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ANALYSIS OF WORK ORDER PRIORITY SYSTEMS

USED BY CIVIL ENGINEERING

THESIS

Steven K. Lillemon
Captain, USAF

AFIT/GEM/LSR/88S-11

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THESIS

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Steven K. Lillemon, B.S.

Captain, USAF

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Abstract

Often the materials, money, and manpower available for work order (WO) accomplishment are limited. Thus, an important task the Base Civil Engineer (BCE) must perform is to prioritize work orders to determine the order in which they will be accomplished and--equally important--to determine which work orders will not be accomplished because of limited resources.

This study examined six methods used by BCEs of major Air Force installations within the Continental United States to prioritize work orders: Checkbook, Engineering Judgment, Corporate Base Panel, Internal BCE Panel, Command Driven, and Weighting. Based on survey questionnaire responses, both an Air Force-wide profile and system specific profiles were developed for the rank ordering process. Of the six methods, the Checkbook system was used the most often. The study also identified several common features among the reported strengths of the six prioritizing methods.

Based on analysis of the survey data, a pairwise comparison technique called the Analytical Hierarchy Process (AHP) was shown to be a useful aid for developing criteria to assess the relative worth of each work order to the goals and objectives set by the Installation Commander and his staff. BCEs using the Checkbook prioritizing method can use the AHP to develop a set of relative weights for criteria that can be used to allocate work orders among organizations. The AHP can also aid users of the other prioritizing methods by generating weighting

coefficients for an automated *scoring* technique that can be used to generate a "strawman" prioritized work order list.

ANALYSIS OF WORK ORDER PRIORITY SYSTEMS
USED BY CIVIL ENGINEERING

I. Introduction

Overview

Air Force Regulation 85-10 states the primary mission of civil engineering activities is to acquire, construct, maintain and operate real property facilities, and provide related management, engineering and other support work and services (12:2). Working with an annual operating budget of approximately $6.5 billion, civil engineering maintains approximately 66,000 facilities (40) with 500 million square feet of floor space and 250 million square yards of pavement on 1,200 installations worldwide. The average age of these facilities is 29 years old, and it would cost over $138 billion to replace them (26:505).

Although proper maintenance of facilities concerns the using organization, an organization is usually more interested in making improvements and additions to meet changing needs. However, budget cuts resulting from the Balanced Budget Deficit Control Act of 1985 (commonly known as Gramm-Rudman-Hollings) and increasing costs do not allow for many of the improvements and additions (called minor construction) these Air Force organizations need to make. For example, the operations and maintenance (O&M) funds for Headquarters AFLC were reduced 30 percent from fiscal year 1987 to fiscal year 1988 (50). In addition, only five percent of the civil engineering operations and maintenance total available direct actual manhours in a fiscal year can be used to accomplish minor construction (12:88).

Often, organization requests for facility improvements and additions, coupled with repair requirements, exceed the resources available to the Base Civil Engineer (BCE). An example is Wright-Patterson's ability to complete only 20 of 417 backlogged minor construction work orders (WOs) per month (20). Thus, the BCE must prioritize work orders to determine the order in which they will be accomplished and--equally important--to determine which projects will not be accomplished because of limited resources. This study deals with the processes used by BCEs to equitably distribute limited in-service resources by prioritizing work requests.

Statement of Problem

At the present time, the Air Force provides very little procedural guidance to the BCE on how to effectively prioritize in-service work orders, preferring to permit each base to develop its own local procedures for handling this important task. This approach creates three potential management problems: 1) some local procedures may be much less efficient than others in accomplishing the prioritization, 2) non-standardization makes it potentially harder for new arrivals to adapt efficiently to each local system, and 3) the *ad hoc* approach provides no mechanism for each base to learn about and adopt more efficient methods used elsewhere.

Background

Work Request/Work Order Description. *Customers submit requests for* work, such as requests for facility improvements or additions, to Base Civil Engineering on the BCE Work Request, AF Form 332. If the requested work does not need detailed planning, special costing, close coordination between shops, or a large bill of materials, the work will normally be accomplished by a job order. Job orders are typically small and require few manhours to complete.

On the other hand, requested work requiring detailed planning, capitalization of real property records (improvements or minor construction require capitalization of real property records), close coordination between shops, and gathering data for review and analysis must be accomplished by a work order. A work order is actually another document, AF Form 327, used to authorize the work requested on the BCE Work Request. For this study, the work order means approved and authorized work which requires detailed planning, capitalization of real property records, close coordination between shops, or the gathering of data for review and analysis.

The work request is used for nearly all minor construction requests and for complex or special interest maintenance or repair work which is performed by the civil engineering in-service work force (12:55). The Air Force defines work as "effort expended in the care, upkeep, construction, and improvement of Air Force real and installed property" (11:8).

To properly control and approve work, civil engineering has divided work into the classifications of maintenance, repair, construction, unspecified minor construction, renovation, demolition, work for others, and services. The classifications this study is concerned with are maintenance, repair, renovation and unspecified minor construction. Minor construction refers to alteration, additions, changes, or new construction required to provide adequate facilities for accomplishing the mission, and is generally limited to $200,000 in cost. Maintenance is the day-to-day, periodic, or scheduled work required to preserve facilities in such a state that they may be used effectively for accomplishing their mission. Repair refers to work required to return a facility to its effective operating state. Renovation is a combination of maintenance, repair, and minor construction in the interior of a facility. As stated previously, the primary work classification of interest to the customer is minor construction and renovation (11:8-62).

Work Request/Work Order Processing System. A brief description of the base civil engineering organization structure and the work request/work order processing system will provide an understanding of the initiation of a work request and the need to prioritize work orders for accomplishment.

On major installations the Base Civil Engineer works directly for the base commander. Normally, the BCE will have the following branches reporting directly to him: Engineering & Environmental Planning, Industrial Engineering, Financial Management, Operations, Squadron Section and Administration, Family Housing Management, and Fire Protection Management and Administration. At the BCEs option, Readiness Management may be moved from the Operations branch and placed immediately beneath the BCE. Air Force Regulation 85-10, Operation and Maintenance of Real Property, provides the official Base Civil Engineering organization chart (10:20).

However, because AFR 85-10 does not reflect recent changes, the chart shown in Figure 1 was taken from the student information guide written for MGT 101, Introduction To Base Civil Engineering, offered by the School of Civil Engineering and Services, Air Force Institute of Technology (9:B-2.9).

