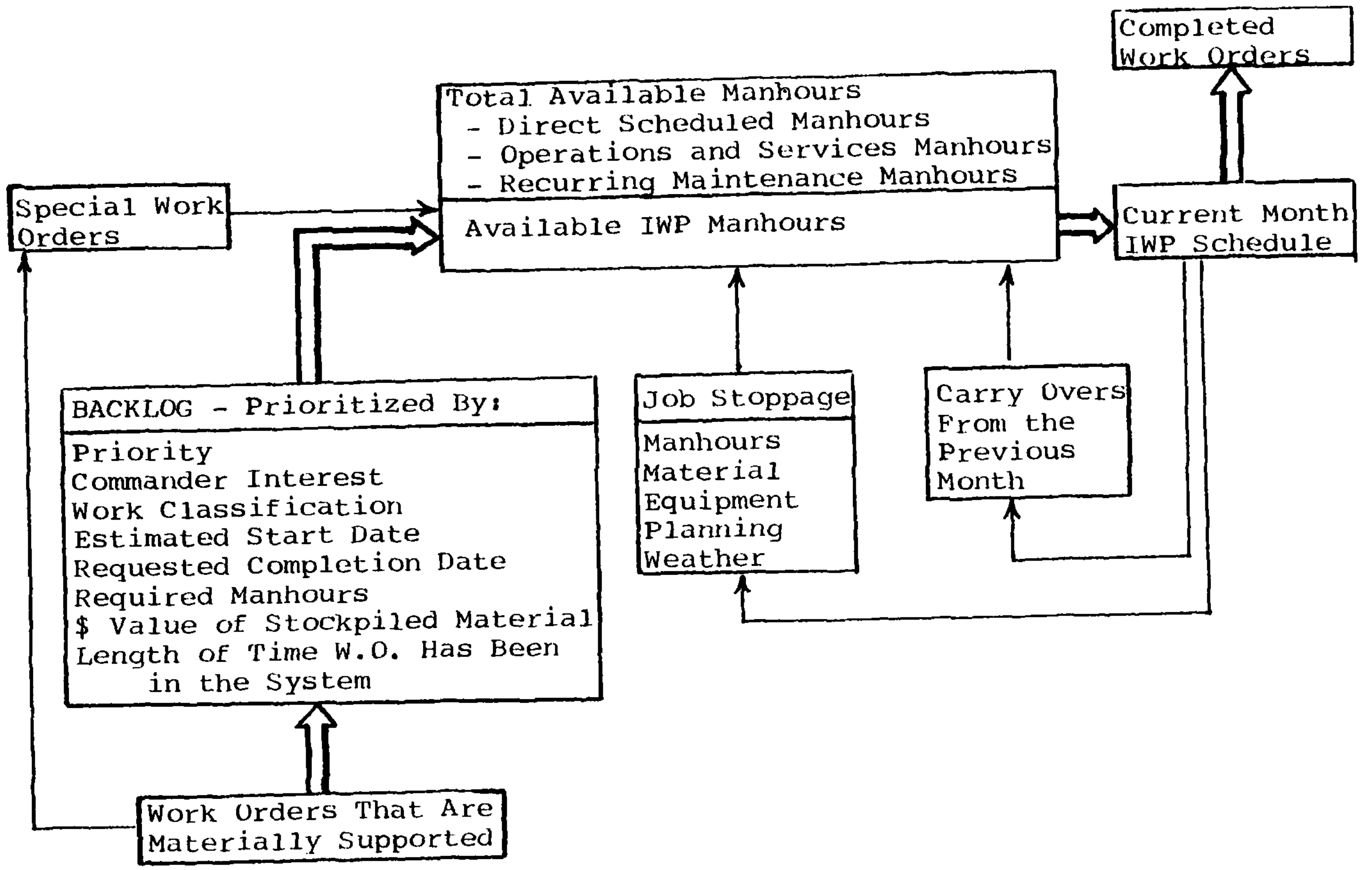

Fig. 3 Flow of Work Orders Through the IWP Scheduling Process

rather than scheduling new work orders that would use up all of the available manhours.

Figure 3 also indicates that the only inputs that compete for the remainder of the IWP manhours after job stoppage and carried over work orders have been scheduled are special and backlogged work orders. The special work orders are considered before any of the backlogged work orders. Special work orders comprise the entire spectrum of "hot" projects that must be injected into the schedule.

The normal or routine flow of work orders through the IWP scheduling process is indicated by the double lines in Figure 3. Consequently, the IWP scheduler must decide what backlogged work orders are to be scheduled once the carry over, job stoppage, and special work orders have been scheduled. Scheduling the backlogged work orders is the real essence of the IWP scheduler's task in developing the IWP. Knowing that all available manhours must be assigned, the scheduler must determine what combination of backlogged work orders to schedule. In deciding which one to schedule, consideration must be given to numerous factors. Which factors to consider and how much emphasis is given to each factor is not easy to determine. It is contended that these factors can be quantified and combined into a payoff matrix which will eliminate much of the subjectivity from the work order evaluation process. The payoff matrix concept is discussed in more detail in the following section.

Payoff Matrix Concept

In order to determine which work order to consider scheduling first, some method must be established for determining how much completing any one work order is worth. One problem with the existing scheduling system is that often no rationale can be shown for the inclusion of specific work orders into the IWP. If a payoff matrix is used to quantify the various factors considered in the decision process, then an objective evaluation of the worth of a work order can be derived and the payoff matrix provides a basis for the decision.

An example of a payoff matrix using three factors is shown in Figure 4. The three factors considered are the priority of the work order, whether or not the work order is of commander interest, and the work classification. The priority of a work order is based on the definitions provided in AFR 85-1, Resources and Work Force Management, and must be determined for every work order (12:p.4-2). The numerical values chosen to represent the priorities are arbitrary with the higher numbers corresponding to the higher priorities. For example, priority one equals 40 and priority two equals 13 in this instance. The commander's interest in a work order is typically a simple yes or no. In this example, four equals yes and one equals no. The last factor considers the work classification of the work order. A convincing argument can be made for the BCE organization preferring to do repair work first,

Work Classification		Priority of Work Order: (I) 40	(II) 13	(III) 4	(IV) 1	Command Interest: YES 4	NO 1
Repair	3	480 / 120	136 / 39	48 / 12	12 / 3	4	1
Maintenance	2	320 / 80	104 / 26	32 / 8	8 / 2	4	1
Construction	1	160 / 40	52 / 13	16 / 4	4 / 1	4	1

Fig. 4 Payoff Matrix Example With Three Factors

maintenance work next, and construction work last (5:28). In this example repair equals three, maintenance equals two, and construction equals one.

The numerical values for the factors are multiplied together, in this example, to yield the payoff values. For instance, a priority three, commander interest, maintenance work order is worth 32, while a priority two, non-commander interest, repair work order is worth 39. In a similar fashion every possible combination of the three factors can be assigned a value using the matrix concept. The numerical values or weights, that are assigned to each factor can be determined by each BCE organization. Also, which factors to include in the payoff matrix and how to combine the factors to yield the payoff value, can also be determined locally. For instance, one BCE organization might decide that if a project is of commander interest, then the priority of the work order is effectively increased by one. Using this rule, a priority three, construction work order with commander interest would have a value of 13 instead of the value of 4 which would have been assigned to this same work order without commander interest. Also, the factors might be additive instead of multiplicative. For instance, for every month a work order has been in the BCE organization its payoff value could be increased by two units.

The payoff matrix concept is a visable, systematic approach to deciding the value of a work order. The concept is very adaptable in that the factors, the weights of the factors, and the rule for combining the factors can be tailored to a specific BCE organization's requirements.

Justification of the Research Effort

Political, economic, strategic, and command requirements constantly change the priorities and availability of the resources which the BCE organization must utilize. Civil Engineering operations are of such a dynamic nature that planners must react to changes on a continuing basis (5:14-15). The key to success in the scheduling activities of this organization is flexibility (10:35).

The need for flexibility makes the use of the computers attractive for BCE scheduling. The computer's ability to rapidly and accurately perform repetitive operations and manipulate large volumes of data far exceeds that of man. The need for this ability was highlighted in a recent Inspector General Report of a BCE organization in which it was revealed that 814 work orders, involving more than 140,000 manhours and $422,000 of material expenditures, were backlogged (15:C-1). Proper consideration of such a large number of work orders is clearly beyond the capabilities of current manual methods to easily accomplish, but are well within the abilities of the computer.

Flexibility is a characteristic lacking in the current manual system of scheduling the IWP. The lack of flexibility is illustrated by a situation which frequently occurs when an unexpected project must be injected into the IWP in the "eleventh hour." The injection of this new work order results in the rejection of one or more previously scheduled work orders potentially freeing manhours in some shops. The time available to the IWP scheduler, with the manual system, typically limits him to the consideration of only manhours in an effort to shuffle the schedule to allow for the new work order and insure no shop manhours go unscheduled. Very little consideration can be given to other factors such as the customer commitments, classes of work, dollar amount of materials being stored for other work orders, and how long the work order has been in the IWP. The assimilation and correlation of such varied and voluminous information is clearly a job better suited for a computer than a human.

In their research effort, R. G. Bush and R. E. Richardson discovered little research being done toward improving either IWP development or weekly scheduling within Air Force Civil Engineering. Instead, most articles dealt with the overall IWP and its importance to BCE operations (5:16). A literature review indicates that this situation has not changed. However, the review revealed numerous articles dealing with solutions to planning and scheduling problems in the civilian industrial sector. These articles indicated that in recent years extensive use of the computer has been made in the area of work scheduling.

Of the large number of mathematical models discussed in the literature, some form of linear programming seems to be the most common technique in use. The linear programming technique is characterized as dealing with the problem of allocating limited resources among competing activities in the best possible way (8:15). Scheduling problems have similar characteristics in that they deal with the distribution of limited production manhours among various alternatives to accomplish some goal. This similarity between linear programming and scheduling explains the popularity of this technique observed in the literature review.

The characteristics common to linear programming and scheduling problems are inherent in the construction of the IWP for the BCE organization. The IWP involves the allocation of limited funds and available shop manhours among many competing work orders. The ultimate work schedule for the IWP would be the optimal combination of work orders based on:

1. the priority of the work order.
2. the manhour availability.
3. the requested completion date.
4. utilizing all available shop manhours.
5. commitments made to the customer.

6. classification of the work order.
7. the material costs.
8. weather or equipment limitations.

In their research effort, Bush and Richardson developed a schedule using (0,1) integer linear programming which was at least as good as manually derived solutions (5:87). It should be noted that (0,1) integer linear programming is a special type of linear programming that only permits the decision variables to take on a value of either 0 or 1, whereas linear programming allows the decision variables to take on any non-negative value (8:553). Bush and Richardson's solution, however, did not achieve the efficiency or the effectiveness desired. For example, a small-scale problem involving 15 work orders took two hours to manually schedule. This same problem took their model 22.5 minutes of computer operating time to achieve an equivalent solution. The inefficiency of the model became even more apparent in a large-scale problem for which seven hours of computer operating time were used in achieving a workable solution without achieving optimality (5:87). The model was ineffective in that it did not schedule all of the available shop manhours which is a basic goal of the IWP scheduling process.

The IWP is a highly structured, formal method of tracking and scheduling work orders. Even though BEAMS is a useful automated means of tracking work orders, the actual scheduling decisions are made by humans. These schedules are typically developed "heuristically with primary consideration given to commitment of all available manhours against work requirements [5:11]." Heuristic procedures are intuitively designed, trial and error in nature, and do not guarantee an optimal solution (8:17). It is the intent of this research effort to develop a more efficient scheduling system and demonstrate that the computer can be used as an effective tool in the construction and modification of the IWP.

Problem Statement

The need exists for a computer based scheduling system for use in the construction and modification of the In-Service Work Plan for base level Civil Engineering Squadrons. The present manual scheduling system lacks the flexibility for rapid and effective modification of the In-Service Work Plan as revisions are required.

Objectives

The primary objective is to develop a computer based scheduling system that is capable of effectively constructing the In-Service Work Plan and rapidly incorporating revisions into the work plan.

A secondary objective is to refine the scheduling system for practical application at base level.

Research Questions

1. Can a computer based scheduling system be

developed that will construct the In-Service Work Plan as effectively as existing manual methods?

2. Is the computer based scheduling system able to effectively and rapidly incorporate revisions into the work plan?

3. Is the computer based scheduling system feasible for use at base level Civil Engineering Squadrons?

CHAPTER II

METHODOLOGY

Overview

This chapter consists of a discussion of how the research effort was carried out. Included are discussions of the breadth of the study, the data collection plan, how the computer based scheduling system was assessed, and the plan for answering the research questions which in turn determined the success of the research effort. Summary lists of assumptions and limitations pertaining to the computer based scheduling systems are also included.

Breadth of Study

Universe. The universe under study consisted of all U.S. Air Force BCE organizations. With the exception of possible wartime missions, the basic objective of the BCE organization differs very little from base to base. The BCE activity in the engagement of wartime missions is considered to be atypical and as such was not addressed in this research effort. Although the size of BCE organizations varies greatly and the environmental circumstances under which they operate may be vastly different, their basic objective is the same: to complete work requests received from base organizations.

Population. The population under study was limited to BCE organizations that utilize the IWP schedule. Although the basic objective remains the same for all BCE organizations, it must be recognized that there are circumstances which will affect the manner in which the BCE activity goes about accomplishing the objective. Such things as the Major Air Command (MAJCOM) to which the organization is assigned, the desires of the local commander, the economic environment, and location of the community in which the base is situated will all have an impact. The MAJCOM and the local commander will determine the policies under which the organization must operate and these policies may differ between commands. The economic environment and location of the base will determine the availability of required resources. These considerations may also impact whether contract or in-service work forces are used to accomplish work requests and thereby affect the nature of a base's IWP schedule.

Sample. Two data producing sample BCE organizations were used in the development of the computer based scheduling system. The 416th Civil Engineering Squadron (CES), Griffiss AFB, New York, and the 6550th CES, Patrick AFB, Florida, were selected as the sample BCE organizations.

The selection of the 416th CES at Griffiss AFB, New York, represented a sample of convenience. There were two primary reasons for the selection of the 416th CES. The researchers had some familiarity with the base and with the personnel who construct and use the IWP schedule. The 416th CES is a medium-sized BCE organization and does not process as large a number of work orders as the Patrick BCE organization processes. It is also under a different MAJCOM and consequently was operating under somewhat different policies. The initial planning for this research effort called for the 416th CES to serve as large-scale test of the computer based scheduling system. However, budgetary limitations imposed upon the 416th CES resulted in insufficient materially supported work orders to provide an adequate test. Therefore, it became necessary to find another BCE organization which was willing to provide the data and analysis needed for a test of the computer based scheduling system.

The Chief of Resources and Requirements in the 6550th CES, Patrick AFB, Florida, agreed to provide the assistance needed to evaluate the computer based scheduling system. Therefore, the selection of the Patrick BCE organization also represented the selection of a sample of convenience. The 6550th CES is as large as most BCE organizations. As such, the organization plans, schedules, and completes about the same number of work orders as most BCE organizations. Therefore, if the computer based scheduling system works in scheduling the number of work orders required at Patrick AFB, the system will also work in the BCE organizations that schedule a similar number of work orders. Consequently, the 6550th CES provided the data for a large-scale test of the computer based scheduling system.

Data Collection Plan

There are two basic sources of the data that were collected. First, the BEAMS work control subsystem was used to gather data on work orders to be considered in developing the schedule for the first future month. The specific report used was the BCE Work Order Backlog Report (PCN:SF100-360).

The second source of data was the AF Form 919, BCE In-Service Work Plan Work Sheet. These forms provided the projected manhours for each shop for the first, second, and third future months.

The first data collected were from the 416th CES. Data on a group of 25 work orders, limited to five shops, were collected and used in development and testing of the computer based scheduling system.

The second data collected were from the 6550th CES. Data were collected on all the materially supported work orders available for consideration for scheduling among all the shops in the Operations Branch in the first future month of April 1980. These data were used for a large-scale test of the computer based scheduling system.

For the large-scale test an IWP schedule was constructed using the computer based scheduling system and the results were compared to the IWP schedule manually constructed by the personnel in the 6550th CES.

The specific data collected were similar in both cases. Data collected on each work order to be considered for scheduling using the BEAMS (PCN:SF100-360) report consisted of the work order number, priority, class of work, manhours required for each shop, and in the case of the 6550th CES, the date the work was materially supported. The AF Form 919, lines 10 and 11, provided data on the total estimated IWP manhours available for each shop.

Assessment of the Computer Based Scheduling System

The assessment of the computer based scheduling system was accomplished through two tests using data collected from the Griffiss and Patrick organizations. These tests were classified as a small-scale test and a large-scale test.