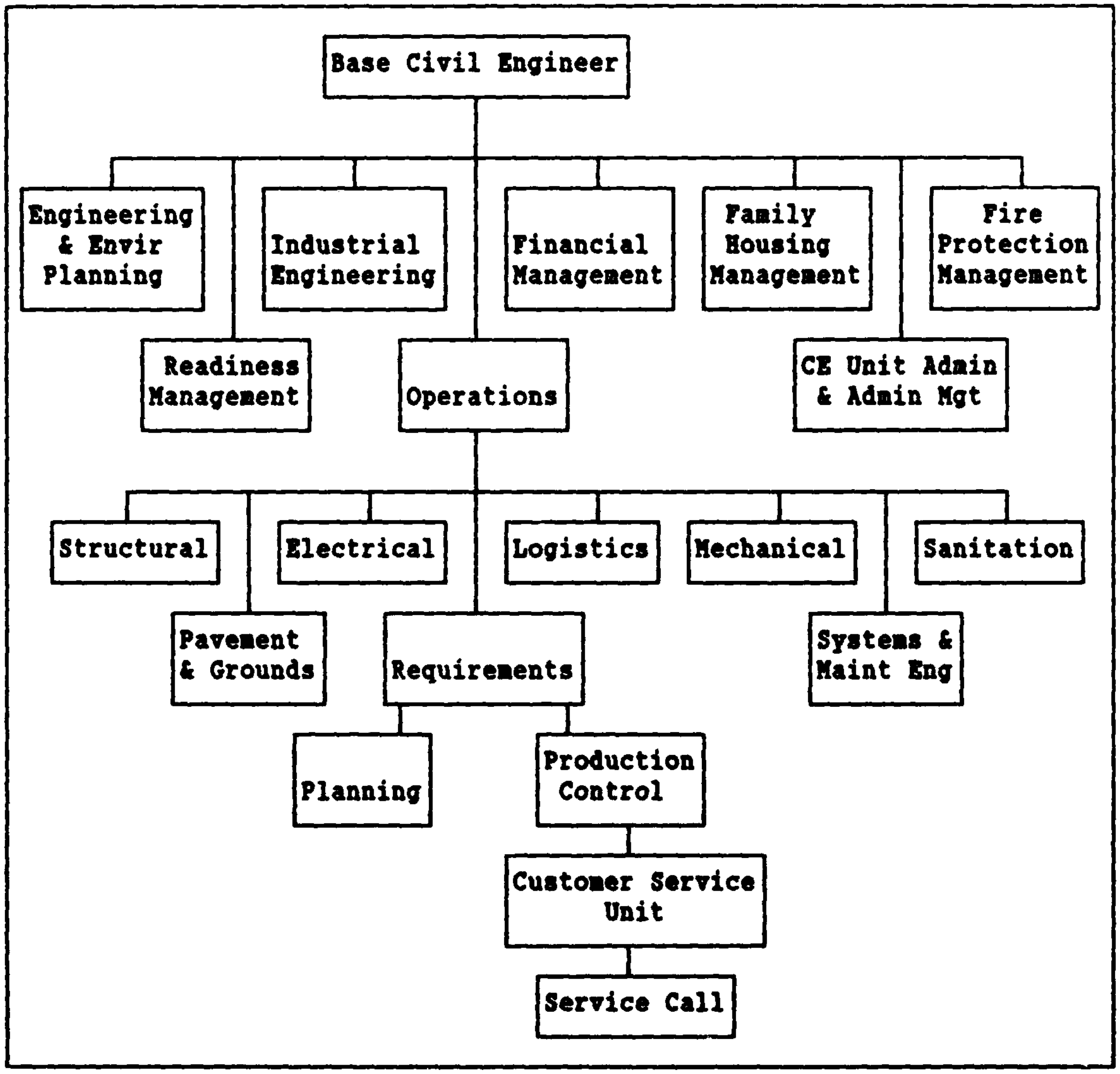


Figure 1. Typical Base Civil Engineer Organization Chart (9:B2.9)

Figure 1 does not show the complete CE organization--it shows branch level functions and functions within Operations that process work orders.

The Requirements Section within O&M is responsible for identifying work, receiving work requests; and processing, controlling, planning, acquiring materials for, and scheduling work orders. Requirements has two sub-sections: Production Control and Planning. Within Production Control is a Customer Service Unit (CSU) with a Service Call sub-unit. These are the initial points of contact for organizations requesting work.

Air Force Regulation 85-1 describes the procedures for processing work requests. Work requests enter civil engineering through the CSU. Customer Service performs the following actions:

1. Reviews the request to insure that it has been properly prepared.
2. Insures all necessary coordination has been obtained.
3. Determines that the work requested is a BCE responsibility.
4. Insures the work does not duplicate work previously identified.
5. Verifies the work supports planned use of the facility.
6. Determines that the work is a solution to the problem.

Once accepted, the work request is assigned a number from the work request/work order register. If necessary, Customer Service will send the work order out for staff work such as on-site investigation, material estimate or technical evaluation, prior to making a recommendation on the method of accomplishment and determination of proper approval authority (12:31-32).

Customer Service notifies the requester when the request is accepted or rejected, clearly explaining the reason if a request is rejected. Approved work requests are assigned to one of four work accomplishment methods: contract, self-help, in-service job or work order (12:31). Figure 2 provides a flow chart of the work request processing system.

Air Force Guidance Concerning Prioritizing Work Orders. This study has been limited to the prioritizing of work orders, which are to be accomplished by the civil engineering in-service work force. Therefore, prioritizing of the other three methods of accomplishment will not be discussed. Air Force Regulation 85-1, Resources and Work Force Management, provides general guidance concerning the approval and prioritization of work requests. Approval authority may be delegated within the BCE organization to the lowest level permitted by AFR 86-1, or the installation commander may be brought into the process. Regarding prioritizing approved work orders, AFR 85-1 suggests several methods the installation commander may use to achieve corporate agreement on priorities:

1. use staff meetings or the BCE commander's update briefing;
2. use special meetings with participation of the staff members who have interest in a particular request (12:32);
3. use the Facilities Board: a board established by the installation commander to provide corporate review and recommendations regarding the use of real property facilities and civil engineering resources in support of the mission. Members are appointed by the installation commander to represent the installation's major functions (11:90).

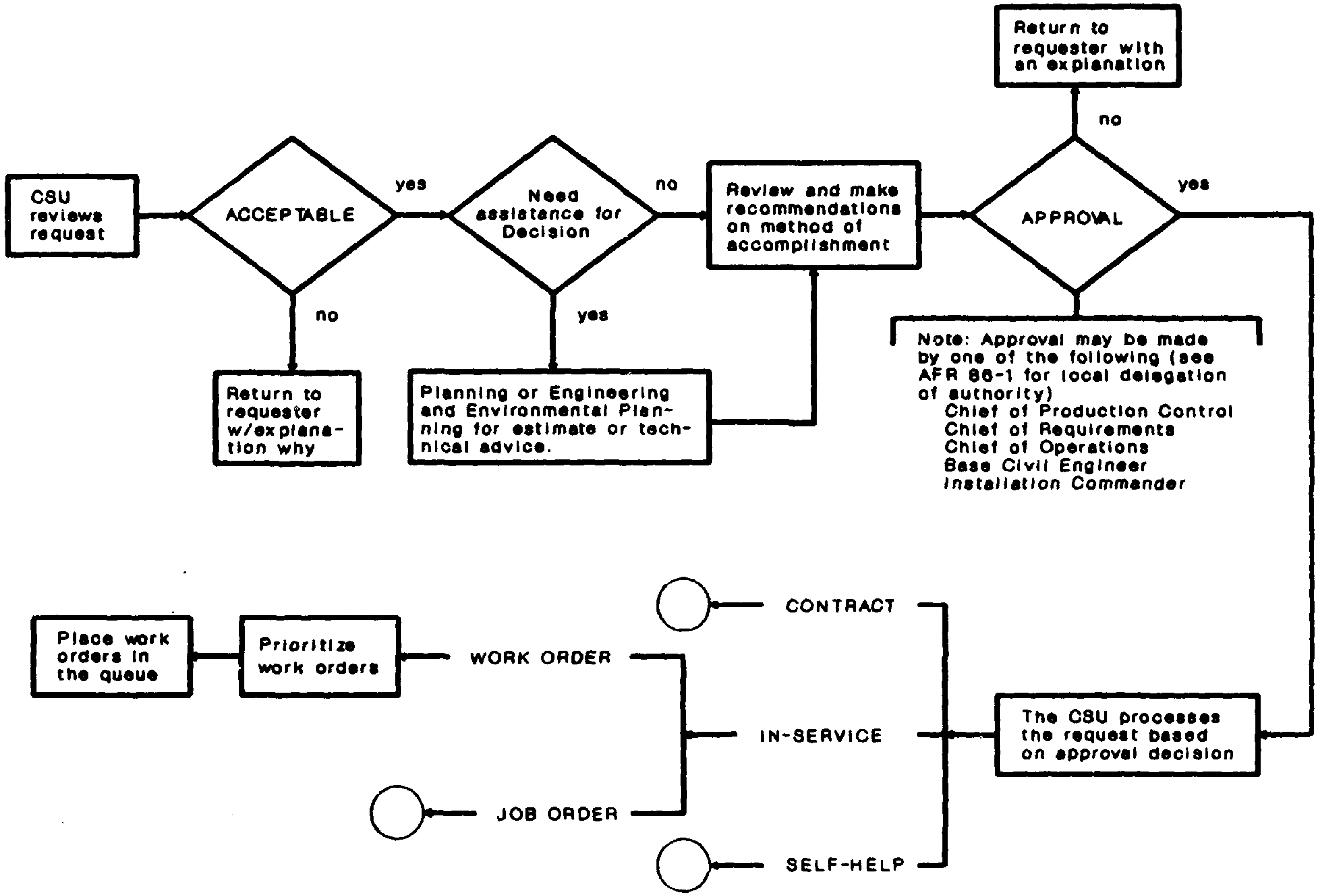


Figure 2. Written Work Request Flow Chart (12:36)

Reorganization of Operations Branch (44; 14). Most CE organizations are organized as shown in Figure 1. However, in July 1988, SAC implemented a program called Readiness and Ownership Oriented Management (ROOM). TAC is testing a similar program at Luke AFB called Combat Oriented Results Engineering (CORE). Both programs reorganize Operations from a trade oriented framework (such as carpenter, electric, paint shop) to a task oriented work force. Figure 3 shows the ROOM organization chart for Operations. CORE has basically the same organization with the exception that Requirements has been eliminated and the Logistics and Production Control sub-sections moved up one level. Also, under CORE, the Planning sub-section has been moved to a new function called Heavy Repair.

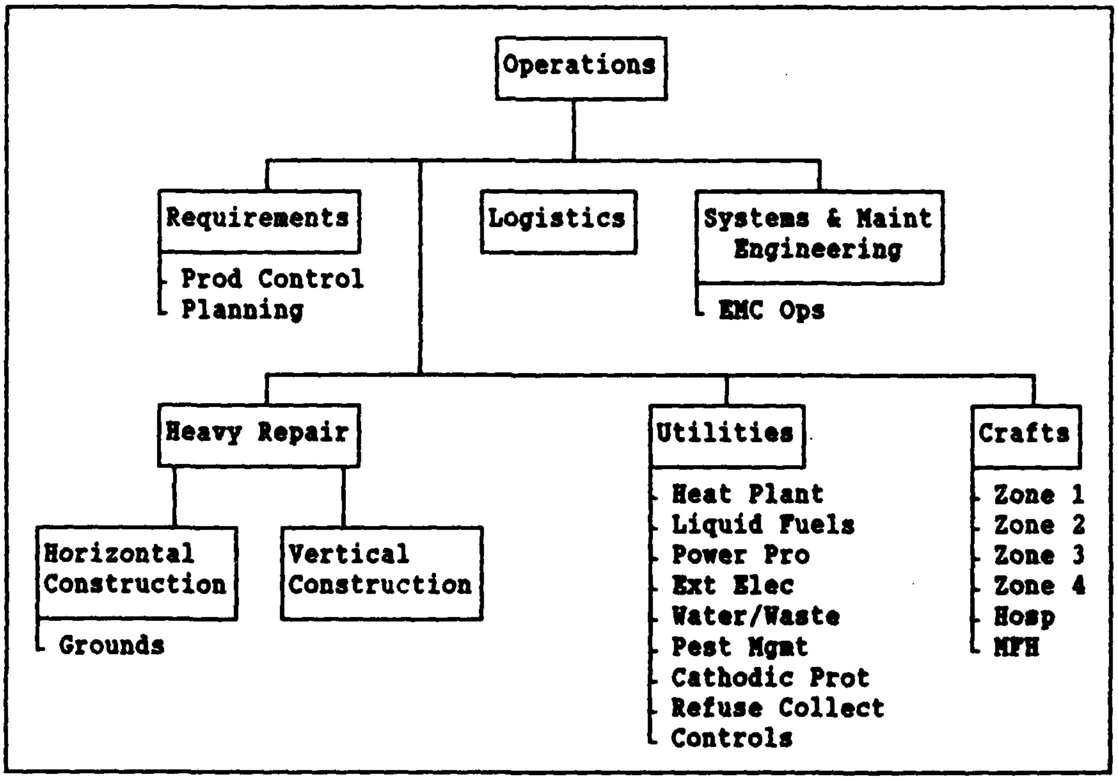


Figure 3. Generic ROOM Organization Chart (43:8)

The stated reason for reorganizing Operations was to improve work force productivity, efficiency, and wartime readiness. The most significant change was the elimination of centralized "shops" and centralized service call. Most of the workforce has been dedicated to zone maintenance groups called "Craft Teams" (SAC) or Facility Maintenance Units (TAC). These multiple-specialty teams are responsible for all Recurring Work and job order accomplishment within their respective zones. The teams may also perform small work orders if RWP and job orders are complete. Small WOs are those within the zone's in-house planning and manpower capabilities and that do not require capitalization.

ROOM and CORE also created a function that is responsible for construction and major work order accomplishment called Heavy Repair. As with the Craft Teams/FMUs, Heavy Repair is composed of a multi-AFSC workforce. Under CORE, the Planning sub-section was moved to Heavy Repair to plan their work orders. Under ROOM, Planning remained as a sub-section of Requirements, with the responsibility to plan work orders.

Even though ROOM and CORE have significantly changed the Operations organization structure; and to a lesser extent, the processing of work orders; both programs still use the normal prioritization of work orders for accomplished by Heavy Repair. Therefore, the findings of this study will be applicable for both the current Operations organization and the CORE and ROOM Operations organization.

Scope

This study was limited to the decision making process concerned with prioritizing work orders. In addition, due to communication difficulties involved with worldwide installations, the geographic area of interest for this study was limited to the Continental United States (CONUS) and Hawaii. Hawaii has been included in this study because Hickam AFB is known to have a functioning work order system which has been integrated with civil engineering's management information system, called the Work Information Management System (WIMS). Elements of Hickam's work order priority system may be useful in development of a generic work order prioritizing method.

Objective

The objective of this study was to identify the factors and procedures used at base level to evaluate and prioritize work orders at CONUS bases and attempt to combine the best features of current methods into a generic method that would be flexible enough to suit the needs of most bases. As used in this study, "factors" refers to both the internal and external forces that influence the way the BCE does business. The BCE has varying degrees of control over those factors and some clearly come from outside of Civil Engineering. This study focussed on work orders to be accomplished by in-service civil engineering.

Research Questions

The following research questions were used to develop a profile of the methods employed by civil engineering to prioritize work orders for in-service accomplishment and to provide the information required to permit combining the best features of current methods into a generic method that would be flexible enough to suit the needs of most bases:

1. How do Air Force Civil Engineering organizations allocate in-service work order accomplishment among base organizations?

2. What factors internal to the Civil Engineering organization are considered when making decisions about the priority of in-service work order accomplishment?

3. What factors external to the Civil Engineering organization are considered when making decisions about the priority of in-service work order accomplishment?

4. In the opinions of Base Civil Engineers, what are the shortcomings and advantages of the work order decision priority systems they currently use?

5. What common features exist among the reported strengths and weaknesses of the current systems?

6. Having identified the commonalities among the current systems, what is required to combine the best features or strengths into a generic priority method that will avoid repeating the reported shortcomings.

This chapter discussed the need to identify the factors and procedures used by base level Civil Engineering to prioritize work orders for the purpose of developing a generic decision method. Chapter II will discuss suitable decision concepts for developing the decision model, and Chapter III will state the approach and steps followed in this study to solve the research problem.

II. Literature Review

Overview

As stated in Chapter I, often the resources (materials and manpower) available for work order accomplishment are limited. Thus, an important task of the BCE is to determine the order in which work orders will be handled and, equally important, to determine which projects will not be accomplished because of limited resources.

The discipline of management science (sometimes called operations research or decision science) is concerned with analytical techniques that aid managers and leaders in the decision making process. When a decision is made, it is assumed the chosen alternatives are in some sense best.

> Ideally, a decision maker would like to have a meter to hold up to each alternative with the reading on the meter being the so-called goodness of each alternative. In evaluating alternatives with such a meter, the manager would simply choose [rank order] the alternative[s] with the highest reading [from the highest to the lowest readings] (49:96).

Although imperfect, a manager's decision making ability can be thought of as such a meter. "The true meter is very imprecise; it is subject to errors" (49:96). For example, at different times the BCE may make two different decisions concerning the priority of the same type of work order. His emotions may affect the outcome of a decision, as can an unrelated problem with a Directorate or lack of sleep. "At best, we may regard a manager's decision making ability as imperfect, and recognize its limitations" (49:96).