The small-scale test was accomplished in the initial development of the computer based scheduling system. As previously stated, this test was accomplished using data gathered on a group of 25 work orders from the Griffiss BCE organization. A computer generated IWP schedule was compared with an IWP schedule generated manually using a set of heuristic rules. Both schedules were generated by the researchers from the same data. The basis of comparison, explained in detail in the next section, was the number of work orders scheduled, the priority of the work orders, and the available shop manhours used. The small-scale test provided an initial assessment of the computer based scheduling system in developing an IWP and at the same time allowed for debugging of the program.

The second test was a large-scale test and was accomplished in the same manner as the small-scale test with two exceptions. The first exception was that in this test all the materially supported work orders available for scheduling, in the first future month, by the Patrick BCE organization were included. The number of work orders considered for scheduling in this test was as large as the number which would be considered in most BCE organizations.

The second exception was that the computer generated schedule was compared to an actual IWP. The computer based scheduling system was used to construct an IWP schedule using data collected on the work orders that the 6550th CES was currently processing. The computer generated schedule was then compared to the IWP schedule manually constructed from the same data by 6550th

CES personnel. The basis of comparison, explained in detail in the next section, was the number of work orders scheduled, the priority of the work orders, and the available shop manhours used. Finally, differences between the two schedules were examined and explained.

Limited time allowed this procedure to be repeated for only one month with the 6550th CES. However, sufficient data were accumulated upon which to base a conclusion as to the adaptability and useability of the computer based scheduling system.

Testing the Research Questions

The initial test of the computer based scheduling system, once it has been developed, will be a comparison of schedules produced manually using a set of heuristic decision rules and the computer based scheduling system for the small-scale test. This test will consist of 25 work orders scheduled into five shops.

The following criteria have been established for answering research question 1.

1. The computer based scheduling system will be adjudged as constructing the IWP as effectively as existing manual methods if:

a. it can schedule at least an equivalent number of work orders for the first future month, and

b. it can schedule the high priority work first, and

c. it schedules at least 95 percent of the projected available manhours.

If the answers to the first research question are in the affirmative, based on the small-scale test, then two new work orders will be inserted into the initial schedules. Both the computer based scheduling system and the manual system will then be tasked to establish revised schedules.

To answer the second research question, the following criteria have been established:

2. The computer based scheduling system will be adjudged as being able to effectively and rapidly incorporate revisions into the IWP if:

a. the revised computer based schedule contains at least an equivalent number of work orders as the revised heuristic schedule, and

b. it schedules the high priority work first, and

c. it schedules at least 95 percent of the projected available manhours, and

d. the computer based scheduling system can be revised in 15 minutes or less.

If the answers to the first two research questions are in the affirmative, then the computer based scheduling system will be used to develop the IWP for a large-scale problem using the Patrick BCE data. Then a comparison will be made between the computer based schedule and the manually generated schedule constructed by the personnel in the 6550th CES. This procedure will be accomplished for one month using data from the 6550th CES. After completion of this test, research question 1 will again be evaluated by the same criteria used for the small-scale test. If any work orders are inserted into the actual schedule at the 6550th CES, then the computer based scheduling system will be tasked to insert the same work orders and research question 2 will be evaluated by the criteria used in the previous tests. If the answers to research question 1 and 2, if applicable, are in the affirmative for this large-scale test, the primary research objectives will be considered achieved.

To answer research question 3, the following criteria have been established.

3. The computer based scheduling system will be adjudged as feasible for use at base level Civil Engineering Squadrons if:

a. it can interface with the BEAMS work control subsystem for input data, and

b. unique revisions to the input data can be made directly in the computer based scheduling system without updating BEAMS, and

c. the output format is identical to the format of the visual charts presently used for displaying IWP information.

Summary List of Assumptions

1. The Base Civil Engineering organization is operating in accordance with AFR 85-1, Resources and Work Force Management. This results in the following specific assumptions that are relative to the scheduling process:

a. Material expenditures are made separately from the scheduling process of the work orders; therefore, material costs do not constrain the IWP scheduling process (12:p.8-2).

b. The decision of when to schedule a work order is based on the priority of the work, projected shop manhour availability, the requested completion date, and commitments made to the requestor (12:p.8-2).

c. The IWP scheduler will insure the shops are kept productive in that available shop manhours are scheduled (12:p.13-1).

2. Inter-shop loans of personnel are already incorporated in the projected available manhours.

3. The craftsmen in the shop constitute a homogeneous group when considering productivity and skill level. This same assumption is the basis of the estimates of required shop manhours that the Planning Unit develops utilizing the Engineered Performance Standards (12:p.11-1).

4. All work orders being considered for scheduling in the first future month can actually be started during that month. For instance, exterior painting would not be considered for the January IWP schedule.

Summary Limitation

The computer based scheduling system will be developed and tested using the CREATE computer system to access the Honeywell Series 600 Linear Programming System (LP600). CREATE is an acronym for Computational Resources for Engineering and Simulation, Training and Education. The scheduling system, as developed, will not be "directly" useable at a BCE organization without access to an LP600 program via a CREATE system. This limitation applies only to the development and initial test of the computer based scheduling system as it is conceivable, that once developed, the scheduling system can be adapted for use on any computer system capable of solving linear programming problems. However, the adaptation of the scheduling system for use on another computer system is not possible within the limited time and resources available to the researchers.

CHAPTER III

MODEL DEVELOPMENT

Introduction

The In-Service Work Plan is the means by which work order labor requirements are matched to the available shop manhours projected for the first future month. Therefore, the main thrust of the scheduling process is to allocate, in the best possible manner, the limited available shop manhours among the work orders available for scheduling. When considered in this perspective, the IWP scheduling process seems like a classic setting for a linear programming model.

This chapter includes the development of the basic linear programming model used in the computer based scheduling system. Also, after the entire model is developed, an illustrative example involving two work orders and two shops is solved graphically to demonstrate how the model works.

Objective Function

The objective function is truly the key to the entire model and it is the most difficult to quantify. The payoff matrix concept, explained in Chapter I, is used for determining how much accomplishing any one work order is worth. This worth will be referred to as the "payoff" of the work order and the larger the payoff, the greater the worth. It is reasonable to expect the IWP to schedule as many of the higher payoff work orders as is possible to accomplish. This can be mathematically expressed as:

$$\text{Maximize } Z = \sum_{i=1}^{n} C_i X_i \qquad (1)$$

Where: X_i = a decision variable that represents work order i.

C_i = the payoff value for work order i.

i = 1,2,3,...,n. Where n is the total number of work orders.

This equation will maximize the sum of the product of the payoff times the decision variable for each of the work orders available for scheduling. However, the utilization of all available manhours is also a primary consideration in the development of the IWP. One method of minimizing the unscheduled shop manhours is to include them as a penalty in the objective function. This can be mathematically expressed as:

$$\text{Maximize } Z = \sum_{i=1}^{n} C_i X_i - \sum_{j=1}^{m} P_j S_j \qquad (2)$$

Where: S_j = a decision variable that represents the unscheduled manhours for shop j.

P_j = a constant value that represents the penalty for not scheduling all available manhours for shop j.

j = 1,2,3,...,m. Where m is the total number of shops.

C_i, X_i are as previously defined.

Now the objective function, in essence, attempts to maximize the sum of the payoffs and minimize, because of the negative sign, the unscheduled shop manhours. These two goals, which sometimes conflict, are complicated by the fact that the available shop manhours are normally fewer than the manhour requirements of the work orders that are available.

<u>Constraints</u>

The major constraint that affects the IWP scheduling process is the obvious limitation in the manhours available for each shop. Since the available manhours are projected for the first future month and the required hours to accomplish the work are also estimated for each shop involved in the work, these constraints can be written as:

$$\sum_{j=1}^{m} [(\sum_{i=1}^{n} A_{ij}X_i) + S_j] = B_j \quad (3)$$

Where: A_{ij} = the estimated manhours in shop j for work order i.

B_j = the projected available IWP manhours for shop j.

S_j, X_i are as previously defined.

Since the decision variable S_j, from the objective function, has also been incorporated into the manhour constraint equations, these constraints can be expressed as equalities instead of the inequality, less-than-or-equal-to form.

The IWP, and this model of the IWP, schedules at the monthly, aggregate level and the daily sequencing problems are not considered. However, the ability to carry a work order over from one month to the next tends to lessen the impact of the sequencing problem. For example, if 400 manhours are projected available for the carpenter shop and the current schedule shows five work orders requiring carpenter shop hours totaling 525 hours, clearly some 125 hours of work cannot be performed until the following month. These extra hours provide some flexibility for the day to day sequencing problems.

With the inclusion of the aforementioned assumptions the model is nearly complete except for restricting the value of X in the objective function and the constraints as follows:

$$0 \leq X_i \leq 1.0 \qquad (4)$$

This constraint assures that a work order is either scheduled in its entirety ($X_i = 1$), or for partial completion and to carry over into the next month ($0 < X_i < 1$), or the work order is not scheduled ($X_i = 0$).

Since linear programming does not permit negative decision variables, the last constraint of the model is for non-negativity:

$$S_j, X_i \text{ are both } \geq 0. \qquad (5)$$

It should be noted that budgetary limitations are considered prior to the ordering of any materials and only materially supported work orders are considered for scheduling. As such, the scheduling process is not constrained by dollars or materials. Also items such as seasonal work, transportation problems, and special equipment requirements are assumed to be evaluated by the IWP scheduler before consideration is given to scheduling the work order. This is essential since the model considers only the payoff, the penalty for unscheduled manhours, available manhours, and required manhours. The IWP scheduler must assure that the work orders considered for scheduling can actually be accomplished during the month, otherwise the model will produce an inappropriate schedule.

Assumptions of Linear Programming

All linear programming models have four underlying assumptions that must be satisfied if the model is appropriate for the situation being modeled. The four assumptions of the model are that it is: deterministic, proportional, additive, and divisable (8:22).

The deterministic assumption requires that each coefficient is fixed and known with certainty. In this application the coefficients are the payoff, the penalty, the required manhours, and the available manhours. Both of the manhour coefficients are estimates, but they are presently used to manually develop the IWP. Also, sensitivity analysis, or post optimal analysis, can be used to evaluate the effects of changes in these coefficients. As for the payoff value, it is determined from the payoff matrix. Lastly, the penalty value is arbitrarily determined. As such, the deterministic assumption is adequately fulfilled.

The proportional assumption requires that the objective function and the constraints expand or contract proportionally to the level of each activity (4:112). Conditions such as, start up costs and "economies of scale" are examples of non-proportional situations. In the IWP scheduling application, all of the tradeoffs are proportional, as they are only a function of the decision variable, X_i.

The additive assumption requires that there are no joint or interactions between the constraints or the objective function; hence, the total contribution of each activity must be identical to the sum of the contribution for each activity individually (4:113). Since the work is separated into discrete work packages, called work orders, with its own unique payoff and labor requirements, there are no joint effects or interactions in the model.

Lastly, the model must be divisible, which indicates that fractional levels for the decision variables must be possible. In this formulation of the scheduling system a fractional level of the decision variable simply indicates the work order will be partly completed this month and carried over into the next month. As such, the divisibility requirement is also satisfied by the scheduling model formulation.

Model Summarization

For convenience, the model formulation is again presented:

$$\text{Maximize:} \quad Z = \sum_{i=1}^{n} C_i X_i - \sum_{j=1}^{m} P_j S_j \qquad (2)$$

$$\text{Subject to:} \quad \sum_{j=1}^{m} [(\sum_{i=1}^{n} A_{ij} X_i) + S_j] = B_j \qquad (3)$$

$$0 \leq X_i \leq 1.0 \qquad (4)$$

$$S_j, X_i \text{ are both } \geq 0. \qquad (5)$$

Where:

A_{ij} = the estimated manhours in shop j for work order i.

B_j = the projected available IWP manhours for shop j.

C_i = the payoff value for work order i.

P_j = a constant value that represents the penalty for not scheduling all available manhours for shop j.

S_j = a decision variable that represents the unscheduled manhours for shop j.

X_i = a decision variable that represents work order i.

i = 1,2,...,n. Where n is the total number of work orders.

j = 1,2,...,m. Where m is the total number of shops.

Graphically Solved Example

In order to demonstrate how the model works, a very simple example involving two work orders and two shops will be solved graphically. The data used for this example is from Table 1.

WORK ORDER NUMBER	PAYOFF	HOURS REQUIRED	
		CARPENTER SHOP	PAINT SHOP
1	15	25	10
2	20	15	10
	PROJECTED AVAILABLE MANHOURS	25	10

Table 1. DATA for GRAPHICALLY SOLVABLE EXAMPLE

Certainly, a scheduling system is not needed to solve this simple problem. However, the ability to graphically display the solution in only two dimensions necessitated limiting the example to two work orders.

Using equations (1), (3), (4), and (5) this problem can be formulated as:

Maximize: $Z = 15X_1 + 20X_2$ (6)

Subject to the Following Constraints:

$$25X_1 + 15X_2 \leq 25 \quad (7)$$

$$10X_1 + 10X_2 \leq 10 \quad (8)$$

$$0 \leq X_1 \leq 1 \quad (9)$$

$$0 \leq X_2 \leq 1 \quad (10)$$

Note that equation (6) is an objective function <u>without</u> a penalty for unscheduled manhours. The four inequalities, labeled (7) through (10), are the constraints on the problem. In the carpenter shop, for instance, the manhours required by the work orders cannot exceed the available manhours; this relationship is expressed by inequality (7). Similarly, inequality (8) expresses the paint shop's manhour constraint. Inequalities (9) and (10) constrain the values of the decision variables, X_1 and X_2, to be greater-than-or-equal-to zero and less-than-or-equal-to one, as explained in the previous section of the Chapter.

In order to graphically solve this problem the linear inequalities, (7) through (10), must be graphed. This is accomplished by replacing the inequality symbol by an "equals to" sign and then graphing the resulting equation, or straight line. This line represents the border of the original "half space" that was defined by the inequality. Then by determining which side of the border the half-space occupies, the graph is completed. Figure 5 shows all six of the resulting lines that the inequalities produce. Further, by combining the associated six half-spaces, the shaded "feasible region," is determined, as shown in Figure 5.

This feasible region is significant because if there are any solutions to the problem, they will be located in this region.

To determine the solution to the problem, the objective function is simply graphed, or superimposed on the feasible region. Because the objective function is linear, its graph is actually a family of parallel lines (8:19). In the case of equation (6), the slope of each member of the objective family is -3/4. Since the objective is to be maximized, selecting the objective family member that is farthest from the origin, yet contains at least one point in the feasible region, reveals the solution to the problem. The two "dashed" lines, labeled Z_1, in Figure 6 is the graph of two family members of equation (6). Note that the corner of the feasible region that is indicated as "solution 1" is the solution to the problem. This solution chose to perform work order 2 only and has an objective function value of 20 and no consideration is given to unscheduled manhours.