The goal, then, of management science is to help state preferences and provide relevant information to the decision maker. The manager makes the decisions. As stated above, the requirement to rank order work orders comes from the need to allocate resources. As used in this study, the term "resource allocation" means making an attempt to distribute limited resources among competing alternatives (work orders) to minimize total costs or maximize total returns or benefits. Management science calls a problem requiring this type of general decision a "resource allocation" problem.

This chapter will discuss available analytical techniques that could be used to aid in the work order prioritizing decision process. The decision flow model shown in Figure 4 has been developed to facilitate the discussion of each technique and to identify what decision(s) the technique can aid in making.

The first task in the work order priority decision making model is to identify the criteria important to the Installation Commander and his staff to meet established goals and objectives. As work requests are received, Civil Engineering must evaluate each as described in Chapter I to determine that it is a valid requirement and is a BCE responsibility. If approved for in-service work force accomplishment, the next decision task is to evaluate the worth or value of the work order using the established criteria. Once the worth of work orders has been determined, a rank ordered list can be developed based on the worth assessments. Finally, civil engineering develops an In-Service-Work Plan, or master production schedule, for accomplishment of the work orders in the order established by the work order priority list.

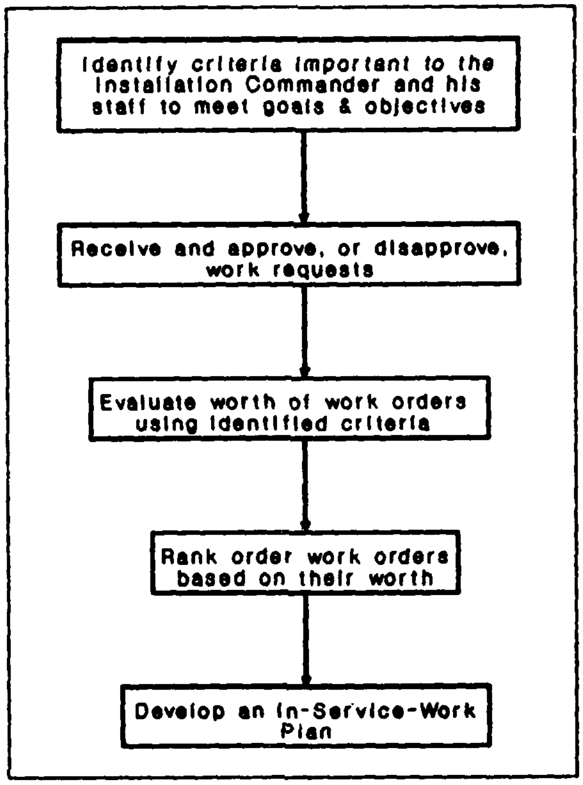


Figure 4. Work Order Decision Flow Model

The next section will discuss two prior studies that developed techniques to allocate Civil Engineering resources by rank ordering work orders.

Previous Studies

The need to allocate resources by rank ordering is sufficiently well recognized that two previous studies related to civil engineering work orders have been conducted. The purpose of these studies was to develop a method to automate the development of the In-Service-Work Plan (a schedule for accomplishing approved or programmed operations, services, maintenance, repair, and minor construction work by the in-service civil engineering work force). Figure 5 shows the decision tasks the analytical techniques proposed by these two studies were intended to aid.

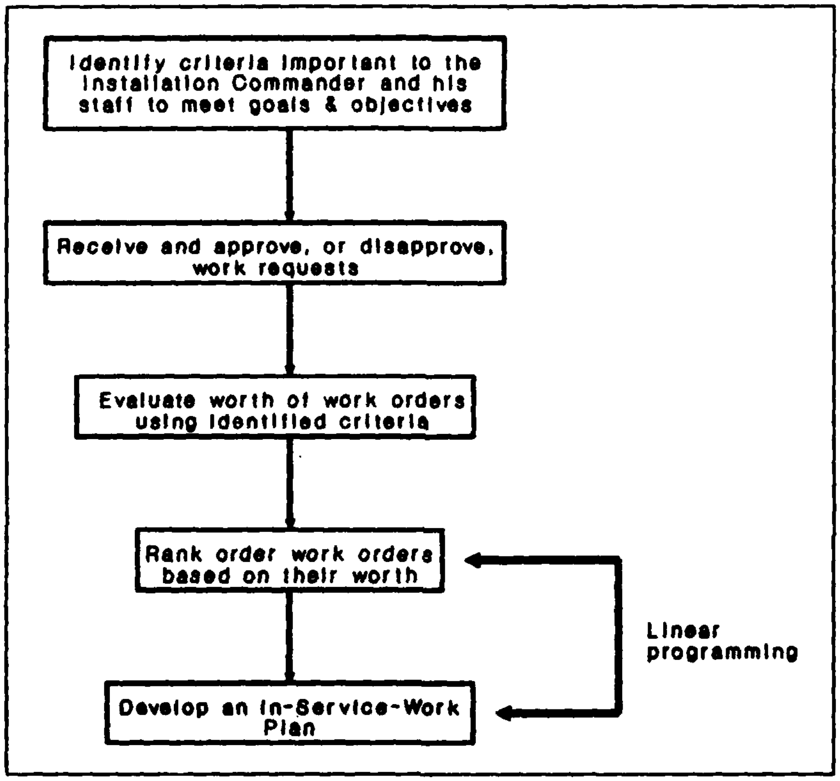


Figure 5. Tasks in the WO Decision Process Aided by Linear Programming

In the first study, Maj Bush and Capt Richardson attempted to use a zero-one linear program to model the scheduling process. Their intent was to develop an automated six month schedule to replace the manual heuristic WO selection process being used by CE. The objective function developed by Bush and Richardson was to schedule high priority, important class work orders according to a prioritized order subject to the constraints of available shop manhours and funds (7:30-31).

To elicit and quantify civil engineering managers' subjective preferences and judgments concerning the proper order of work order accomplishment, Bush and Richardson developed the "product value" coefficient for use in the linear programming objective function. This coefficient was determined by multiplying values assigned to the priority (as defined in AFR 85-1) by values assigned to the class of work (repair, maintenance, or construction) to obtain a product called the "product value." The values assigned to priority were weighted in such a manner as to assure the priority of work always took precedence over the class of work. Thus, the goal was to schedule high priority, important class work first, and all work was to be scheduled in the minimum time (7:29). Table 1 shows an example of the priority and classification products taken from Bush's study.

Table 1.

Priority Classification Product Values (7:30)

	Priority			
	1	2	3	4
	Numerical Assignment			
Class	100	20	5	1
R (3)	300	60	15	3
M (2)	200	40	10	2
C (1)	100	20	5	1

Bush and Richardson reported that the zero-one programming model performed satisfactorily in a small scale test but took too long in a large scale test due to inadequate computing power. In addition, the model was ineffective in that it did not schedule all of the available shop manhours (7:87).

There were several other shortcomings not discussed by the researchers. First, the study did not provide a method to capture manager's preference of criteria to be used in computing the "product value." Second, the study did not provide a method for soliciting the degree of importance manager's associated with the criteria used in computing the "product value." Thus, both the criteria and degree of importance among the criteria were determined by the researchers and not by the intended users.

In the second study, Capt Belyeu and Capt Kuhn attempted to use a linear program to model the scheduling process. The intent of this study was to develop a computer-based scheduling system for the development and modification of the civil engineering Operations branch In-Service Work Plan. The objective function was designed to maximize the sum of the payoffs (benefit of doing the work order) and minimize the unscheduled shop manhours subject to the constraints of available manhours. The researchers did not incorporate a budgetary constraint into their model because "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" (6:38). In summary, the intent of this study was to schedule high priority work first while making maximum use of available shop manhours.

Similar to Bush and Richardson, Belyeu and Kuhn attempted to capture and quantify CE managers' subjective preferences and judgments concerning the proper order of work order completion. The mechanism used by Belyeu and Khun to capture subjective judgments was a "payoff matrix," which provided a value for the worth of completing a work order. The payoff matrix was developed by determining the criteria to measure each work order by and the weights to assign to each criteria (no attempt was made to determine the degree of preference among criteria). The researchers provided an example in which the criteria used to develop the payoff matrix were work classification (repair, maintenance, or construction), priority of work (as defined in AFR 85-1), and commander interest.