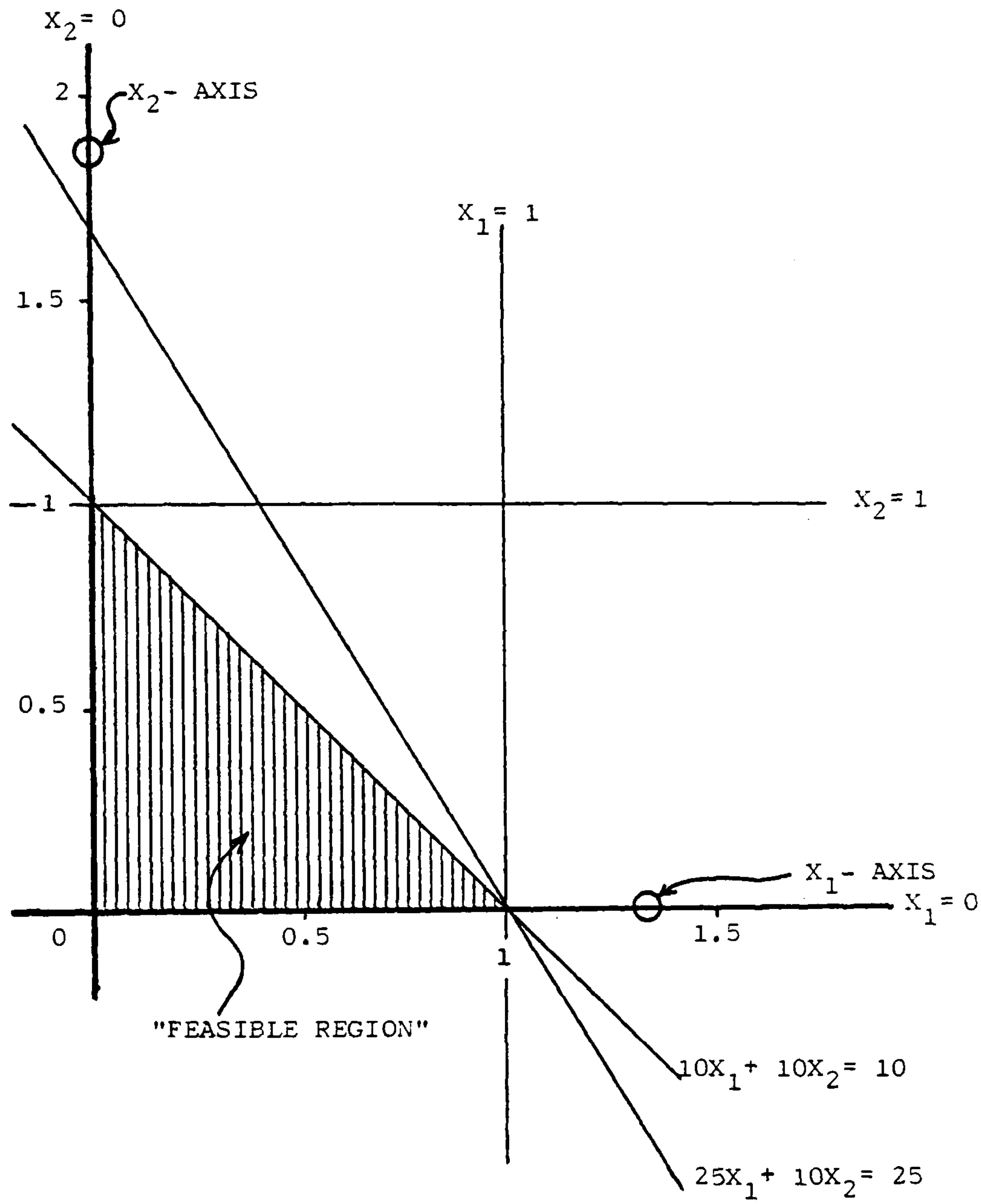

Fig. 5 Graph of Example Problem Constraint Equations

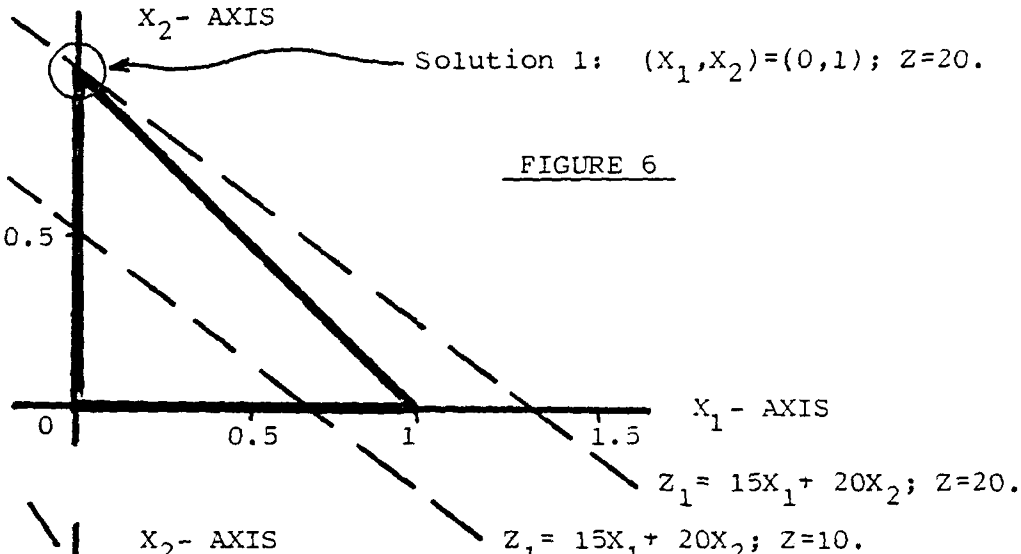

FIGURE 6

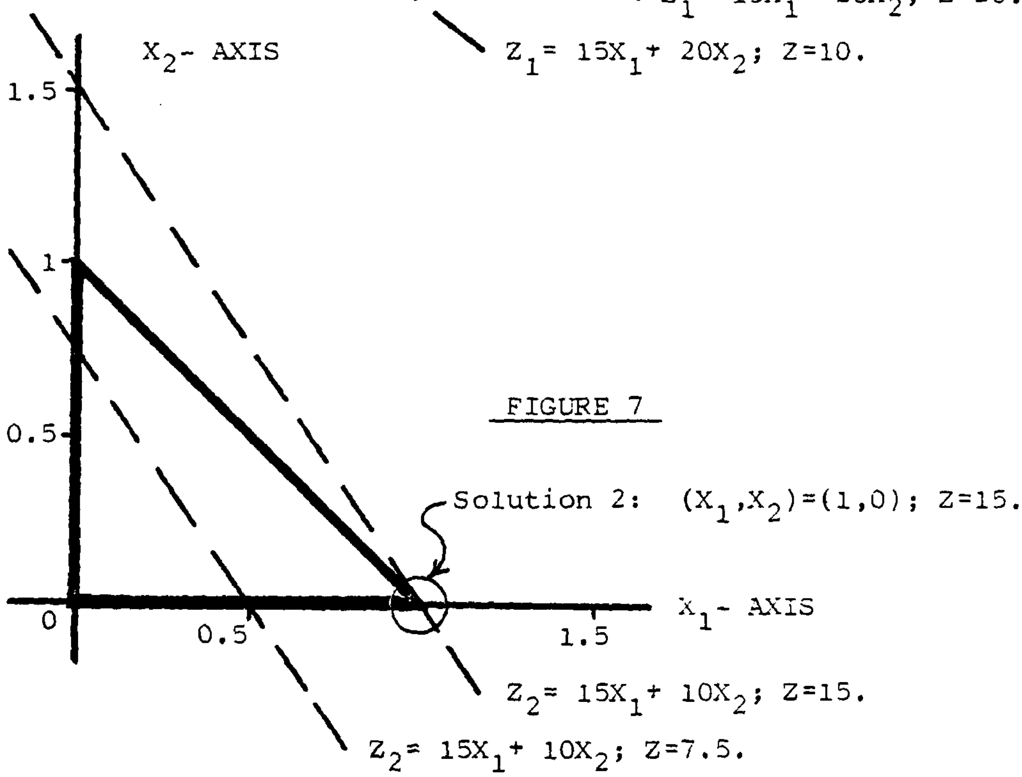

FIGURE 7

Fig. 6 & 7 Graphs of Example Problem Solutions with Different Objective Function.

A penalty for unscheduled manhours can be incorporated by using equation (2) as the objective function. A penalty of "one" for every unscheduled manhour was arbitrarily chosen. This penalty indicated that the value of now scheduling 15 manhours is equal in magnitude to the payoff derived from accomplishing work order 1. This objective function can be expressed as:

$$\text{Maximize: } Z = 15X_1 + 20X_2 - 0X_1 - 10X_2 \Rightarrow 15X_1 + 10X_2. \quad (11)$$

The two "dashed" lines, labeled Z_2, in Figure 7 is the graph of two family members of equation (11). The corner of the feasible region labeled "solution 2" is the solution for the objective function that penalizes unscheduled manhours. This solution picked work order 1 only and has an objective function value of 15. Observe that the model, when taking unscheduled manhours into consideration, chose the work order with the lower payoff value, rather than accept the penalty associated with the unscheduled manhours. This is exactly the desired result that equation (2) was developed to produce: maximize the work order payoff value while minimizing the unscheduled manhours.

The next chapter will describe a small-scale test, in which the computer based model will be used to develop a schedule for 25 work orders among five shops. The computer based schedule will then be compared to a heuristically developed schedule to demonstrate the appropriateness of the linear programming model for scheduling work orders.

CHAPTER IV

SMALL-SCALE TEST

Introduction

This chapter describes the Honeywell Series 600 Linear Programming System (LP600) which was used to develop the IWP schedule from the model described in Chapter III. The heuristic rules used to manually develop the IWP schedule are also included. Then a small-scale test is presented and solved both manually and by the computer based model. A comparison of the two schedules is then discussed in answer to Research Question 1, "Can a computer based scheduling system be developed that will construct the In-Service Work Plan as effectively as existing manual methods?"

Finally, two additional work orders were inserted into the schedule and both the computer based system and the manual system were tasked to establish revised schedules. A comparison of these two schedules is then presented in answer to Research Question 2, "Is the computer based scheduling system able to effectively and rapidly incorporate revisions into the work plan?"

The Honeywell Series 600 Linear Programming System (LP600)

The LP600 system has the capacity to solve linear programming problems of up to 4,095 rows and 262,000 columns (9:1-2). In the model presented in Chapter III, each row represents a shop and each column represents a work order. Consequently, the LP600 system has more than adequate capacity to accomodate any realistic IWP scheduling problem. The LP600 system uses an English-like agenda control macro-language which is straightforward and easy to use. The majority of the LP600 inputs are the coefficients for the constraint equations. Each nonzero coefficient must be identified by the row and by the column of its location. The LP600 system also has the capability to restrict the range of values that a variable can assume. Thus, restricting the values of the work order decision variable X_i from $0 \leq X_i \leq 1$, is readily accomplished at the same time the objective function is defined. Also, the LP600 system has post-optimal operations (sensitivity analysis) that can be obtained by adding only one line to the agenda control segment of the program. The "automatic" sensitivity analysis feature negates the need to perform manual calculations for post-optimal analysis. Finally, additional information on the LP600 system and its capabilities may be found in the Honeywell "Series 600/6000" manuals. Several of these manuals are listed in the Bibliography under "Related Sources."

Heuristic Rules

A set of heuristic scheduling rules was used to manually develop an IWP schedule for comparison with the computer based schedule. The heuristic rules used were:

(1) Scan all work orders and select that work order, not previously considered, with the highest payoff value. If ties exist, select the work order involving the most shops. If ties still exist, select the work order with the fewest total required manhours. If no more work orders remain, go to (3); otherwise, go to (2).

(2) Compare each shop's manhour requirement for the work order with the projected available manhours for each shop. If all manhour requirements are less than or equal to the projected available manhours, schedule the work order and reduce the projected available manhours by the amount required for the work order; go to (1). If manhour requirements are greater then the projected available manhours, the work order can not be scheduled; return to (1) to identify the next work order to be considered.

(3) Select the shop with the most projected available manhours remaining to be scheduled. Scan all unscheduled work orders to identify any work orders that require only the one shop just selected. Partially schedule the work order that yields the greatest "actual payoff", where:

$$\text{ACTUAL PAYOFF} = \text{payoff} \;\; X \;\; \frac{\text{unscheduled manhours}}{\text{required work order manhours}}$$

If no suitable work order exists go to (4).

(4) Return to (3) until all shops with unscheduled available manhours have been considered; then stop.

These heuristic rules attempt to schedule the higher payoff, multi-shop work orders first. The reason for breaking ties with the work order having the fewest total required manhours is that possibly two or more equal payoff work orders might be scheduled. Whereas, by choosing the work order with the largest total required manhours for scheduling first might result in fewer work orders being scheduled. This heuristic rule is in agreement with the objective of maximizing the sum of the work order payoffs.

The partial scheduling portion of the heuristic, rules (3) and (4), is aimed at reducing the unscheduled available manhours to the minimum amount possible. This is in agreement with the computer based schedule's objective that imposes a penality for unscheduled manhours. Thus, these heuristic rules are designed to do the same thing as the IWP programmer does. That is, schedule the most important work first and also schedule all projected available manhours.

Initial Comparison of the Small-Scale Test Schedules

The model developed in Chapter III and the heuristic rules were both used in a small-scale test consisting of 25 work orders to be scheduled into five different shops. The specific information used for the required manhours per work order, the payoff values, and the available manhours per shop is shown in Table 2. These data are from actual work orders found in the PCN: SF100-360 report (as of 19 Dec 1979) for the 416th CES, Griffiss AFB, New York. The available manhours per shop

Work Order Number	Priority/Class	Payoff Value	Manhours				
			Carp	Paint	Plumb	Metal	Int.Elec
1. 05605	3/M	10	30	4			
2. 06516	3/M	10	179				
3. 10766	2/C	20	116				
4. 40070	2/C	20					175
5. 40100	3/C*	20			32	16	
6. 40369	3/C*	20	64	64	9	36	76
7. 40649	2/C	20	94	24	24	14	24
8. 40679	2/C	20		26		60	18
9. 40859	2/C	20					220
10. 42029	2/C	20				65	
11. 42079	3/C	5					159
12. 42369	2/C	20				64	
13. 42609	3/C	5			32		37
14. 42719	2/C	20		18		50	
15. 42789	2/C	20	2			111	8
16. 43219	2/C*	80	166	220			30
17. 43239	3/C	5					62
18. 50110	3/M**	20			32		6
19. 50130	3/M**	20	68		57		16
20. 50629	3/M	10			125		
21. 50830	3/M	10	92	28			
22. 50850	2/M	40			102		
23. 50859	3/M	10		16		4	
24. 53519	3/M**	20	68			28	
25. 53769	3/M	10		950			
Total Available Manhours			421	1036	117	403	491

Note: * = Commander Interest
** = Other Interest

Table 2 Small-Scale Test Data

are the total of lines 10 and 11 from AF Form 919, for January 1980, for the 416th CES.

The payoff values used for this small-scale test are a function of the work order priority, work classification, commander interest, and other interests. The payoff matrix used to arrive at these values is shown in Figure 8.

The schedules developed using both methods are shown in Table 3. Both methods scheduled all of the available manhours, as desired. The computer based schedule did end up with a higher total payoff value of 356, as compared to 330 for the heuristic based schedule. The main reason for the difference in the two schedules is work order 50850 with a payoff value of 40. Since this is the work order with the second highest payoff value, the heuristic scheduled it fully because enough manhours were available. However, work order 50850 used up 87 percent of the available plumbing shop manhours. The computer based schedule was able to fully schedule work orders 40100 and 50110, by only partially scheduling 50850. The result of this tradeoff was an increase in the total payoff value of over 20 points for the computer based schedule since 2 1/2 work orders were scheduled instead of only one.

Of the total number of work orders scheduled, there were 15 work orders that were picked by both methods. There also were four work orders that were not scheduled

Priority of Work Order

Work Classification		(I) 70	(II) 20	(III) 5	(IV) 1
Repair	3	210	60	15	3
Maintenance	2	140	40	10	2
Construction	1	70	20	5	1

Note: (1) If work order is "Commander interest," multiply payoff by 4.
(2) If work order is "Other Interest," multiply payoff by 2.

Fig. 8 Small-Scale Test Payoff Matrix

Work Order Number	Payoff Value	Scheduled By: Computer Based Model	Scheduled By: Heuristic
1. 05605	10	1	
2. 06516	10		0.03
3. 10766	20	1	1
4. 40070	20	1	1
5. 40100	20	1	
6. 40369	20	0.14	1
7. 40649	20		
8. 40679	20	1	1
9. 40859	20	1	0.55
10. 42029	20	1	0.77
11. 42079	5		
12. 42369	20	1	1
13. 42609	5		
14. 42719	20	1	1
15. 42789	20	1	1
16. 43219	80	1	1
17. 43239	5	0.38	1
18. 50110	20	1	
19. 50130	20		
20. 50629	10		0.05
21. 50830	10	0.33	
22. 50850	40	0.51	1
23. 50859	10	1	1
24. 53519	20	1	1
25. 53769	10	0.77	0.73
Number Fully Scheduled:		14	12
Number Partially Scheduled:		5	5
Total Number Scheduled:		19	17
Total Unscheduled Manhours:		0	0
Total Payoff Value:		356	330

Table 3 Initial Comparison of the Small-Scale Test Computer Based Schedule and Heuristic Schedule.

by either method. It should be noted that two of the four unscheduled work orders had the lowest possible payoff value of 5. Of the six remaining work orders, three were partially scheduled, 0.03, 0.05, 0.33, respectively, to use up remaining available manhours and two of the work orders were previously discussed in conjunction with the plumbing shop manhour situation. Thus, there was only one work order that the computer based model scheduled that cannot be intuitively explained. Considering the facts that the computer based schedule had a higher total payoff value and scheduled all available manhours, there is little reason to doubt that the computer based model scheduled at least as well as the manual heuristic method.

Research Question 1 Answered

Research Question 1 asked, "Can a computer based scheduling system be developed that will construct the IWP as effectively as existing manual methods?" The answer to this question is yes. The computer based scheduling system did in fact:

(1) schedule more work orders than the manual method;

(2) schedule the high priority work first;

(3) schedule 100% of the projected available manhours.