Once weights had been assigned to each criteria, the payoff values were determined by multiplying the criteria weights applicable to each work order together. The numerical values assigned to the criteria were arbitrary, with the higher numbers corresponding to the higher priorities. Thus, the higher the priority of the work order, the higher the payoff for completing it (see Table 2, extracted from the Belyeu and Kuhn study).

Unlike the earlier study, Belyeu and Kuhn recognized the importance of obtaining a group consensus when establishing the criteria and weights to measure the "worth" or benefit of completing a work order. However, their conception of a group consensus was limited to the civil engineering organization and an "IWP scheduling policy of a BCE organization" (6:81). Although Belyeu and Kuhn recognized the need for a group consensus, they did not provide a technique for obtaining it. In addition, like Bush and Richardson's earlier study, Belyeu and Kuhn did not recognize the need nor provide the technique to solicit the

Table 2.

Payoff Matrix (6:54)

Work Classification		Priority of Work Order (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.

degree of importance managers' associated with the criteria used in computing the "payoff values."

To summarize, the concept of automating the scheduling process and method of determining the rank order of work order completion by quantifying a manager's subjective judgement, subject to resource constraints, were good pioneering steps in the application of decision making techniques to the work order decision process. However, what the two earlier attempts lack is a technique for identifying and selecting criteria and the degree of importance associated with each criterion to measure the worth or benefit of each work order.

Decision Making Models

Since the two previous studies did not provide a technique for identifying and selecting criteria and the degree of importance associated with each criterion, the next appropriate action was to look at theoretical models in search of a more complete solution for the work order ranking problem. A series of interviews was conducted with management science specialists (34; 33; 25) to identify potential models for allocating resources. The results of these interviews were combined with information in papers that reviewed models used in Research and Development, another major area where allocation of resources to projects must be undertaken (4; 42; 24; 47), to identify the following models worthy of further research: 1) economic analysis, 2) constrained optimization models, 3) scoring models, 4) checklists, and 5) comparative models. The following paragraphs will discuss the five models listed above in order to determine their suitability for rank ordering work orders.

Economic Analysis. Economic analysis attempts to determine whether a firm should undertake a project or whether it should reject the project as an investment opportunity by using economic data to compare the investment opportunities associated with projects. In other words, economic analysis attempts to select an optimal portfolio of investments based on financial considerations. Two basic approaches to the problem of selecting an optimal investment portfolio are the methods of ranking and mathematical programming (mathematical programming will be discussed later in the section under constrained optimization models) (8:248). In this method of ranking, the internal rate of return (IRR), return on investment (ROI), net present value (NPV), or benefit-cost ratio is determined for each project and used to rank projects in decreasing order. Projects are then accepted in that order until the budget is exhausted.

The benefit-cost ratio method is often used in R&D to evaluate candidate projects (32:26; 17:18). Using this method, costs and benefits associated with each project are assessed in terms of a common set of measures, dollars. Costs are the total resource costs of supporting the project, such as material, manpower, and transportation; and benefits are the net earnings to be realized from future product sales. To summarize, a benefit-cost ratio is simply a measure of benefits per dollar expended. Figure 6 shows the work order decision task the ranking method would aid CE management in making. Economic analysis models exhibit the following underlying assumptions.

- First the funds available for investment are insufficient to permit the firm to accept all otherwise acceptable candidate projects (capital rationing).

- Second, projects are indivisible, meaning that a project as an entity is accepted or rejected in its entirety. Partial projects or "parts" of a complete project will not be undertaken.

- Third, the projects are economically independent, meaning that the acceptance or rejection of one does not measurably alter the acceptance or rejection of any other project--except in the sense that resource constraints tighten as projects are accepted.

- Finally, all costs and benefits can be reduced to a monetary unit of measure, the dollar (8:245-249).

When applied to the problem of rank ordering work orders, economic analysis, and in particular, benefit-cost ratios, has the advantage of being a technique that is easily understood by almost anyone and adds a less subjective quantitative aspect to work order selection (32:27; 43:29).

Although the benefit-cost ratio may be a useful technique to prioritize work orders, a primary disadvantage is that currently "there is no generally agreed method--or at least, no generally accepted

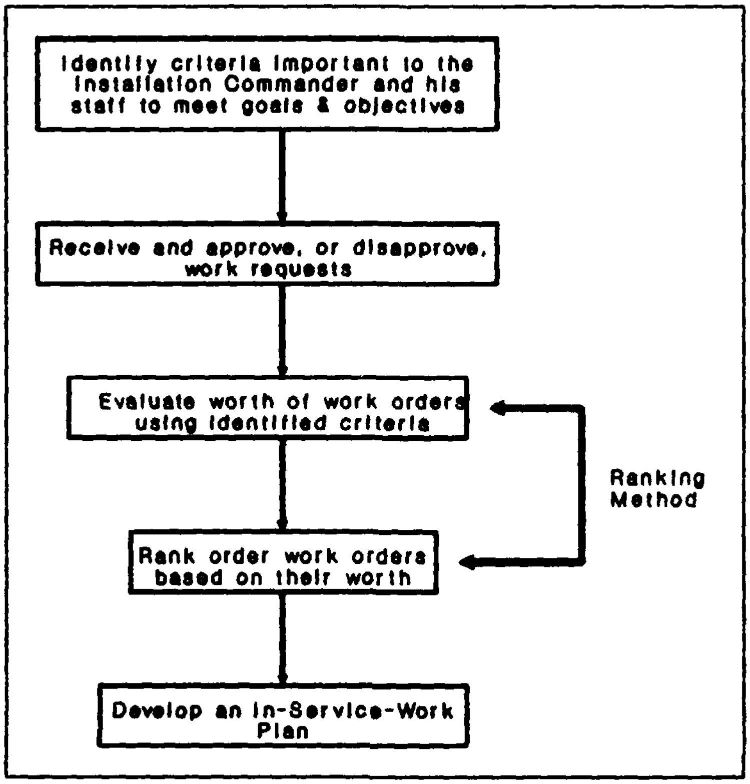


Figure 6. Tasks in the WO Decision Process Aided by the Ranking Method

method--for measuring the benefits of public projects in terms of dollars" (8:5). Thus, economic models normally consider only the financially based resources. Obtaining the information for the determination of a benefit-cost ratio can be difficult when people are asked to express their feelings about non-economic intangibles (intangibles are those objects such as customer service, good will, quality of life, community reputation, job satisfaction, safety, and so on which cannot be directly expressed in cost or profit terms [29:229]). In summary, social, environmental, and political costs or benefits of the projects can be added into the calculations of the benefit-cost ratio, but they must be expressed in the same unit of measurements, which normally would be dollars.

A second disadvantage in the use of benefit-cost ratios is that they do not recognize resource constraints such as manpower and material limitations (17:18). Thus, although benefit-cost ratios can be and have been applied to ranking public projects, the difficulty of expressing intangibles in monetary terms leads to a conclusion the model does not provide a good fit with the task of rank ordering work orders.

Constrained Optimization Models. Similar to economic analysis models, constrained optimization models attempt to select an optimal set of projects by using a mathematical programming procedure such as linear programming, zero-one integer programming, or goal programming with the goal of maximizing some criterion of interest to the firm subject to a number of feasibility constraints such as budget, manpower, and transportation (8:249). For example, in the earlier studies concerning formulation of civil engineering In-Service-Work Plan, Bush and Richardson used a zero-one linear program, and Belyeu and Kuhn used a linear program. Figure 7 shows the work order decision task the mathematical programming procedures would aid CE management in making.