In addition, the computer based system developed the optimal schedule for the work orders considered and had a total payoff value that was about eight percent higher than the manual method. Lastly, the LP600 program required 33 iterations and only 54 seconds of computer operating time to reach the optimal solution.

Comparison of the Revised Small-Scale Test Schedules

To address Research Question 2, two new work orders were inserted into the schedule and both the manual system and the computer based system were tasked to establish revised schedules. The two new work orders were actual work orders taken from the same PCN:SF100-360 report from the 416th CES as the other small-scale test data. The specific information used regarding the two new work orders is as follows:

Work Order Number	Payoff Value	MANHOURS				
		Carp.	Paint	Plumb.	Metal	Int. Elec.
26. 42289	20	130	26		40	36
27. 53029	20			40	20	32

Both of these new work orders were considered to be commander interest work, as such, they were "forced" into the IWP by simply reducing the projected available manhours by the amount required for these two work orders. To accomplish this change for the LP600 program, only five lines had to be changed and only required typing some 75 characters to effect the change. This is in comparison to the heuristic method which had to be completely reaccomplished in order to effect the change.

The payoff values for the revised small-scale test were the same as for the initial small-scale test.

The schedules developed using both methods are shown in Table 4. As in the initial test, both methods succeeded in scheduling all of the available manhours. Again, there were a total of 15 work orders that were scheduled by both methods, and seven work orders that were not scheduled by either method. Interestingly, both methods partially scheduled the same four work orders, yet in the initial small-scale test there was only one work order that was partially scheduled by both methods. As before, the computer based schedule had the highest total payoff value.

Research Question 2 Answered

Research Question 2 asked, "Is the computer based scheduling system able to effectively and rapidly incorporate revisions into the work plan?" The answer to this question is yes. The computer based scheduling system did in fact:

(1) schedule more work orders than the manual method;

(2) schedule the high priority work first;

(3) schedule 100% of the available manhours;

(4) was able to be revised to accomodate the new work orders in about three minutes.

Additionally, the computer based schedule provided the optimal solution for the data used and the total

Work Order Number	Payoff Value	Scheduled By	
		Computer Based Model	Heuristic
1. 05605	10	1	
2. 06516	10		
3. 10766	20	0.22	0.25
4. 40070	20	1	1
5. 40100	20	1	
6. 40369	20		
7. 40649	20		1
8. 40679	20	1	1
9. 40859	20	0.86	0.45
10. 42029	20	1	0.62
11. 42079	5		
12. 42369	20	1	1
13. 42609	5		
14. 42719	20	1	1
15. 42789	20	0.50	1
16. 43219	80	1	1
17. 43239	5		1
18. 50110	20	1	1
19. 50130	20		
20. 50629	10		
21. 50830	10		
22. 50850	40	0.12	0.21
23. 50859	10	1	1
24. 53519	20	1	
25. 53769	10	0.76	0.74
26. 42289	20	1	1
27. 53029	20	1	1
Number Fully Scheduled:		13	12
Number Partially Scheduled:		5	5
Total Number Scheduled:		18	17
Total Unscheduled Manhours:		0	0
Total Payoff Value:		345	317

Table 4 Comparison of Revised Small-Scale Test Computer Based Schedule and Heuristic Schedule

payoff value was about nine percent higher than the manual method's schedule. The LP600 program required 33 iterations and about 51 seconds of computer operating time to reach the optimal solution.

The small-scale tests have provided a basis to evaluate Research Question 1 and 2, and the results indicate that the linear programming computer based scheduling model has definite potential for aiding in the development of the IWP. The applicability of the model was further evaluated by developing the April IWP for Patrick AFB, Florida, and comparing the computer based schedule's results with the base's actual schedule. This comparison is the topic of Chapter V.

CHAPTER V

LARGE-SCALE TEST

Introduction

This chapter contains a discussion of the large-scale test of the computer based scheduling system. This test consisted of generating the IWP for April using the model developed in Chapter III and the backlogged work orders actually used by the 6550th CES scheduler in generating the same IWP for Patrick AFB, Florida. A comparison of the computer generated IWP with the actual Patrick IWP was then made and the results are included. Research questions 1,2, and 3 are addressed based on the results of the large-scale test.

Large-Scale Test

The large-scale test consisted of scheduling 147 work orders among 12 shops. The data used was actual data from the 6550th CES, Patrick AFB, Florida. The specific data used for the required manhours per work order and priority are shown in Appendix G. These data were taken from the PCN:SF100-360 report (as of 28 Feb 80) for the 6550th CES. Additionally, a Base Level Inquiry System (BLIS) report PCN:N114007 (as of 3 March 80) was utilized to determine which work orders were materially complete and waiting to be scheduled. It should be noted that BLIS is a built-in feature of the BEAMS system that allows for data to be sorted on the basis of common attributes. In this case, the work orders were sorted by being materially complete and also having no manhours charged against the work order.

Further, the IWP scheduler also provided information concerning work orders that could not be scheduled in April. For example, two materially complete work orders could not be scheduled because they were to follow a contract construction project that was not completed. Thus, a "pool" of materially complete work orders that could be scheduled for April was identified. To determine the available shop manhours for new work orders, the required manhours, by shop, from the actual Patrick IWP schedule were added together. This procedure negated the need to total the carry-over manhours and assumed that all available manhours were scheduled. Then the two commander interest work orders were "forced" into the schedule by reducing the available manhours by the amount required for them.

The payoff values used for the large-scale test are a function of the work order priority, commander interests, and length of time the work order has been materially complete. These were the relevant factors identified by the Chief of Resources and Requirements and the IWP scheduler at the 6550th CES. Further, they were having a problem in that several work orders had been materially supported for over a year. Therefore, the payoff matrix shown in Figure 9 was developed to emphasize the older materially supported work orders by giving them higher payoffs.

The computer based schedule and the actual Patrick AFB, April IWP are shown in Table 5. The computer based method did schedule all of the available manhours. By assigning payoff values to the actual April IWP, the total payoff for newly scheduled work orders is 1211. While the computer based method produced a total payoff of 1439, which is about a 19 percent improvement. A summary of the two schedules is provided on the last page of Table 5. Clearly, the computer based schedule contains a lot more work orders than the actual April IWP. For instance, the computer based system scheduled 41 work orders that required carpenter shop hours, while the April IWP scheduled 33. The researchers perceived this as a potential problem, however, the IWP scheduler at the 6550th contends that the shops can manage any number of work orders as long as the available manhours are not exceeded. Consequently, the computer based scheduling system was not further constrained to limit the number of work orders scheduled for each shop.

It should be noted that several relatively high payoff work orders were not scheduled by either method. For instance, work order 80384 with a payoff value of 65 was not

Priority of Work Order

		(I)	(II)	(III)	(IV)
		70	20	3	1
Commander Interest	3	210	60	9	3
Routine	1	70	20	3	1

Aging Process For Materially Complete Work Orders:

0-6 Months Materially Complete ⇒ Matrix Value + 2(Number of Months Materially Complete).
7-12 Months Materially Complete ⇒ Matrix Value + 12 + 4(Number of Months Materially Complete >6).
13+ Months Materially Complete ⇒ Matrix Value + 36 + 8(Number of Months Materially Completed >12).

Fig. 9 Large-Scale Test Payoff Matrix

WORK ORDER	PRI	PAY-OFF	PATRICK IWP	LP600 IWP
68448	3	11		.21
70412	3	65	1	1
70418	3	5	1	
80145	3	65	1	1
80154	3	11		
80190	4	1	1	
80214	2	26	1	1
80285	3	9	1	.10
80300	3	9	1	
80306	3	37	1	1
80384	3	65		
80395	3	81	1	1
80402	3	9		
80424	3	25	1	1
80427	3	9	1	1
80430	3	9	1	1
80431	3	57	1	1
80455	3	5	1	
80457	3	57	1	1
80469	3	7		.71
80471	3	9		.67
80482	3	9	1	
80484	3	5	1	1
80485	3	9		
80553	3	29	1	1
80569	3	9		1
90024	3	29	1	1

WORK ORDER	PRI	PAY-OFF	PATRICK IWP	LP600 IWP
90102	3	49	1	1
90418	3	9		
90165	3	29		
90169	3	29	1	1
90198	3	9		
90199	3	9	1	
90200	3	9		
90221	3	7		
90222	3	7		
90224	3	9		
90226	3	9		1
90229	3	9		1
90232	3	37	1	1
90243	3	7		1
90249	3	9	1	1
90264	3	7		
90308	3	33	1	1
90338	3	15		
90372	3	7		1
90386	3	7	1	
90455	3	15	1	1
90480	3	33		
90517	3	5	1	1
90521	3	13		
90538	3	7		1
90563	3	5	1	1
90563	3	5	1	1

Table 5 Comparison of Large-Scale Test Computer Based Schedule (LP600 IWP) for April and Actual April IWP for Patrick AFB, Florida.

WORK ORDER	PRI	PAY-OFF	PATRICK IWP	LP600 IWP
90581	3	13		1
90612	3	9		1
90614	3	11		
90626	3	7	1	
90636	3	21	1	1
90652	3	25		1
90659	3	5	1	1
90660	3	13		1
90664	3	17		1
90666	3	9		1
90676	3	7		
90677	3	15		1
90681	3	25	1	1
90687	3	7		
90693	3	15		
90698	3	21		1
90703	3	11		1
90708	3	5	1	
90712	3	15		.29
90723	3	15		.72
90724	3	7		
90726	3	11		
90728	3	9		
90733	3	11		
90740	3	9		1
90766	3	7		1
90769	3	5	1	1
90772	3	15		1
90780	3	17	1	1
90792	3	11		1
90793	3	15		.06
90794	3	13		
90797	3	7		1
90801	3	9	1	1
90819	3	5	1	
90821	3	5	1	
90828	3	25		
90870	3	13	1	
90880	3	15	1	1
90884	3	13		1
90898	3	9		1
90906	3	21	1	1
90908	3	13		.17
90919	3	5	1	
90920	3	7		1
90922	3	11		
90927	3	9	1	1
90945	3	11	1	1
90958	3	9		1
90983	3	9		1
91007	3	7	1	1
91023	3	11	1	1
91029	3	7		1
91040	3	5	1	
91041	3	9		1
91056	3	9		1
91066	4	7		1
91081	3	11		1

Table 5 continued

WORK ORDER	PRI	PAY-OFF	PATRICK IWP	LP600 1WP
91111	3	7		1
91114	3	7		1
91116	3	11		1
91120	3	13		
91122	3	9		
91163	3	7		1
91176	3	13		1
91181	3	7		.33
91193	2	22	1	1
91194	3	7	1	1
91208	3	7		1
92000	3	7		1
92014	3	9		
92015	3	5	1	1
92019	3	5	1	1
92036	2	20	1	1
92037	2	20	1	1
92040	3	9		1
92069	3	7		1
92086	3	5	1	.61
92088	3	11		1
92097	3	7		
92116	2	24	1	1
92152	3	7		1
92198	2	62	1	1
92214	3	7		1
92219	3	7		1
92227	3	7		1
92242	2	20	1	.63
92270	3	5	1	1

WORK ORDER	PRI	PAY-OFF	PATRICK IWP	LP600 1WP
92274	2	60	1	1
92370	3	5	1	1
92383	3	5	1	1
92523	3	5	1	1
92541	3	5	1	
Number Fully Scheduled:			65	90
Number Partially Scheduled:			0	11
Total Number Scheduled:			65	101
Total Unscheduled Manhours:			0	0
Total Payoff Value:			1211	1439

Table 5 continued

scheduled. This was because of the large number of carpenter shop hours (688) required for the work order. In a similar fashion, all of the higher payoff work orders were either scheduled, or not scheduled because of large manhour requirements for an individual shop. The important thing is that both methods generally handled the higher payoff work orders in the same manner. Of the 30 work orders with payoffs of twenty or more, there were only two work orders, 90652 and 90698, that were scheduled by only one method. It is noteworthy that both of these work orders were scheduled by the computer based method, and not scheduled in the actual April IWP.

Lastly, the LP600 program required 140 iterations and 1.9 minutes of computer operating time to schedule the 147 work orders among twelve shops. This compares very favorably to the research done by Bush and Richardson, in which scheduling 153 work orders into nine shops required over seven hours of computer operating time to reach a non-optimal solution (5:75). Clearly, the model developed in Chapter III has proven to be well within the realm of feasibility, when considering the required computer operating time.

Research Question 1 Answered

Research question 1 asked, "Can a computer based scheduling system be developed that will construct the IWP as effectively as existing manual methods?" The results of the large-scale test indicate that the answer to this question is yes. The computer based schedule did in fact:

(1) schedule more work orders than the manual method;

(2) schedule the high priority work first;

(3) schedule 100% of the projected available manhours.

Therefore, both the small-scale and large-scale tests support the theory that a computer based linear programming type of scheduling system is an applicable technology for use in scheduling BCE work orders.

Research Question 2 Answered

Research question 2 asked, "Is the computer based scheduling system able to effectively and rapidly incorporate revisions into the work plan?" Ideally, the large-scale test would have been used to further test this question. However, due to the dynamic nature of the IWP and the numerous changes that were made to the Patrick IWP during the month of April, it was not possible to obtain the data necessary to utilize the computer based scheduling system and make a valid comparison with a revised Patrick IWP. For example, the data needed included all materially complete work orders that had not been started and the remaining available manhours per shop. This information could not be obtained from the 6550th CES without considerable effort on the part of the IWP scheduler. The researchers decided that an interruption of the work flow at the 6550th was not justifiable. Research question 2 was answered by the small-scale test and the problem encountered in the large-scale test is simply one of data availability. Further, the needed data is available, but not in a form that facilitates its use by the computer based scheduling system. Consequently, the data must be manipulated by hand from several sources. In essence, the Patrick IWP system would not hold still long enough to get a clear "snapshot" of its current status. Fortunately, at the end of every month, there is a short time when a clear "snapshot" is possible and the data gathered during that time is quite useable. This is true primarily because the projected manhour availability is determined for one month periods and the required manhours for carry over work orders are only estimated and tallied at the end of the month.

Thus, the answer to research question 2 becomes a "qualified" yes. Clearly the computer based scheduling system can easily be modified to produce a new schedule. However, the data needed to develop a schedule is presently updated only on a monthly basis. Therefore, under these circumstances the computer based scheduling system would only be effective in revising the schedule very early in the month. Of course there is no reason to believe that the necessary computer based scheduling system input data could not be updated more frequently, possibly on a weekly basis. Under such conditions the computer based scheduling system would be a much more powerful tool for the IWP scheduler to use. However, the answer to research question 2 must remain a "qualified" yes.

Research Question 3 Answered

Research question 3 asked, "Is the computer based scheduling system feasible for use at base level Civil Engineering Squadrons?" The first criteria established to evaluate this question was, "Can a computer based scheduling system interface with the BEAMS work control sub-system for input data?" This is important since the large-scale test required a computer program that was 591 lines long, and all but 30 lines were essentially data inputs. Through the BEAMS "expert" at the 416th CES, it was discovered that all of the data necessary for the computer based scheduling system was available in the BEAMS system. Further, this data can be transferred from the BEAMS system to magnetic tape and then cards can be used as input for an LP600 program. Conceptually, the transfer process is certainly possible, but may be somewhat cumbersome to actually accomplish. A sample of two BLIS programs that would transfer some of the BEAMS data to magnetic tape is shown in Appendix J. Also, several punched cards containing the type of data needed by the computer based scheduling system is provided in Appendix K. Another possibility for the input data is to use the magnetic tape directly for input to the LP600 program without punching cards. Finally, LP600 was designed to interface with user-generated Fortran programs and actually contains several intermediate files to facilitate transferring data (9:1-4). Although, time did not permit its actual demonstration, conceptually there is no reason to doubt that the BEAMS system can interface with the computer based scheduling system utilizing the LP600 system.

The second criterion to research question 3 required that, "Unique revisions to the input data can be made directly in the computer based scheduling system without updating BEAMS." Clearly, the answer to this criterion depends on the type of input utilized for the first criterion. If punched cards are used, then there would only be a need to remove, add, or revise several cards, since each card contains the data for one specific work order. The LP600 system also has designed in capabilities for revising a problem file (9:1-7). Lastly, depending on the software capabilities, the magnetic tape could be revised through the use of an interactive terminal. In any event, the ability to revise the input data without updating BEAMS also seem certain.

The last criterion to research question 3 required that, "The output format be identical to the format of the visual charts presently used for displaying the IWP information." The versatility of the LP600 system is demonstrated by the built-in capability to provide special report formats. "The format generator language provides a means for processing and formatting solution results and other data to meet any reporting need [9:2-26]." Limited time did not permit the researchers to utilize the somewhat complex LP600 format generator language. However, the capability to produce the desired format is seemingly built into the LP600 system.

Therefore, it can be conceptually argued that research question 3 has been successfully answered and that the computer based scheduling system is feasible for base level Civil Engineering Squadrons. As emphasized, this is only a conceptual argument and no rigorous proof has been offered. Yet the soundness of the basic underlying logic is inescapable.

In summary, the large-scale test has added additional support for research question 1, research question 2 was unable to be evaluated, and research question 3 was addressed only on a conceptual level. The next chapter contains a more detailed discussion of the conclusions drawn from this research effort and recommendations for further research.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter contains a discussion of the researchers conclusions on how the findings of this research effort support the three research questions, which in turn support the primary and secondary research objectives. Then two other general conclusions are described. Lastly, recommendations for further research are presented.

Conclusions

Discussion of the primary research objective. The primary objective of this research effort was, "To develop a computer based scheduling system that is capable of effectively constructing the In-Service Work Plan and rapidly incorporating revisions into the work plan." In support of this primary objective, research question 1 asked, "Can a computer based scheduling system be developed that will construct the In-Service Work Plan as effectively as existing manual methods?" Based on the results of the small-scale and large-scale tests as measured by the criteria established to test research question 1, the principal conclusion drawn from this research is that the computer based scheduling system presented in this thesis does construct the In-Service Work Plan as effectively as current manual methods. This conclusion stems from the fact that in both the small-scale and large-scale tests the computer based scheduling system scheduled more work orders than either the heuristic or the Patrick IWP scheduler. It scheduled the higher priority work first, and scheduled all the projected available manhours.

In further support of the primary research objective, research question 2 asked, "Is the computer based scheduling system able to effectively and rapidly incorporate revisions into the work plan?" The results of the small-scale test, lead to the conclusion that the computer based scheduling system is able to effectively and rapidly incorporate revisions into the work plan. The revised computer based schedule did contain as many work orders as the heuristic, it scheduled the highest priority work first, and it scheduled all the available manhours. In addition, the revisions required changes to only 5 lines which took less than 5 minutes to accomplish. On the other hand the heuristic method had to be completely reaccomplished. Although revisions were not attempted in the large-scale test, changes to only 12 lines would have been necessary to accomplish a revision similar to that in the small-scale test. As discussed in Chapter V, there was some difficulty in obtaining the necessary information to input the computer based scheduling system for the large-scale test. The information is available; however, the current "bookkeeping" methods make the data difficult to assimilate. Therefore, it is concluded that the criteria for answering research question 2 in the affirmative was only "partially" satisfied.

Discussion of the secondary research objective. The secondary research objective was, "To refine the scheduling system for practical application at base level." In support of this secondary objective research question 3 asked, "Is the computer based scheduling system feasible for use at base level Civil Engineering Squadrons?" As described in Chapter V, this question was only addressed on a conceptual level and no actual demonstration of feasibility has been accomplished. However, the logical basis for the conceptual argument in support of this research question is sound.

Further, the computer based scheduling system was very efficient in comparison to the manual heuristic method and to the integer programming method used by Bush and Richardson. The maximum computer operating time used by the computer based system was 1.9 minutes. This compares to seven hours of computer time used by the Bush and Richardson model without reaching an optimal solution. Certainly from the standpoint of required computer operating time, the computer based scheduling system developed through this research effort is indeed feasible.

<u>Other related conclusions</u>. In addition to the conclusions directly related to the research questions, there were two other conclusions reached by the researchers that are considered noteworthy. These additional conclusions are:

1. The use of the payoff matrix concept to determine the value of completing a specific work order provides the flexibility needed to allow the computer based scheduling system to be used at any BCE organization. Despite the fact that circumstances differ from base to base, it is contended that the computer based scheduling system was shown to be useable in all BCE organizations, even though the data used in the system's development was obtained from only two BCE organizations. This contention is based on three points.

First, there are basic factors, such as the priority of the work, the requested completion date, and the availability of shop manhours, that are considered in the construction of every IWP (10:1-2).

The second point is that the incorporation of the payoff matrix in the computer based scheduling system will permit every BCE organization much flexibility in adapting the system to their specific needs. Each BCE organization can include any factors they consider relevant, then weight and combine these factors to suit their specific requirement.

Lastly, because of the number of work orders scheduled by the Patrick BCE organization, the capability of the computer based scheduling system to deal with a large number of work orders was necessarily tested. Additionally, the tremendous capacity of LP600 is able to easily accomodate any realistic BCE scheduling problem.

2. It is the conclusion of the researchers that the computer based scheduling system presented in this thesis performs very well at the "aggregate" or monthly level of the IWP scheduling process. However, because of the requirement of shop sequencing and the interfacing of many work orders into the schedule, the system cannot readily be applied at the weekly or daily scheduling level. Scheduling at the weekly and daily level seemingly requires the use of a sequence oriented technology. However, as this is not a characteristic of linear programming, some other technology must be used.

In summary, the computer based scheduling system can be a powerful tool for the IWP scheduler. It will never replace the requirement for human input and decision making in the IWP scheduling process, but with proper use a computer based scheduling system can make the scheduler's job much easier.

Recommendations For Further Research

This research effort has shown that a linear programming computer based scheduling system can schedule BCE work orders. However, limited research time did not allow for repeated demonstration of the large-scale test using data from an actual BCE organization. Therefore, the foremost recommendation of the researchers is that the computer based scheduling system be used to develop the IWP for an actual BCE organization over a period of several months as a means of further validation. Selection of the BCE organization should be partially based on the accessibility to the researchers. This will facilitate direct interaction between the IWP scheduler and the researchers to hopefully avoid the problem of obtaining necessary data that was encountered in this research effort. In addition to this recommendation, there are several other issues that warrant further research.

First, the problem encountered in the large-scale test in answering research question 2 could be explored further. The unavailability of certain data, when revisions need to be made to the IWP, is a problem that can be solved. Clearly, the BEAMS system contains the needed information, but the current "bookkeeping" practices make it difficult to access. Further study might well provide a practical means for resolving this problem.

Second, a more rigorous examination of research question 3 could also be accomplished through additional research. Conceptually the answer seems certain, but a formal demonstration of the actual procedure is desirable. Also, the actual implementation of the process will provide much more insight into the process and certainly some unforseen difficulties will be discovered. As such, more research in this area is definitely needed.

Third, the idea of a management constraint being introduced into the model seems highly plausible. Certainly, there are situations where a shop does not have enough supervisors to accomodate a large number of small work orders but could adequately handle a few large work orders. Further, by restricting the number of work orders that can be scheduled, there will be a tendency to schedule the larger manhour work orders. It might be remembered that several relatively high payoff work orders were not scheduled in the large-scale test because of their high manhour requirements. The following equation could be used as a "management" constraint to limit the number of work orders that can be scheduled for individual shops:

$$\sum_{j=1}^{m} \sum_{i=1}^{n} X_i \leq K_j \qquad (12)$$

where: X_i = a decision variable which represents work order i.

K_j = the number of work orders that can realistically be managed by shop j within the available manhours for shop j.

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It should be realized that generally the more constraints that are applied to a linear programming problem, the lower the optimal value becomes. However, the problem must contain enough constraints to accurately model the specific situation. In the case of the 6550th CES at Patrick AFB, Florida, management of a large number of work orders was not viewed as a problem for the shops. In general, the researchers do not believe this to be universally true of all BCE organizations. Thus, the "management" constraint would help resolve this inconsistency as well as more realistically address the management capacity of the shops.

Fourth, there was not much formality about the way in which the factors for the payoff matrix were determined. Basically, the Chief of Resources and Requirements and the IWP scheduler were asked what they considered to be important in selecting work orders for the schedule. It is possible to expand in this area by using "policy capturing" techniques to zero in on what the scheduling policy actually is for a particular BCE organization. Often there is a difference between the stated and actual policies and "policy capturing" techniques were developed to provide a formal means of determining the actual policies. If a methodology could be refined to accurately capture the IWP scheduling policy of a BCE organization, then the payoff matrix concept could be used with more certainty. In addition, this methodology could have an immediate application for the current heuristic scheduling methods.

Fifth, it seems reasonable to utilize a linear programming type of scheduling system very early in the IWP process to determine which work orders to send to the Planning Section. Such a model could include a dollar constraint for material expenditures, which would help in controlling that portion of the Operations Branch budget. Considering the Planning Section's work order backlog, it seems like a classic resource allocation problem. The work orders are the "competing activities" that must be allocated among "scarce resources" which would be the available planner hours and the available dollars for material purchases. There are also other constraints on the situation, for instance, the need to have a backlog of planned work for every shop is a factor in deciding which work orders to plan next. Thus, quite possibly a linear programming type of scheduling system could be developed for determining which work orders to send to the Planning Section.

Finally, the only way a linear programming type of scheduling system will be utilized is if it is readily available to the base level Civil Engineering Squadrons. The logical solution would be to incorporate some type of linear programming capability into the BEAMS system.

The ramifications of such an "addition" to the BEAMS system is another area deserving of further investigation. This is especially true in light of the fact that this research effort has demonstrated the applicability of linear programming technology in the scheduling of BCE work orders.

APPENDICES

APPENDIX A

GLOSSARY OF ACRONYMS

BCE - Base Civil Engineering

BEAMS - Base Engineer Automated Management System

BLIS - Base Level Inquiry System

CES - Civil Engineering Squadron

Cost Center Codes -

- 441 - Equipment Operations
- 442 - Pavement
- 443 - Grounds
- 451 - Structures
- 452 - Protective Coatings
- 453 - Plumbing
- 454 - Metal Working
- 455 - Masonry
- 461 - Refrigeration and Air Conditioning
- 463 - Heating Systems
- 471 - Interior Electric
- 472 - Exterior Electric

CREATE - Computational Resources for Engineering and Simulation, Training, and Education

IWP - In-Service Work Plan

LP600 - Honeywell Series 600 Linear Programming System

MAJCOM - Major Air Command

APPENDIX B

SMALL-SCALE TEST: PROGRAM LISTING

```
100##S,R(SL) :,8,16;:,16
110$:IDENT:WP1186,AFIT/  BELYEU & KUHN
120$:USERID:80A045$XC47
130$:PROGRAM:RLHS
140$:LIMITS:10,39K,,5K
150$:PRMFL:H*,R,R,AF.LIB/LP.PAC
160$:REMOTE:SO,SL
170$:DISC:AA,A1,10R
180$:DISC:AB,A2,10R
190$:DISC:AC,A3,10R
200$:DISC:AD,A4,10R
210$:DISC:AE,A5,10R
220$:DATA:IN
230FILE:BCE
300*****   ROW IDENTIFICATION SECTION   *****
301****     (OBJECTIVE FUNCTION NAME)    ****
310L:PLAN(F)
320****      (SHOP NAMES)        ****
330:CARP(Z)
340:PAINT(Z)
350:PLUMB(Z)
360:METAL(Z)
370:INTEL(Z)
400*****   OBJECTIVE ROW COEFFICIENTS   *****
401****     (WORK ORDER 'PAYOFF')        ****
410A:PLAN,X05605(R=0,1)=-10
420:,X06516(R=0,1)=-10
430:,X10766(R=0,1)=-20
440:,X40070(R=0,1)=-20
450:,X40100(R=0,1)=-20
460:,X40369(R=0,1)=-20
470:,X40649(R=0,1)=-20
480:,X40679(R=0,1)=-20
490:,X40859(R=0,1)=-20
500:,X42029(R=0,1)=-20
510:,X42079(R=0,1)=-5
520:,X42369(R=0,1)=-20
530:,X42609(R=0,1)=-5
540:,X42719(R=0,1)=-20
550:,X42789(R=0,1)=-20
560:,X43219(R=0,1)=-80
570:,X43239(R=0,1)=-5
580:,X50110(R=0,1)=-20
590:,X50130(R=0,1)=-20
600:,X50629(R=0,1)=-10
610:,X50830(R=0,1)=-10
620:,X50850(R=0,1)=-40
630:,X50859(R=0,1)=-10
640:,X53519(R=0,1)=-20
650:,X53769(R=0,1)=-10
```

```
700****      (SLACK VARIABLES FOR EACH SHOP)  ****
710:,SLARP(P)=1
720:,SLAINT(P)=1
730:,SLUMB(P)=1
740:,SLETAL(P)=1
750:,SLINT(P)=1
800*****      CARPENTER SHOP WORK ORDERS    *****
810A:CARP,X05605=30
820:,X06516=179
830:,X10766=116
840:,X40369=64
850:,X40649=94
860:,X42789=2
870:,X43219=166
880:,X50130=68
890:,X50830=92
892:,X53519=68
894:,SLARP=1
900*****      PAINT SHOP WORK ORDERS    *****
905A:PAINT,X05605=4
910:,X40369=64
915:,X40649=24
920:,X40679=26
925:,X42719=18
930:,X43219=220
935:,X50830=28
940:,X50859=16
945:,X53769=950
950:,SLAINT=1
1000*****      PLUMBING SHOP WORK ORDERS  *****
1010A:PLUMB,X40100=32
1020:,X40369=9
1030:,X40649=24
1040:,X42609=32
1050:,X50110=32
1060:,X50130=57
1070:,X50629=125
1080:,X50850=102
1090:,SLUMB=1
```

```
1100*****     METAL SHOP WORK ORDERS    *****
1105A:METAL,X40100=16
1110:,X40369=36
1120:,X40649=14
1130:,X40679=60
1135:,X42029=65
1140:,X42369=64
1145:,X42719=50
1150:,X42789=111
1155:,X50859=4
1160:,X53519=28
1170:,SLETAL=1
1200*****    INTERIOR ELECTRIC SHOP WORK ORDERS  *****
1205A:INTEL,X40070=175
1210:,X40369=76
1215:,X40649=24
1220:,X40679=18
1225:,X40859=220
1230:,X42079=159
1235:,X42609=37
1240:,X42789=8
1245:,X43219=30
1250:,X43239=62
1255:,X50110=6
1260:,X50130=16
1265:,SLINT=1
1300*****   RIGHT HAND SIDE VALUES   *****
1305****     (AVAILABLE MANHOURS)     ****
1310B:CARP,HRS=421
1320:PAINT=1036
1330:PLUMB=117
1340:METAL=403
1350:INTEL=491
1400END***
1450$:DATA:I*
1510:PREPRO
1520:TITLE:INSERVICE WORKPLAN - SMALL SCALE TEST 1
1530:CONVERT:SOURCE=BCE/IN,IDENT=IWP
1540:SETUP:SOURCE=IWP
1550:SET:OBJ=PLAN,RHS=HRS
1560:PICTURE
1570:PRIMAL
1580:OUTPUT
1585:RNGRHS
1590:RNGOBJ
1595:RNGSOL
1600:RNGSTR
1610:ENDLP
1620$:ENDJOB
1630***EOF
```

APPENDIX C

INITIAL SMALL-SCALE TEST:
LP600 OUTPUT

F9R4T 01 04/17/80 INSERVICE WORKPLAN - SMALL SCALE TEST 1

PRNAM=INP : : FUNCT= 355.961277+ OBJ=PLAN : : RHS=HRS

COLUMNS

COL KJ	TYPE	COLUMN NAME	STRUCT. INDIC.	X-VALUE	DJ
7	RANGE	X05605	*ATBND	1.00000000+	6.79313501-
8	RANGE	X06516		. +	8.98306636+
9	RANGE	X10766	*ATBND	1.00000000+	7.76292986-
10	RANGE	X40070	*ATBND	1.00000000+	5.88709677-
11	RANGE	X40100	*ATBND	1.00000000+	6.15480957-
12	RANGE	X40369	*BASIS	.13888889+	. -
13	RANGE	X40649		. +	2.65027676+
14	RANGE	X40679	*ATBND	1.00000000+	13.41406230-
15	RANGE	X40859	*ATBND	1.00000000+	2.25806451-
16	RANGE	X42029	*ATBND	1.00000000+	14.73430603-
17	RANGE	X42079		. +	7.82258864+
18	RANGE	X42369	*ATBND	1.00000000+	14.81531670-
19	RANGE	X42609		. +	10.53289057+
20	RANGE	X42719	*ATBND	1.00000000+	15.75999249-
21	RANGE	X42709	*ATBND	1.00000000+	10.15166964-
22	RANGE	X43219	*ATBND	1.00000000+	57.75318520-
23	RANGE	X43239	*BASIS	.37813620+	. -
24	RANGE	X50110	*ATBND	1.00000000+	6.96710942-
25	RANGE	X50130		. +	10.81671913+
26	RANGE	X56629		. +	39.01960784+
27	RANGE	X50830	*BASIS	.32729468+	. -
28	RANGE	X50850	*BASIS	.50735294+	. -
29	RANGE	X50859	*ATBND	1.00000000+	9.50753624-
30	RANGE	X53519	*ATBND	1.00000000+	10.55824568-
31	RANGE	X53769	*BASIS	.77257564+	. -
32	PLUS	SLARP		. +	1.10549199+
33	PLUS	SLAINT		. +	1.01052631+
34	PLUS	SLUMH		. +	1.39215686+
35	PLUS	SLETAL		. +	1.08101067+
36	PLUS	SLINT		. +	1.08064516+
37	RHS	HRS		. +	173.44382105+