Zero-one linear programming is one type of mathematical programming technique that lends itself to solving preferable order selection problems. Zero-one linear programming uses zero-one variables for project selection. The idea is that the decision variable will come out zero if the decision maker chooses not to do the project and will come out one if he chooses to do the project. Just as in linear programming, the decision maker will have constraints which reflect limited resources (money and manpower), and an objective function which is in a sense a

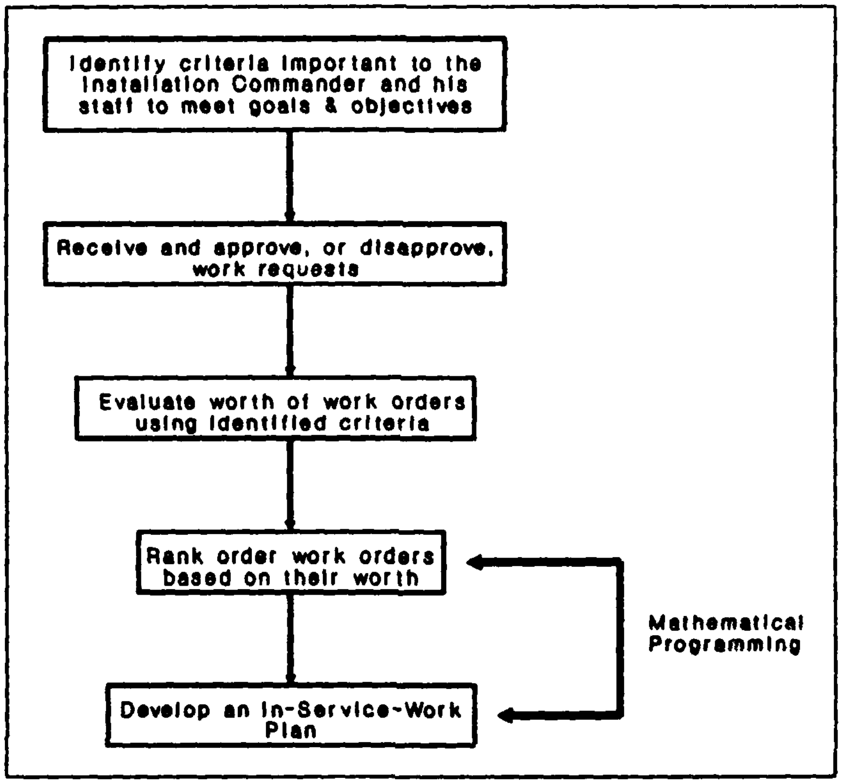


Figure 7. Task in the WO Decision Process Aided by Mathematical Programming

measure of how important it is to do the projects selected. The formulation will have some sort of maximization of benefits: coefficients times the decision variables, just as in linear programming, except now the decision variables can take on a value of zero or one, reflecting a go/no-go decision (25).

If several resources are scarce, one heuristic called Toyoda's Algorithm for Zero-One Progamming defines a composite measure of resource utilization for every project. Then it takes the ratio of the composite measure to the objective function coefficient (the value assigned for completing a project). Finally, it selects projects in the order of the largest benefit-cost ratio. It takes the best (highest) benefit-cost ratio, deducts the resources the best would consume, and than selects the next best one; on down the line. Thus, the projects can be rank ordered by looking at the order in which the projects were selected based on their benefit-cost ratios (46:1417-1427; 25).

Models using linear programming and zero-one linear programming exhibit the following underlying assumptions:

- Linearity. The objective function and every constraint must be linear with respect to the decision variables.

- Proportionality. The measure of effectiveness employed in the objective function and the amount of each resource used in each constraint must be proportional to the value of each decision variable considered individually.

- Additivity. No joint interactions between the constraints or the objective function is permitted. The total contribution of each activity must be identical to the sum of the contribution for each activity individually.

- Divisibility. Fractional levels of the decision variables and resource usage are possible.

- Deterministic Coefficients. All of the coefficients in the model are assumed to be known constants or parameters.

In the case of zero-one linear programming, the assumption of divisibility is replaced with the assumption that a project is generally indivisible, meaning it must be executed in its entirety as a functional unit. Thus, the decision variable is restricted to a value of zero or one (8:439).

When applied to the problem of rank ordering work orders, constrained optimization models, and in particular zero-one linear programming, can compute extremely large scale problems very quickly. It is possible to solve a problem with thousands of zero-one variables in a practical computation time (46:1427). Another advantage is the ability to consider virtually any variable one cares to include in the program (32:27). One important shortcoming of constrained optimization models is the need to develop the worth or benefit of the projects or work orders outside the model (25). Other difficulties with the application of constrained optimization include the fact that large amounts of information expressed in terms of dollars are required; each project's resource requirements must be carefully defined; and limits on the availability of each resource must be carefully defined (24:22).

Constrained optimization models such as Toyoda's Zero-One Linear Program can provide a reasonable fit to the task of rank ordering WOs providing that another model can be found to determine the "worth" or benefit of completing a work order and that a desire to dominate the ranking process on the basis of resource utilization exists.

Scoring Models. Scoring models attempt to determine the order of project selection or accomplishment by computing an overall dimensionless project score based on ratings assigned to each project for each relevant decision criterion and are designed to operate with subjective and objective input data. Criteria are typically related to specific project characteristics such as cost, manpower availability, and scheduling feasibility (29:B213; 4:1168; 23:39; 28:90). Figure 8 shows the work order decision task the scoring method would aid CE management in making.

The first step when using a scoring model is to determine the criteria to measure the projects on. Once criteria have been established, a raw (project) score measuring the basic properties of the model are determined by assigning a score of "1" to projects possessing

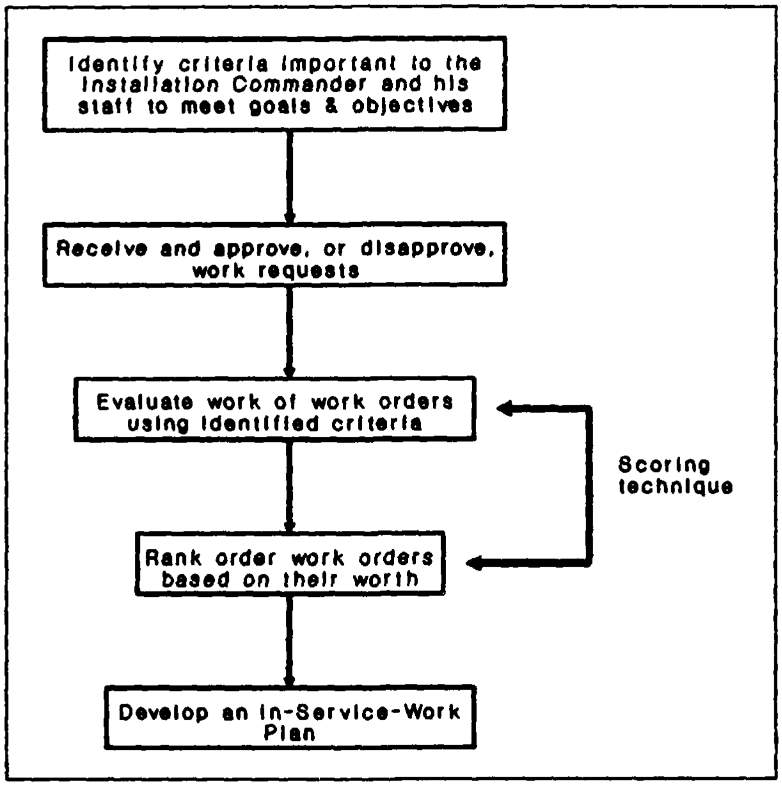


Figure 8. Task in the WO Decision Process Aided by the Scoring Method

a criterion characteristic and a score of "0" to projects not possessing the criterion characteristic. Since the "importance" of criteria are not all equal and are not the same among managers, the next step is to establish importance weights for each criterion using any of a number of consensus techniques. The raw score for each criterion is then multiplied by the criterion importance weights to obtain a criterion score. Finally, criterion scores are added to obtain a composite project score used to rank order projects (42:B529-B532; 30:239-240; 39:88-93). Table 3 provides an example of the computation of a work order project score.

Table 3.