APPENDIX D

REVISED SMALL-SCALE TEST:
LP600 OUTPUT

F921T 01 04/17/80 INSERVICE WORKPLAN - SMALL SCALE TEST 2

PRNAM=IWP : : FUNCT= 304.580890. OBJ=PLAN : : RHS=HRS

COLUMNS

COL	KJ	TYPE	COLUMN NAME	STRUCT. INDIC.	X-VALUE	DJ
	7	RANGE	X05605	.ATBND	1.00000000.	4.78548894-
	8	RANGE	X06516		. .	20.86206896.
	9	RANGE	X10766	.BASIS	.22406826.	. -
	10	RANGE	X40070	.ATBND	1.00000000.	4.09090909-
	11	RANGE	X40100	.ATBND	1.00000000.	4.72263449-
	12	RANGE	X40369		. .	8.28544792.
	13	RANGE	X40619		. .	10.44041368.
	14	RANGE	X40679	.ATBND	1.00000000.	7.85865502-
	15	RANGE	X40859	.BASIS	.06347256.	. -
	16	RANGE	X42029	.ATBND	1.00000000.	8.91609478-
	17	RANGE	X42079		. .	9.45454545.
	18	RANGE	X42369	.ATBND	1.00000000.	9.08661639-
	19	RANGE	X42609		. .	10.91265597.
	20	RANGE	X42719	.ATBND	1.00000000.	11.20444537-
	21	RANGE	X42709	.BASIS	.50450450.	. -
	22	RANGE	X43219	.ATBND	1.00000000.	46.33624814-
	23	RANGE	X43239		. .	.63636363.
	24	RANGE	X50110	.ATBND	1.00000000.	6.90552504-
	25	RANGE	X50130		. .	15.53162456.
	26	RANGE	X50629		. .	39.01960784.
	27	RANGE	X50830		. .	6.15680501.
	28	RANGE	X50850	.BASIS	.12745098.	. -
	29	RANGE	X50859	.ATBND	1.00000000.	9.14949247-
	30	RANGE	X53519	.ATBND	1.00000000.	3.50125674-
	31	RANGE	X53769	.BASIS	.76421052.	. -
	32	PLUS	SLARP		. .	1.17241379.
	33	PLUS	SLAINT		. .	1.01052631.
	34	PLUS	SLUMB		. .	1.39215686.
	35	PLUS	SLETAL		. .	1.17052162.
	36	PLUS	SLINT		. .	1.09090909.
	37	RHS	HRS		. .	107.94353187.

APPENDIX E

INITIAL SMALL-SCALE TEST: HEURISTIC

ACTION	PAY-OFF	CUMMULA-TIVE PAYOFF	MANHOURS				
			CARP	PAINT	PLUMB	METAL	INTEL
TOTAL AVAILABLE MANHOURS			421	1036	117	403	491
1. Schedule W.O. 43219	80	80	-166	-220			-30
			255	816	117	403	461
2. Schedule W.O. 50850	40	120			-102		
			255	816	15	403	461
3. Reject W.O. 40649 (PLUMB HRS)							
4. Schedule W.O. 40369	20	140	-64	-64	-9	-36	-76
			191	752	6	367	385
5. Schedule W.O. 40679	20	160		-26		-60	-18
			191	726	6	307	367
6. Schedule W.O. 42789	20	180	-2			-111	-8
			189	726	6	196	359
7. Reject W.O. 50110 (PLUMB HRS)							
8. Reject W.O. 40100 (PLUMB HRS)							
9. Schedule W.O. 42719	20	200		-18		-50	
			189	708	6	146	359
10. Schedule W.O. 53519	20	220	-68			-28	
			121	708	6	118	359
11. Reject W.O. 50130 (PLUMB HRS)							
12. Schedule W.O. 42369	20	240				-64	
			121	708	6	54	359

ACTION	PAY-OFF	CUMMULA-TIVE PAYOFF	MANHOURS				
			CARP	PAINT	PLUMB	METAL	INTEL
13. Reject W.O. 42029 (METAL HRS)							
14. Schedule W.O. 10766	20	260	-116				
			5	708	6	54	359
							-175
15. Schedule W.O. 40070	20	280					
			5	708	6	54	184
16. Reject W.O. 40859 (INTEL HRS)							
17. Schedule W.O. 50859	10	290		-16		-4	
			5	692	6	50	184
18. Reject W.O. 05605 (CARP HRS)							
19. Reject W.O. 50830 (CARP HRS)							
20. Reject W.O. 50629 (PLUMB HRS)							
21. Reject W.O. 06516 (CARP HRS)							
22. Reject W.O. 53769 (PAINT HRS)							
23. Reject W.O. 42609 (PLUMB HRS)							-62
24. Schedule W.O. 43239	5	295					
			5	692	6	50	122
25. Reject W.O. 42079 (INTEL HRS)							
PARTIAL SCHEDULES							
26. Partial Schedule W.O.53769-73%	7.3	302.3		-692			
			5	0	6	50	122
27. Partial Schedule W.O.40859-55%	11.1	313.4					-122

ACTION	PAY-OFF	CUMMULA-TIVE PAYOFF	MANHOURS CARP	PAINT	PLUMB	METAL	INTEL
			5	0	6	50	0
28. Partial Schedule W.O. 42029-77%	15.4	328.8				-50	
			5	0	6	0	0
29. Partial Schedule W.O. 06516- 3%	.3	329.1			-6		
			5	0	0	0	0
30. Partial Schedule W.O. 50629- 5%	.5	329.6	-5				
			0	0	0	0	0

APPENDIX F

REVISED SMALL-SCALE TEST:
HEURISTIC

ACTION	PAY-OFF	CUMMULA-TIVE PAYOFF	MANHOURS				
			CARP	PAINT	PLUMB	METAL	INTEL
TOTAL AVAILABLE MANHOURS			291	1010	77	343	423
1. Schedule W.O. 43219	80	80	-166	-220			-30
			125	790	77	343	393
2. Reject W.O. 50850 (PLUMB HRS)							
3. Schedule W.O. 40649	20	100	-94	-24	-24	-14	-24
			31	766	53	329	369
4. Reject W.O. 40369 (CARP HRS)							
5. Schedule W.O. 40679	20	120		-26		-60	-18
			31	740	53	269	351
6. Schedule W.O. 42789	20	140	-2			-111	-8
			29	740	53	158	343
7. Schedule W.O. 50110	20	160			-32		-6
			29	740	21	158	337
8. Reject W.O. 40100 (PLUMB HRS)							
9. Schedule W.O. 42719	20	180		-18		-50	
			29	722	21	108	337
10. Reject W.O. 53519 (CARP HRS)							
11. Reject W.O. 50130 (CARP&PLUMB HRS)							
12. Schedule W.O. 42369	20	200				-64	
			29	722	21	44	337
13. Reject W.O. 42029 (METAL HRS)							

ACTION	PAY-OFF	CUMMULA-TIVE PAYOFF	MANHOURS				
			CARP	PAINT	PLUMB	METAL	INTEL
14. Reject W.O. 10766 (CARP HRS)							
15. Schedule W.O. 40070	20	220					-175
			29	722	21	44	162
16. Reject W.O. 40859 (INTEL HRS)							
17. Schedule W.O. 50859	10	230		-16		-4	
			29	706	21	40	162
18. Reject W.O. 05605 (CARP HRS)							
19. Reject W.O. 50830 (CARP HRS)							
20. Reject W.O. 50629 (PLUMB HRS)							
21. Reject W.O. 06516 (CARP HRS)							
22. Reject W.O. 53769 (PAINT HRS)							
23. Reject W.O. 42609 (PLUMB HRS)							
24. Schedule W.O. 43239	5	235					-62
			29	706	21	40	100
25. Reject W.O. 42079 (INTEL HRS)							
PARTIAL SCHEDULES							
26. Partial Schedule W.O. 53769-74%	7.4	242.4		-706			
			29	0	21	40	100
27. Partial Schedule W.O. 40859-45%	9.1	251.5					-100
			29	0	21	40	0
28. Partial Schedule W.O. 42029-62%	12.3	263.8				-40	

ACTION	PAY-OFF	CUMMULA-TIVE PAYOFF	MANHOURS				
			CARP	PAINT	PLUMB	METAL	INTEL
			29	0	21	0	0
29. Partial Schedule W.O. 10766-25%	5	268.8	-29				
			0	0	21	0	0
30. Partial Schedule W.O. 50850-21%	8.2	277.0			-21		
			0	0	0	0	0

APPENDIX G

LARGE-SCALE TEST: PATRICK APRIL IWP DATA

WORK ORDER	PRI	PAY-OFF	Manhours Per Cost Center											
			441	442	443	451	452	453	454	455	461	463	471	472
68448	3	11				4	12			60				
70412	3	65	24	31						56				122
70418	3	5	56			64	17		70		189		60	
80145	3	65											91	81
80154	3	11				32	110			704	8		8	
80190	4	1	32			16	13	74	32	70			27	
80214	2	26	48	24	8				2				48	230
80285	3	9	32			24	26		86		168		32	
80300	3	9				60	28		48	15				8
80306	3	37				250								
80384	3	65	40			688			39					
80395	3	81	16			26		4	5		16			
80402	3	9	16			150			8	24				
80424	3	25	16	32	54									
80427	3	9							27	17			8	
80430	3	9				24	4						34	
80431	3	57					8			100		24	16	
80455	3	5				48		28		8	16		20	
80457	3	57	16			26		43	56				8	
80469	3	7										134		
80471	3	9				4		6	24				40	4
80482	3	9							13			150	16	

WORK ORDER	PRI	PAY-OFF	Manhours Per Cost Center											
			441	442	443	451	452	453	454	455	461	463	471	472
80484	3	5				17	7	43		2				
80485	3	9		48				66		27				
80553	3	29		8					2				37	
80569	3	9	96											
90024	3	29	32			46	26	32	41			187		
90102	3	49	16			120	20	7	80	21				
90148	3	9	96					111	47	96			52	
90165	3	29	80				320							
90196	3	29							5		4		40	
90198	3	9											298	40
90199	3	9											120	
90200	3	9					150		280		200	80		
90221	3	7				528	226	48	57			8	224	
90222	3	7	48			16			24					
90224	3	9				80	120			40	16	16		
90226	3	9					48							
90229	3	9				36	12							
90232	3	37							80		64			
90243	3	7				20	22		5				6	
90249	3	9							64		64			
90264	3	7							12			280		
90308	3	33				16				16	16		16	

WORK ORDER	PRI	PAY-OFF	Manhours Per Cost Center											
			441	442	443	451	452	453	454	455	461	463	471	472
90338	3	15				2				124				
90372	3	7	24				8			34	54		21	
90386	3	5				40		6	6				80	
90401	3	7					350							
90455	3	15				8			82					
90480	3	33				582							112	
90517	3	5											29	45
90521	3	13				600	110							
90538	3	7	24						52		96	17	12	
90563	3	5	80		120									
90581	3	13				16	4		4					
90612	3	9				34							8	
90614	3	11				264	72						64	
90626	3	7		16			90							
90636	3	21				16	6			24				
90652	3	25				52								
90659	3	5				8				8	8			
90660	3	13						4			47		8	
90664	3	17							90					
90666	3	9					88							
90676	3	7				32	16		40	16				
90677	3	15							10		8	38	16	

WORK ORDER	PRI	PAY-OFF	Manhours Per Cost Center											
			441	442	443	451	452	453	454	455	461	463	471	472
90681	3	25							8					
90687	3	7				46	72							
90693	3	15				145								
90698	3	21				34	6			64			2	
90703	3	11						68						
90708	3	5				64	40							
90712	3	15		24			72							
90723	3	15											104	
90724	3	7											71	
90726	3	11											95	
90728	3	9											107	
90733	3	11				156							16	
90740	3	9				8	4							
90766	3	7											7	
90769	3	5							20	4				
90772	3	15		16			72							
90780	3	17								80				
90792	3	11				24					65			
90793	3	15				10			8	160				80
90794	3	13				530		35					60	
90797	3	7				8	4						16	
90801	3	9				58								

WORK ORDER	PRI	PAY-OFF	Manhours Per Cost Center											
			441	442	443	451	452	453	454	455	461	463	471	472
90819	3	5				120								
90821	3	5											71	
90828	3	25							500					
90870	3	13		43				12	8					
90880	3	15				40	31						13	
90884	3	13				64							12	
90898	3	9											16	
90906	3	21				80							8	
90908	3	13		24					32					4
90919	3	5					12			32				
90920	3	7					32						9	
90922	3	11				122	68		21				95	
90927	3	9				40								
90945	3	11				16	16							
90958	3	9											40	
90983	3	9				41	9						10	
91007	3	7				8	4							
91023	3	11				10	2						2	
91029	3	7											11	
91040	3	5	4			8	16	8	28					
91041	3	9						28	18					
91056	3	9											16	

WORK ORDER	PRI	PAY-OFF	Manhours Per Cost Center											
			441	442	443	451	452	453	454	455	461	463	471	472
91066	4	7											15	
91081	3	11				1	37			3				
91111	3	7					2		10					
91114	3	7				9	1			16				
91116	3	11		9			28							
91120	3	13				116						13		
91122	3	9				9							56	
91163	3	7											10	
91176	3	13				28								
91181	3	7							40	3				
91193	2	22											8	
91194	3	7							18	10	27			
91208	3	7						17						
92000	3	7	16						34		87		16	
92014	3	9							62					
92015	3	5											12	
92019	3	5				12	24		5					
92036	2	20											64	
92037	2	20											6	
92040	3	9					10		17					
92069	3	7				4	5							
92086	3	5	120											

WORK ORDER	PRI	PAY-OFF	Manhours Per Cost Center											
			441	442	443	451	452	453	454	455	461	463	471	472
92088	3	11		23										
92097	3	7				61	36						18	
92116	2	24				8								
92152	3	7				36	7							
92198	2	62											6	
92214	3	7						4					20	
92219	3	7											5	
92227	3	7											30	
92242	2	20				160								
92270	3	5											5	
92274	2	60		3					2				7	
92370	3	5				5	6							
92383	3	5				6								
92523	3	5										95		
92541	3	5				103	205		32	25			4	
Total Required														
Manhours:			932	301	182	6139	2734	644	2254	1859	1153	1042	2614	614
Total Available														
Manhours:			484	157	182	1362	579	254	780	478	572	456	869	486

APPENDIX H

LARGE-SCALE TEST: PROGRAM LISTING
FOR PATRICK APRIL IWP

```
10##S,R(SL) :,8,16;:,16
20$:IDENT:WP1186,AFIT/ BELYEU & KUHN
30$:USERID:80A045$XC47
40$:PROGRAM:RLHS
50$:LIMITS:10,39K,,5K
60$:PRMFL:H*,R,R,AF.LIB/LP.PAC
70$:REMOTE:SO,SL
80$:DISC:AA,A1,10R
90$:DISC:AB,A2,10R
100$:DISC:AC,A3,10R
110$:DISC:AD,A4,10R
120$:DISC:AE,A5,10R
130$:DATA:IN
140FILE:BCE
150L:PLAN(F)
160:CC441(Z)
170:CC442(Z)
180:CC443(Z)
190:CC451(Z)
200:CC452(Z)
210:CC453(Z)
220:CC454(Z)
230:CC455(Z)
240:CC461(Z)
250:CC463(Z)
260:CC471(Z)
270:CC472(Z)
280A:PLAN,X68448(R=0,1)=-11
290:,X70418(R=0,1)=-5
300:,X70412(R=0,1)=-65
310:,X80145(R=0,1)=-65
320:,X80154(R=0,1)=-11
330:,X80190(R=0,1)=-1
340:,X80214(R=0,1)=-26
350:,X80285(R=0,1)=-9
360:,X80300(R=0,1)=-9
370:,X80306(R=0,1)=-37
380:,X80384(R=0,1)=-65
390:,X80395(R=0,1)=-81
400:,X80402(R=0,1)=-9
410:,X80424(R=0,1)=-25
420:,X80427(R=0,1)=-9
430:,X80430(R=0,1)=-9
440:,X80431(R=0,1)=-57
450:,X80455(R=0,1)=-5
460:,X80457(R=0,1)=-57
470:,X80469(R=0,1)=-7
480:,X80471(R=0,1)=-9
490:,X80482(R=0,1)=-9
500:,X80484(R=0,1)=-5
510:,X80485(R=0,1)=-9
```