Calculation of a Work Order Project Score Using the Scoring Method

Criteria	Project Score		Criterion Weight		Criterion Score
Safety	1	x	0.141	=	0.141
Quality of Life	1	x	0.141	=	0.141
Mission	0	x	0.445	=	0.000
Infrastructure	1	x	0.263	=	0.263
Composite Project Score				=	0.545

Models using scoring methods employ the following underlying assumptions:

- Decision makers are able to provide subjective judgment concerning criteria to be used and the degree of intensity of preferences.

- Projects either possess a criterion characteristic or do not possess a criterion characteristic. Projects do not possess "parts" of a criterion characteristic.

- Projects being considered are independent, meaning acceptance or rejection of one project has no effect upon the value of any other project except in the sense that resource constraints tighten as projects are accepted (29:B217).

- "The contribution of an alternative in achieving an objective must be independent of the contribution of other alternatives" (39:96).

- "The rate of substitution of value or utilities between any two objectives must be constant" (39:96).

When applied to rank ordering problems, scoring models exhibit the following advantages:

- These models can incorporate noneconomic criteria as well as subjective estimates provided by knowledgeable people.

- Conflicting or even inconsistent objectives can be incorporated to form a project score (28:91).

- Weak points of specific projects can be detected by unusually low ratings on certain criteria (29:B214; 24:22).

- Subjective "guesses" are used overtly where other methods generally require a more costly and sophisticated quantitative form of the same guess.

- Scoring technique results are on average 90 percent rank-order consistent with economic and constrained methods.

- Lastly, multiple criteria can be incorporated into the model. (24:22).

A disadvantage is that rank order consistency can be adversely affected through poor selection of the effective range over which each criterion measurement space is defined (29:B231).

On balance, the Scoring model appears to provide a good fit with the rank ordering problem due to its simplicity, ability to consider multiple criteria, and ability to measure criteria across large sets of projects (work orders). A major shortcoming which must be overcome, however, is the need for a method to identify the criteria and to determine the degree of preference among the criteria.

Checklists. Checklists attempt to select an optimal set of projects by developing a list of criteria believed to be important in determining the value or worth of a project. Each candidate project is then subjectively rated on the basis of each criterion listed (17:16; 3:114). Figure 9 shows the work order decision task the checklist method would aid CE management in making.

Table 4 shows how the rank of a work order might be determined using the checklist method.

Models using Checklists exhibit the underlying assumption that decision makers are able to provide subjective judgment concerning criteria to measure each project on.

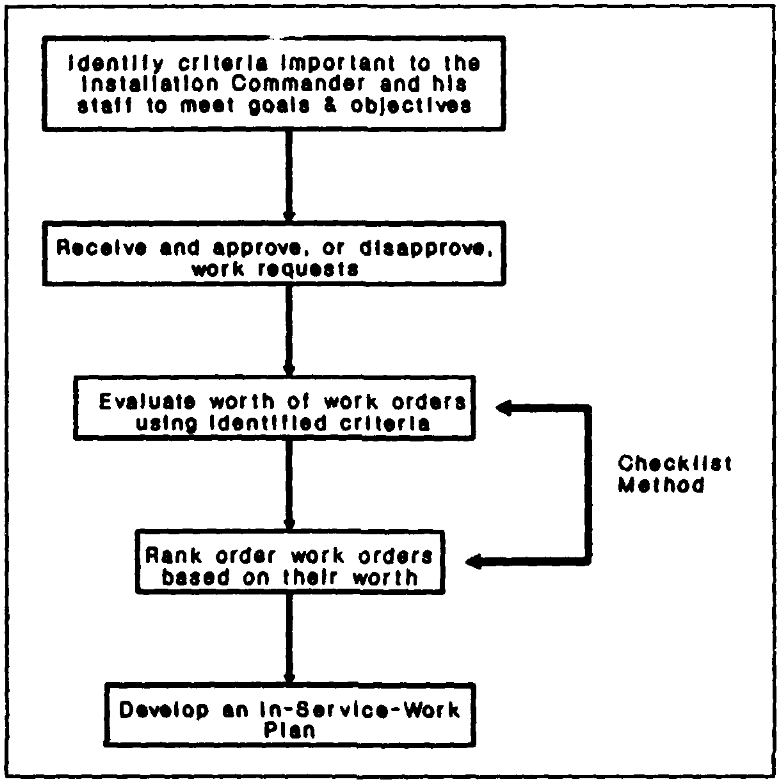


Figure 9. Task in the WO Decision Process Aided by the Checklist Method

Table 4

Typical Work Order Ranking Checklist

Criteria	Unimportant 1	2	Neutral 3	Important 4	5	
Work Classification			X			
Priority		X				
Command Interest				X		
Time in System	X					
Total:	1 +	2 +	3 +	4 +	0	= 10

When used to solve the rank ordering problem, checklists possess the following advantages:

- The virtue of simplicity and ease of use while providing a formal structure to the process of rank order decision making.
- Criteria are easily matched with information that is readily available.
- Checklists can easily be used to evaluate criteria that often prove awkward or nearly impossible to include in more formal model constructions, such as social impacts and environmental concerns.
- Finally, particular weaknesses of individual projects can be quickly identified by their poor ratings on certain criteria (17:16; 3:114).

In spite of the above advantages, the checklist methodology has several deficiencies:

- Although many important criteria are included in a checklist, the relevance or importance of each criterion is left unknown.
- Since a nonrigorous technique is used to construct checklists, there is no way of ensuring that respondents have given proper consideration to their answers (17:16).
- The checklist technique is not suitable for evaluating a large number of projects.

The above shortcomings lead to a conclusion that the checklist technique does not provide a good fit to the work order rank ordering problem.

Comparative Models. Comparative models attempt to allocate resources based on priorities by requiring a manager to compare one project either to another project or to a subset of alternative projects. The manager is required to "specify which of the two entries is preferred and, in some approaches, to specify the strength of preference. A set of project benefit measures is then computed by performing specified mathematical operations on the stated preferences" (4:1168).

The Analytical Hierarchy Process (AHP) is a comparative model that lends itself to rank ordering or determining the relative importance of a set of activities (projects) or criteria through a method of pairwise comparisons to weight multiple criteria. The creator of AHP describes it as follows:

> Basically the AHP is a method of breaking down a complex, unstructured situation into its component parts; arranging these parts, or variables, into a hierarchic order; assigning numerical values to subjective judgments on the relative importance of each variable; and synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation. (35:5)

Using the AHP to aid in decision making involves four steps.

- First, break down the decision problem into a hierarchy with each level consisting of a few manageable elements (see Figure 10).

- Second, collect input data by pairwise comparisons of decision elements.

- Third, assess or prioritize elements of the hierarchy by using a nine point scale (see Table 5).

- Fourth, aggregate the relative weights of decision elements to arrive at a set of ratings for the decision alternatives called the decision alternative scores.

Finally, the decision alternative scores can be used to implement the most important projects by rank (48:96; 37:16; 35:94).

The Analytical Hierarchy Process assumes the following:

- The manager has the ability to discriminate between both members of a pair and to judge the intensity of his preference for one over the other.

- The manager has the ability to establish relationships among objects or ideas in such a way that they relate well to each other and their relations exhibit consistency.