520:,X80553(R=0,1)=-29
530:,X80569(R=0,1)=-9
540:,X90024(R=0,1)=-29
550:,X90102(R=0,1)=-49
560:,X90148(R=0,1)=-9
570:,X90165(R=0,1)=-29
580:,X90196(R=0,1)=-29
590:,X90198(R=0,1)=-9
600:,X90199(R=0,1)=-9
610:,X90200(R=0,1)=-9
620:,X90221(R=0,1)=-7
630:,X90222(R=0,1)=-7
640:,X90224(R=0,1)=-9
650:,X90226(R=0,1)=-9
660:,X90229(R=0,1)=-9
670:,X90232(R=0,1)=-37
680:,X90243(R=0,1)=-7
690:,X90249(R=0,1)=-9
700:,X90264(R=0,1)=-7
710:,X90308(R=0,1)=-33
720:,X90338(R=0,1)=-15
730:,X90372(R=0,1)=-7
740:,X90386(R=0,1)=-5
750:,X90401(R=0,1)=-7
760:,X90455(R=0,1)=-15
770:,X90480(R=0,1)=-33
780:,X90517(R=0,1)=-5
790:,X90521(R=0,1)=-13
800:,X90538(R=0,1)=-7
810:,X90563(R=0,1)=-5
820:,X90581(R=0,1)=-13
830:,X90612(R=0,1)=-9
840:,X90614(R=0,1)=-11
850:,X90626(R=0,1)=-7
860:,X90636(R=0,1)=-21
870:,X90652(R=0,1)=-25
880:,X90659(R=0,1)=-5
890:,X90660(R=0,1)=-13
900:,X90664(R=0,1)=-17
910:,X90666(R=0,1)=-9
920:,X90676(R=0,1)=-7
930:,X90677(R=0,1)=-15
940:,X90681(R=0,1)=-25
950:,X90687(R=0,1)=-7
960:,X90693(R=0,1)=-15
970:,X90698(R=0,1)=-21
980:,X90703(R=0,1)=-11
990:,X90708(R=0,1)=-5
1000:,X90712(R=0,1)=-15
1010:,X90723(R=0,1)=-15
1020:,X90724(R=0,1)=-7
1030:,X90726(R=0,1)=-11
1040:,X90728(R=0,1)=-9
1050:,X90733(R=0,1)=-11
1060:,X90740(R=0,1)=-9
1070:,X90766(R=0,1)=-7
1080:,X90769(R=0,1)=-5
1090:,X90772(R=0,1)=-15
1100:,X90780(R=0,1)=-17
1110:,X90792(R=0,1)=-11
1120:,X90793(R=0,1)=-15
1130:,X90794(R=0,1)=-13
1140:,X90797(R=0,1)=-7
1150:,X90801(R=0,1)=-9
1160:,X90819(R=0,1)=-5
1170:,X90821(R=0,1)=-5
1180:,X90828(R=0,1)=-25
1190:,X90870(R=0,1)=-13
1200:,X90880(R=0,1)=-15
1210:,X90884(R=0,1)=-13
1220:,X90898(R=0,1)=-9
1230:,X90906(R=0,1)=-21
1240:,X90908(R=0,1)=-13
1250:,X90919(R=0,1)=-5
1260:,X90920(R=0,1)=-7
1270:,X90922(R=0,1)=-11
1280:,X90927(R=0,1)=-9
1290:,X90945(R=0,1)=-11
1300:,X90958(R=0,1)=-9
1310:,X90983(R=0,1)=-9
1320:,X91007(R=0,1)=-7
1330:,X91023(R=0,1)=-11
1340:,X91029(R=0,1)=-7
1350:,X91040(R=0,1)=-5
1360:,X91041(R=0,1)=-9
1370:,X91056(R=0,1)=-9
1380:,X91066(R=0,1)=-7
1390:,X91081(R=0,1)=-11
1400:,X91111(R=0,1)=-7
1410:,X91114(R=0,1)=-7
1420:,X91116(R=0,1)=-11
1430:,X91120(R=0,1)=-13
1440:,X91122(R=0,1)=-9
1450:,X91163(R=0,1)=-7
1460:,X91176(R=0,1)=-13
1470:,X91181(R=0,1)=-7
1480:,X91193(R=0,1)=-22
1490:,X91194(R=0,1)=-7
1500:,X91208(R=0,1)=-7
1510:,X92000(R=0,1)=-7
1520:,X92014(R=0,1)=-9
1530:,X92015(R=0,1)=-5

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1540:,X92019(R=0,1)=-5
1550:,X92040(R=0,1)=-9
1560:,X92069(R=0,1)=-7
1570:,X92036(R=0,1)=-20
1580:,X92037(R=0,1)=-20
1590:,X92086(R=0,1)=-5
1600:,X92088(R=0,1)=-11
1610:,X92097(R=0,1)=-7
1620:,X92116(R=0,1)=-24
1630:,X92152(R=0,1)=-7
1640:,X92214(R=0,1)=-7
1650:,X92219(R=0,1)=-7
1660:,X92227(R=0,1)=-7
1670:,X92242(R=0,1)=-20
1680:,X92270(R=0,1)=-5
1690:,X92370(R=0,1)=-5
1700:,X92383(R=0,1)=-5
1710:,X92523(R=0,1)=-5
1720:,X92541(R=0,1)=-5
1730:,SL441(P)=1
1740:,SL442(P)=1
1750:,SL443(P)=1
1760:,SL451(P)=1
1770:,SL452(P)=1
1780:,SL453(P)=1
1790:,SL454(P)=1
1800:,SL455(P)=1
1810:,SL461(P)=1
1820:,SL463(P)=1
1830:,SL471(P)=1
1840:,SL472(P)=1
1850A:CC441,X70412=24
1860:,X70418=56
1870:,X80190=32
1880:,X80214=48
1890:,X80285=32
1900:,X80384=40
1910:,X80395=16
1920:,X80402=16
1930:,X80424=16
1940:,X80457=16
1950:,X80569=96
1960:,X90024=32
1970:,X90102=16
1980:,X90148=96
1990:,X90165=80
2000:,X90222=48
2010:,X90372=24
2020:,X90538=24
2030:,X90563=80
2040:,X91040=4
2050:,X92000=16
2060:,X92086=120
2070:,SL441=1
2080A:CC442,X70412=31
2090:,X80214=24
2100:,X80424=32
2110:,X80485=48
2120:,X80553=8
2130:,X90626=16
2140:,X90712=24
2150:,X90772=16
2160:,X90870=43
2170:,X90908=24
2180:,X91116=9
2190:,X92088=23
2200:,SL442=1
2210A:CC443,X80214=8
2220:,X80424=54
2230:,X90563=120
2240:,SL443=1
2250A:CC451,X68448=4
2260:,X70418=64
2270:,X80154=32
2280:,X80190=16
2290:,X80285=24
2300:,X80300=60
2310:,X80306=250
2320:,X80384=688
2330:,X80395=26
2340:,X80402=150
2350:,X80430=24
2360:,X80455=48
2370:,X80457=26
2380:,X80471=4
2390:,X80484=17
2400:,X90024=46
2410:,X90102=120
2420:,X90221=528
2430:,X90222=16
2440:,X90224=80
2450:,X90229=36
2460:,X90243=20
2470:,X90308=16
2480:,X90338=2
2490:,X90386=40
2500:,X90455=8
2510:,X90480=582
2520:,X90521=600
2530:,X90581=16
2540:,X90612=34
2550:,X90614=264
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2560:,X90636=16
2570:,X90652=52
2580:,X90659=8
2590:,X90676=32
2600:,X90687=46
2610:,X90693=145
2620:,X90698=34
2630:,X90708=64
2640:,X90733=156
2650:,X90740=8
2660:,X90792=24
2670:,X90793=10
2680:,X90794=530
2690:,X90797=8
2700:,X90801=58
2710:,X90819=120
2720:,X90880=40
2730:,X90884=64
2740:,X90906=80
2750:,X90922=122
2760:,X90923=40
2770:,X90945=16
2780:,X90983=41
2790:,X91007=8
2800:,X91023=10
2810:,X91040=8
2820:,X91081=1
2830:,X91114=9
2840:,X91120=116
2850:,X91122=9
2860:,X91176=28
2870:,X92019=12
2880:,X92069=4
2890:,X92097=61
2900:,X92116=8
2910:,X92152=36
2920:,X92242=160
2930:,X92370=5
2940:,X92383=6
2950:,X92541=103
2960:,SL451=1
2970A:CC452,X68448=12
2980:,X70418=17
2990:,X80154=110
3000:,X80190=13
3010:,X80285=26
3020:,X80300=28
3030:,X80430=4
3040:,X80431=8
3050:,X80484=7
3060:,X90024=26
3070:,X90102=20
3080:,X90165=320
3090:,X90200=150
3100:,X90221=226
3110:,X90224=120
3120:,X90226=48
3130:,X90229=12
3140:,X90243=22
3150:,X90372=8
3160:,X90401=350
3170:,X90521=110
3180:,X90581=4
3190:,X90614=72
3200:,X90626=90
3210:,X90636=6
3220:,X90666=88
3230:,X90676=16
3240:,X90687=72
3250:,X90698=6
3260:,X90708=40
3270:,X90712=72
3280:,X90740=4
3290:,X90772=72
3300:,X90797=4
3310:,X90880=31
3320:,X90919=12
3330:,X90920=32
3340:,X90922=68
3350:,X90945=16
3360:,X90983=9
3370:,X91007=4
3380:,X91023=2
3390:,X91040=16
3400:,X91081=37
3410:,X91111=2
3420:,X91114=1
3430:,X91116=28
3440:,X92019=24
3450:,X92040=10
3460:,X92069=5
3470:,X92097=36
3480:,X92152=7
3490:,X92370=6
3500:,X92541=205
3510:,SL452=1
3520A:CC453,X80190=74
3530:,X80395=4
3540:,X80455=28
3550:,X80457=43
3560:,X80471=6
3570:,X80484=43
```

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3580:,X80485=66
3590:,X90024=32
3600:,X90102=7
3610:,X90148=111
3620:,X90221=48
3630:,X90386=6
3640:,X90660=4
3650:.X90703=68
3660:,X90794=35
3670:,X90870=12
3680:,X91040=8
3690:,X91041=28
3700:,X91208=17
3710:,X92214=4
3720:,SL453=1
3730A:CC454,X70418=70
3740:,X80190=32
3750:,X80214=2
3760:,X80285=86
3770:,X80300=48
3780:,X80384=39
3790:,X80395=5
3800:,X80402=8
3810:,X80427=27
3820:,X80457=56
3830:,X80471=24
3840:,X80482=13
3850:,X80553=2
3860:,X90024=41
3870:,X90102=80
3880:,X90148=47
3890:,X90196=5
3900:,X90200=280
3910:,X90221=57
3920:,X90222=24
3930:,X90232=80
3940:,X90243=5
3950:,X90249=64
3960:,X90264=12
3970:,X90386=6
3980:,X90455=82
3990:,X90538=52
4000:,X90581=4
4010:,X90664=90
4020:,X90676=40
4030:,X90677=10
4040:,X90681=8
4050:,X90769=20
4060:,X90793=8
4070:,X90828=500
4080:,X90870=8
4090:,X90908=32
4100:,X90922=21
4110:,X91040=28
4120:,X91041=18
4130:,X91111=10
4140:,X91181=40
4150:,X91194=18
4160:,X92000=34
4170:,X92014=62
4180:,X92019=5
4190:,X92040=17
4200:,X92541=32
4210:,SL454=1
4220A:CC455,X68448=60
4230:,X70412=56
4240:,X80154=704
4250:,X80190=70
4260:,X80300=15
4270:,X80402=24
4280:,X80427=17
4290:,X80431=100
4300:,X80455=8
4310:,X80484=2
4320:,X80485=27
4330:,X90102=21
4340:,X91040=8
4350:,X90148=96
4360:,X90224=40
4370:,X90308=16
4380:,X90338=124
4390:,X90372=34
4400:,X90636=24
4410:,X90659=8
4420:,X90676=16
4430:,X90769=4
4440:,X90780=80
4450:,X90793=160
4460:,X90698=64
4470:,X90919=32
4480:,X91081=3
4490:,X91114=16
4500:,X91181=3
4510:,X91194=10
4520:,X92541=25
4530:,SL455=1
4540A:CC461,X70418=189
4550:,X80154=8
4560:,X80285=168
4570:,X80395=16
4580:,X80455=16
4590:,X90196=4
```

```
4600:,X90200=200
4610:,X90224=16
4620:,X90232=64
4630:,X90249=64
4640:,X90308=16
4650:,X90372=54
4660:,X90538=96
4670:,X90659=8
4680:,X90660=47
4690:,X90677=8
4700:,X90792=65
4710:,X91194=27
4720:,X92000=87
4730:,SL461=1
4740A:CC463,X80431=24
4750:,X80469=134
4760:,X80482=150
4770:,X90024=187
4780:,X90200=80
4790:,X90221=8
4800:,X90224=16
4810:,X90264=280
4820:,X90538=17
4830:,X90677=38
4840:,X91120=13
4850:,X92523=95
4860:,SL463=1
4870A:CC471,X70418=60
4880:,X80145=91
4890:,X80154=8
4900:,X80190=27
4910:,X80214=48
4920:,X80285=32
4930:,X80427=8
4940:,X80430=34
4950:,X80431=16
4960:,X80455=20
4970:,X80457=8
4980:,X80471=40
4990:,X80482=16
5000:,X80553=37
5010:,X90148=52
5020:,X90196=40
5030:,X90198=298
5040:,X90199=120
5050:,X90221=224
5060:,X90243=6
5070:,X90308=16
5080:,X90372=21
5090:,X90386=80
5100:,X90480=112
5110:,X90517=29
5120:,X90538=12
5130:,X90612=8
5140:,X90614=64
5150:,X90660=8
5160:,X90677=16
5170:,X90698=2
5180:,X90723=104
5190:,X90724=71
5200:,X90726=95
5210:,X90728=107
5220:,X90733=16
5230:,X90766=7
5240:,X90794=60
5250:,X90797=16
5260:,X90821=71
5270:,X90880=13
5280:,X90884=12
5290:,X90898=16
5300:,X90906=8
5310:,X90920=9
5320:,X90922=95
5330:,X90958=40
5340:,X90983=10
5350:,X91023=2
5360:,X91029=11
5370:,X91056=16
5380:,X91066=15
5390:,X91122=56
5400:,X91163=10
5410:,X91193=8
5420:,X92000=16
5430:,X92015=12
5440:,X92036=64
5450:,X92037=6
5460:,X92097=18
5470:,X92214=20
5480:,X92219=5
5490:,X92227=30
5500:,X92270=5
5510:,X92541=4
5520:,SL471=1
5530A:CC472,X70412=122
5540:,X80145=81
5550:,X80214=230
5560:,X80300=8
5570:,X80471=4
5580:,X90198=40
5590:,X90517=45
5600:,X90793=80
5610:,X90908=4
```

```
:,SL472=1
B:CC441,HRS=484
:CC442=154
:CC443=182
:CC451=1362
:CC452=579
:CC453=254
:CC454=778
:CC455=478
:CC461=572
:CC463=456
:CC471=856
:CC472=486
END***
$:DATA:I*
:PREPRO
:TITLE:INSERVICE WORKPLAN - PATRICK AFB, APRIL IWP
:CONVERT:SOURCE=BCE/IN,IDENT=IWP
:SETUP:SOURCE=IWP
:SET:OBJ=PLAN,RHS=HRS
:PICTURE
:PRIMAL
:OUTPUT
:RNGRHS
:RNGOBJ
:RNGSOL
:RNGSTR
:ENDLP
$:ENDJOB
***EOF
```

APPENDIX I

LARGE-SCALE TEST: LP600 OUTPUT
FOR PATRICK APRIL IWP

E1227 01 05/02/80   INSERVICE WORKPLAN - PATRICK AFB, APRIL IWP

PNNAM=IWP   FUNCT= 1439.31399+ OBJ=PLAN   RHS=HRS

COLUMNS

COL KJ	TYPE	COLUMN NAME	STRUCT. INDIC.	X-VALUE	DJ
14	RANGE	X80448	•BASIS	.21155142+	. -
15	RANGE	X70410		. +	9.55630821+
16	RANGE	X70412	•ATBND	1.00000000+	63.62056316-
17	RANGE	X80145	•ATBND	1.00000000+	64.65074281-
18	RANGE	X80154		. +	113.75418949+
19	RANGE	X80190		. +	16.75307387+
20	RANGE	X80214	•ATBND	1.00000000+	44.64259786-
21	RANGE	X80285	•BASIS	.09523809+	. -
22	RANGE	X80390		. +	9.90745102+
23	RANGE	X80306	•ATBND	1.00000000+	5.75000000-
24	RANGE	X80384		. +	29.03335699+
25	RANGE	X80395	•ATBND	1.00000000+	78.19661994-
26	RANGE	X80402		. +	15.48314488+
27	RANGE	X80424	•ATBND	1.00000000+	13.12354012-
28	RANGE	X80427	•ATBND	1.00000000+	.77476498-
29	RANGE	X80430	•ATBND	1.00000000+	.72989523-
30	RANGE	X80431	•ATBND	1.00000000+	37.93735224-
31	RANGE	X80455		. +	.98499056+
32	RANGE	X80457	•ATBND	1.00000000+	46.77150927-
33	RANGE	X80469	•BASIS	.70895522+	. -
34	RANGE	X80471	•BASIS	.66666666+	. -
35	RANGE	X80482		. +	3.26574331+
36	RANGE	X80484	•ATBND	1.00000000+	5.98460969-
37	RANGE	X80485		. +	5.93036154+
38	RANGE	X80553	•ATBND	1.00000000+	20.53451629-
39	RANGE	X80569	•ATBND	1.00000000+	5.00000000-
40	RANGE	X90024	•ATBND	1.00000000+	6.03091156-
41	RANGE	X90102	•ATBND	1.00000000+	15.98878280-
42	RANGE	X90148		. +	14.93052181+
43	RANGE	X90165		. +	3.63402263+
44	RANGE	X90196	•ATBND	1.00000000+	27.90475944-
45	RANGE	X90198		. +	27.66780981+
46	RANGE	X90199		. +	8.30769231+
47	RANGE	X90200		. +	35.116747[illegible]2+
48	RANGE	X90221		. +	117.27719252+
49	RANGE	X90222		. +	.01796127+
50	RANGE	X90224		. +	17.53213192+
51	RANGE	X90226	•ATBND	1.00000000+	4.60409[illegible]60-
52	RANGE	X90229	•ATBND	1.00000000+	1.40122415-
53	RANGE	X90232	•ATBND	1.00000000+	30.17564331-
54	RANGE	X90243	•ATBND	1.00000000+	.80395864-
55	RANGE	X90249	•ATBND	1.00000000+	4.78781883-
56	RANGE	X90264		. +	9.50584731+
57	RANGE	X90300	•ATBND	1.00000000+	27.74424481-
58	RANGE	X90338		. +	4.67919658+

E122T 01 05/02/80 INSERVICE WORKPLAN - PATRICK AFB, APRIL IMP

PRNAM=IMP I I FUNCT= 1439,31399+ OBJ=PLAN I I RHS=HRS I

COLUMNS

COL KJ	TYPE	COLUMN NAME	STRUCT. INDIC.	X-VALUE	DJ
59	RANGE	X90372	•ATBND	1.00000000+	2.17266577-
60	RANGE	X90386		. +	11.96285425+
61	RANGE	X90401		. +	25.04762892+
62	RANGE	X90455	•ATBND	1.00000000+	.61362547-
63	RANGE	X90480		. +	55.98384615+
64	RANGE	X90517	•ATBND	1.00000000+	7.91938703-
65	RANGE	X90521		. +	72.07211194+
66	RANGE	X90538	•ATBND	1.00000000+	4.24583198-
67	RANGE	X90563	•ATBND	1.00000000+	1.66666666-
68	RANGE	X90581	•ATBND	1.00000000+	9.98074758-
69	RANGE	X90612	•ATBND	1.00000000+	3.59615384-
70	RANGE	X90614		. +	37.82342432+
71	RANGE	X90626		. +	6.84571547+
72	RANGE	X90636	•ATBND	1.00000000+	14.69012241-
73	RANGE	X90652	•ATBND	1.00000000+	10.50000000-
74	RANGE	X90659	•ATBND	1.00000000+	3.52596856-
75	RANGE	X90660	•ATBND	1.00000000+	16.79611011-
76	RANGE	X90664	•ATBND	1.00000000+	2.30763771-
77	RANGE	X90666	•ATBND	1.00000000+	.94231044-
78	RANGE	X90676		. +	7.50196636+
79	RANGE	X90677	•ATBND	1.00000000+	9.85421348-
80	RANGE	X90681	•ATBND	1.00000000+	23.69481224-
81	RANGE	X90687		. +	5.34265509+
82	RANGE	X90693		. +	3.12500000+
83	RANGE	X90698	•ATBND	1.00000000+	5.88417811-
84	RANGE	X90703	•ATBND	1.00000000+	17.30017850-
85	RANGE	X90708		. +	6.66258616+
86	RANGE	X90712	•BASIS	.29146100+	. -
87	RANGE	X90723	•BASIS	.72398110+	. -
88	RANGE	X90724		. +	3.24038461+
89	RANGE	X90726		. +	2.70192307+
90	RANGE	X90728		. +	6.43269231+
91	RANGE	X90733		. +	10.88769231+
92	RANGE	X90740	•ATBND	1.00000000+	7.63374138-
93	RANGE	X90766	•ATBND	1.00000000+	5.99038461-
94	RANGE	X90769	•ATBND	1.00000000+	1.10824232-
95	RANGE	X90772	•ATBND	1.00000000+	2.80244838-
96	RANGE	X90788	•ATBND	1.00000000+	4.46583446-
97	RANGE	X90792	•ATBND	1.00000000+	14.33315403-
98	RANGE	X90793	•BASIS	.05832305+	. -
99	RANGE	X90794		. +	50.66110722+
100	RANGE	X90797	•ATBND	1.00000000+	3.32684007-
101	RANGE	X90801	•ATBND	1.00000000+	1.75000000-
102	RANGE	X90819		. +	10.00000000+
103	RANGE	X90821		. +	5.24038461+

F122T 01 05/02/80 INSERVICE WORKPLAN - PATRICK AFB, APRIL IWP

PRNAM=IWP : : FUNCT= 1439.31399+ OBJ=PLAN : : RHS=HRS :

COLUMNS

COL KJ	TYPE	COLUMN NAME	STRUCT. INDIC.	X-VALUE	RJ
104	RANGE	X90820		. +	56.62423490+
105	RANGE	X90870		. +	2.25735118+
106	RANGE	X90880	*ATBND	1.00000000+	5.28649572-
107	RANGE	X90884	*ATBND	1.00000000+	3.26923077-
108	RANGE	X90898	*ATBND	1.00000000+	6.69230769-
109	RANGE	X90906	*ATBND	1.00000000+	9.84615384-
110	RANGE	X90908	*BASIS	.16687232+	. -
111	RANGE	X90919		. +	1.11276206+
112	RANGE	X90920	*ATBND	1.00000000+	2.77185414-
113	RANGE	X90922		. +	27.60653742+
114	RANGE	X90927	*ATBND	1.00000000+	4.00000000-
115	RANGE	X90945	*ATBND	1.00000000+	7.53496553-
116	RANGE	X90958	*ATBND	1.00000000+	3.23076923-
117	RANGE	X90983	*ATBND	1.00000000+	1.60861842-
118	RANGE	X91007	*ATBND	1.00000000+	5.63374138-
119	RANGE	X91023	*ATBND	1.00000000+	9.27848915-
120	RANGE	X91029	*ATBND	1.00000000+	5.41346154-
121	RANGE	X91040		. +	2.71495737+
122	RANGE	X91041	*ATBND	1.00000000+	8.65571869-
123	RANGE	X91056	*ATBND	1.00000000+	6.69230769-
124	RANGE	X91066	*ATBND	1.00000000+	4.93653846-
125	RANGE	X91081	*ATBND	1.00000000+	7.01704659-
126	RANGE	X91111	*ATBND	1.00000000+	5.18438599-
127	RANGE	X91114	*ATBND	1.00000000+	3.27644224-
128	RANGE	X91116	*ATBND	1.00000000+	5.28343534-
129	RANGE	X91120		. +	2.17918448+
130	RANGE	X91122		. +	.28192387+
131	RANGE	X91163	*ATBND	1.00000000+	5.55769231-
132	RANGE	X91176	*ATBND	1.00000000+	9.50000000-
133	RANGE	X91181	*BASIS	.32507562+	. -
134	RANGE	X91193	*ATBND	1.00000000+	20.84615384-
135	RANGE	X91194	*ATBND	1.00000000+	5.12535160-
136	RANGE	X91200	*ATBND	1.00000000+	8.57584462-
137	RANGE	X92008	*ATBND	1.00000000+	6.95187615-
138	RANGE	X92014		. +	1.12148513+
139	RANGE	X92015	*ATBND	1.00000000+	3.26923077-
140	RANGE	X92019	*ATBND	1.00000000+	.48620595-
141	RANGE	X92040	*ATBND	1.00000000+	5.30912947-
142	RANGE	X92069	*ATBND	1.00000000+	6.04217673-
143	RANGE	X92036	*ATBND	1.00000000+	10.76923077-
144	RANGE	X92037	*ATBND	1.00000000+	19.13461538-
145	RANGE	X92086	*BASIS	.60793651+	. -
146	RANGE	X92088	*ATBND	1.00000000+	2.94296113-
147	RANGE	X92097		. +	6.51748139+
148	RANGE	X92116	*ATBND	1.00000000+	23.00000000-

E122T 01 05/02/80 INSERVICE WORKPLAN - PATRICK AFB, APRIL INP

PRNAM=INP I I FUNCT= 1439,31399+ OBJ=PLAN I I RHS=HRS I

COLUMNS

COL KJ	TYPE	COLUMN NAME	STRUCT. INDIC.	X-VALUE	DJ
149	RANGE	X92152	*ATBND	1.00000000+	1.85984742-
150	RANGE	X92214	*ATBND	1.00000000+	4.48599335-
151	RANGE	X92219	*ATBND	1.00000000+	6.27884615-
152	RANGE	X92227	*ATBND	1.00000000+	2.67307692-
153	RANGE	X92242	*BASIS	.62886364+	. -
154	RANGE	X92270	*ATBND	1.00000000+	4.27884615-
155	RANGE	X92370	*ATBND	1.00000000+	3.82561287-
156	RANGE	X92383	*ATBND	1.00000000+	4.25000000-
157	RANGE	X92523	*ATBND	1.00000000+	.83731343-
158	RANGE	X92541		. +	36.36380492+
159	PLUS	SL441		. +	1.04166666+
160	PLUS	SL442		. +	1.35030604+
161	PLUS	SL443		. +	1.00000000+
162	PLUS	SL451		. +	1.12500000+
163	PLUS	SL452		. +	1.09156465+
164	PLUS	SL453		. +	.98735031+
165	PLUS	SL454		. +	1.16324047+
166	PLUS	SL455		. +	1.15660787+
167	PLUS	SL461		. +	.98256686+
168	PLUS	SL463		. +	1.05223080+
169	PLUS	SL471		. +	1.14423077+
170	PLUS	SL472		. +	.84217601+
171	RHS	HRS		. +	490.59866164+

APPENDIX J

BLIS PROGRAM LISTINGS TO PROVIDE INPUT DATA FOR LP600 FROM BEAMS

BLIS program to get listing of the materially supported work orders from the WCM file of the BEAMS system.

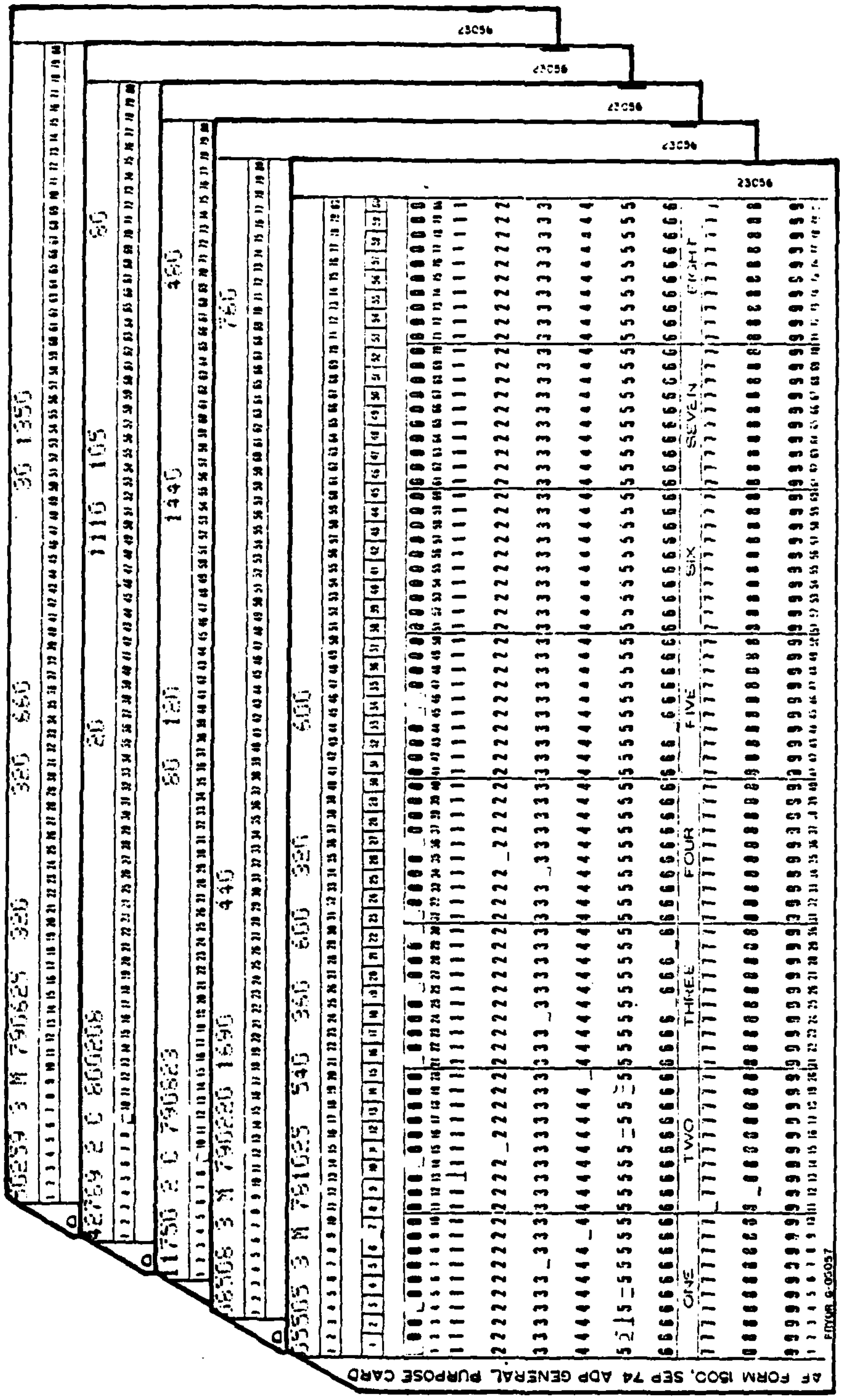
```
 EXECUTE NRIPØØ
 DATA AATG3Y
FILE WCM-FILE
RETRIVAL 1          REQUESTOR'S NAME
SELECT CTL-INSTL = "JREZ" AND NR-DIT = "Ø"
AND WO-IND = "A" "W" AND STATUS = "R" AND
DATE-PERF = "ØØØØØØ"
OUTPUT INFO
SORT WO-IND WO-NR
TITLE "IN HOUSE WORK SUPPORTABLE"
PRINT WO-IND WO-NR PRIORITY WK-CLASS DATE-
MATL SS-TABLE
 END
```

BLIS program to get the listing of the required manhours per work order from the WCN file of the BEAMS system.

```
 EXECUTE NRIPØØ
 DATA ARIPØC
FILE WCN-FILE
RETRIEVAL 1         REQUESTOR'S NAME
SELECT CTL-INSTL = "JREZ" AND WO-NR =
"Ø3753" "Ø3754" "Ø46Ø1" "Ø4617" "Ø55Ø5"
OUTPUT INFO
SORT WO-NR CT-CTR
TALLY WO-NR
TOTAL EST-HRS
TITLE "REQ'D HOURS FOR SUPPORTABLE WORK"
COLUMN 1 "WORK" 13 "COST" 25 "EST" NEXT 1
"ORDER" 12 "CENTER" 24 "HOURS"
PRINT 1 WO-NR 13 CT-CTR 24 EST-HRS
 END
```

APPENDIX K

SAMPLE OF PUNCH CARD INPUT TO LP600 FROM BEAMS



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