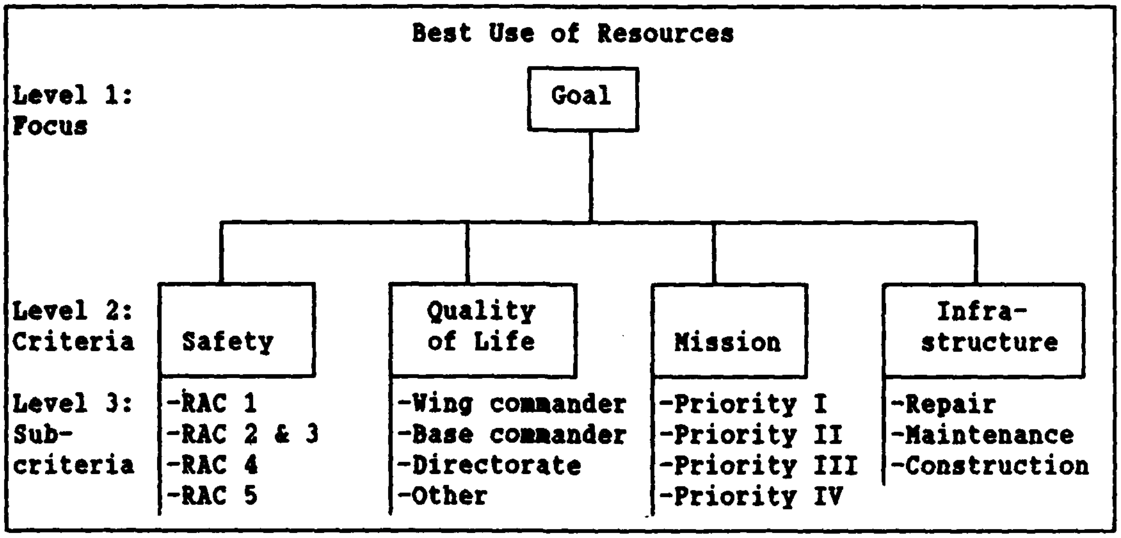


Figure 10. Hierarchy for Determining Work Order Priorities

- The problem can be structured into a functional hierarchy of levels (the problem can be decomposed into its constituent parts according to their essential relationships) (35:17-28).

- Elements in each level of a hierarchy must be relatively homogeneous.

- Adjacent levels in the hierarchy must not differ by more than one order of magnitude (48:98).

Strengths associated with AHP when used to rank order projects include:

- The process alleviates the often complex task of comparing all projects simultaneously by substituting a series of simpler tasks that compare pairs of projects (18:196).

- Manager has the option of expressing preferences between two elements as equally preferred, weakly preferred, strongly preferred, or absolutely preferred (48:98).

- The technique makes it possible to deal with intangible criteria on the same footing as tangible criteria and hard objective data with subjective judgments.

- The process allows for inconsistency in judgments by providing a measure of the degree of inconsistency.

- The process provides a framework for group participation in decision making or problem solving (36:4-22).

Table 5.

The Pairwise Comparison Scale (35:78)

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the property
3	Slight importance of one element over another	Experience and judgement slightly favor one element over another
5	Essential or strong importance of one element over another	Experience and judgment strongly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above non-zero numbers	If an activity has one of the above numbers assigned to it when compared with a second activity, then the second activity has the reciprocal value when compared to the first.	

Weaknesses associated with AHP when used to rank order projects include:

- The number of elements at each level must generally be limited to nine (48:98).
- When the hierarchy is incomplete (all elements of one level are not related to all those above them in the hierarchy) counter-intuitive composite weights may result (19:61-64; 48:102).

- A theoretical framework for modeling decision problems into a hierarchy has not been developed yet (48:102).

- Managers frequently make inconsistent choices in a sequence of paired comparison judgments (the AHP adjusts for these inconsistencies by using the eigenvalue/eigenvector method) (18:196).

The Analytical Hierarchy Process provides a good vehicle for logically structuring the rank ordering problem and developing weights for the criteria to measure each project on. However, it cannot be used to evaluate a large number of projects due to the recommended limit of nine elements per level. Thus, by itself, the technique provides only a partial fit with the task of rank ordering work orders. Figure 11 shows the work order decision task the Analytical Hierarchy Process would aid CE management in making.

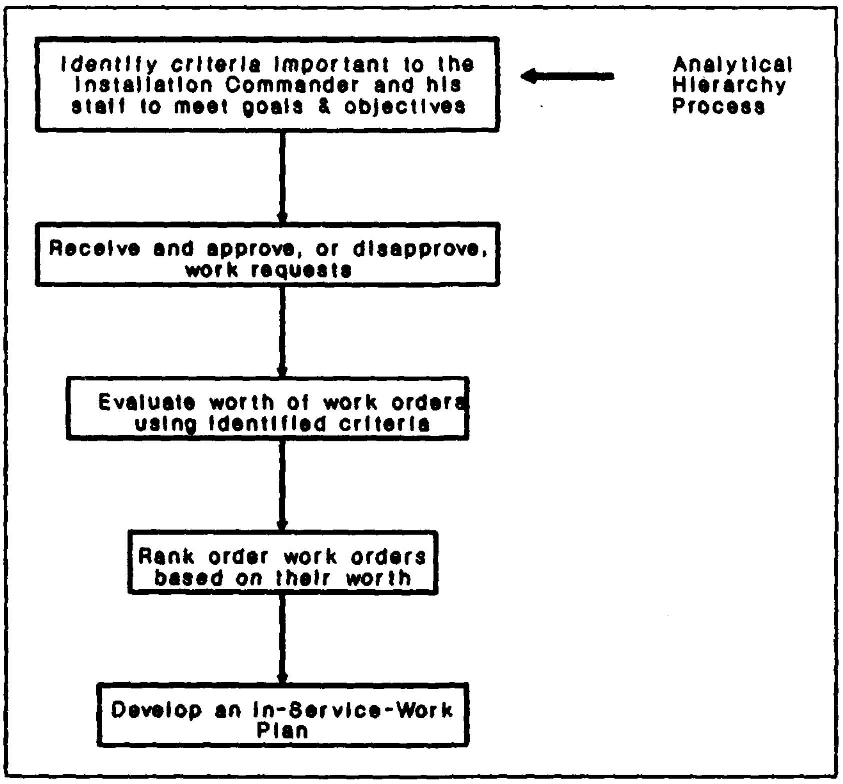


Figure 11. Task in the WO Decision Process Aided by the Analytical Hierarchy Process

Recommended Model

To enhance actual implementation of the decision making technique or set of techniques chosen to model the work order rank ordering problem, the technique(s) should possess the following characteristics:

- First the technique should be elegantly simple. Simplicity is required for two reasons: 1) to facilitate use at the working level of Work Control, and 2) to solicit support or acceptance of base organizations through their understanding of how the system works.

- Second, the technique must be perceived to be equitable and represent the preferences of the decision makers (34).

- Third, the technique must be flexible, able to quickly incorporate revisions.

- Finally, the technique must be readily adaptable to automation by using a personal computer or, even more desirable, civil engineering's Work Information Management System (WIMS).

Review of the decision techniques offered by the literature and discussed earlier in this chapter leads to the conclusion that no one of the reviewed techniques by itself will provide a good fit to the rank ordering problem. However, combining the advantages of several techniques into a logical hierarchical structure can provide a good fit while meeting the criteria discussed above to enhance actual use of the proposed methodology.

Borrowing from the concept of AHP, the rank ordering problem can best be understood and solved by breaking the problem down into its constituent decision making activities and structuring the elements hierarchically. After having established the overall goal of selecting the best work orders, the next level in the decision making hierarchy is to identify the criteria to measure the projects on. This task is well suited to a group consensus gathering technique, used in conjunction with the Analytical Hierarchy Process, to ensure agreement on the criteria and to foster organizational support of the rank ordering process (To facilitate this process, a spreadsheet or an interactive personal computer program such as "Expert Choice™", by Decision Support Software Inc., 1300 Vincent Place, McClean, Virginia, may be used).

Having established the criteria and degree of preference among the criteria, the next step is to measure each project against the criteria. The scoring technique is a method well suited to this task and can be used for evaluating or rank ordering large numbers of projects or work orders. As stated previously, this method is easily understood and can be easily adapted to the computer. Finally, if desired, the "composite project scores," obtained from the scoring technique, can be used as the payoff values needed for the linear program or zero-one linear program used in the previous studies to develop an In-Service-Work Plan for base civil engineering. Incidentally, this procedure corrects the deficiency identified in the two previous studies; namely, the lack of a technique for the identification and selection of criteria and the degree of importance associated with each criterion. Figure 12 provides a diagram of the decision making model proposed to solve the rank ordering problem of this study.

In summary, a group consensus technique/AHP combination provides a vehicle for the decision maker(s) to identify criteria important to the Installation Commander and his staff to meet goals and objectives. For criteria identified by the decision maker(s), the AHP also calculates coefficients for use by the Scoring Technique to measure the "worth" or benefit of each work order in the form of a composite work order score.

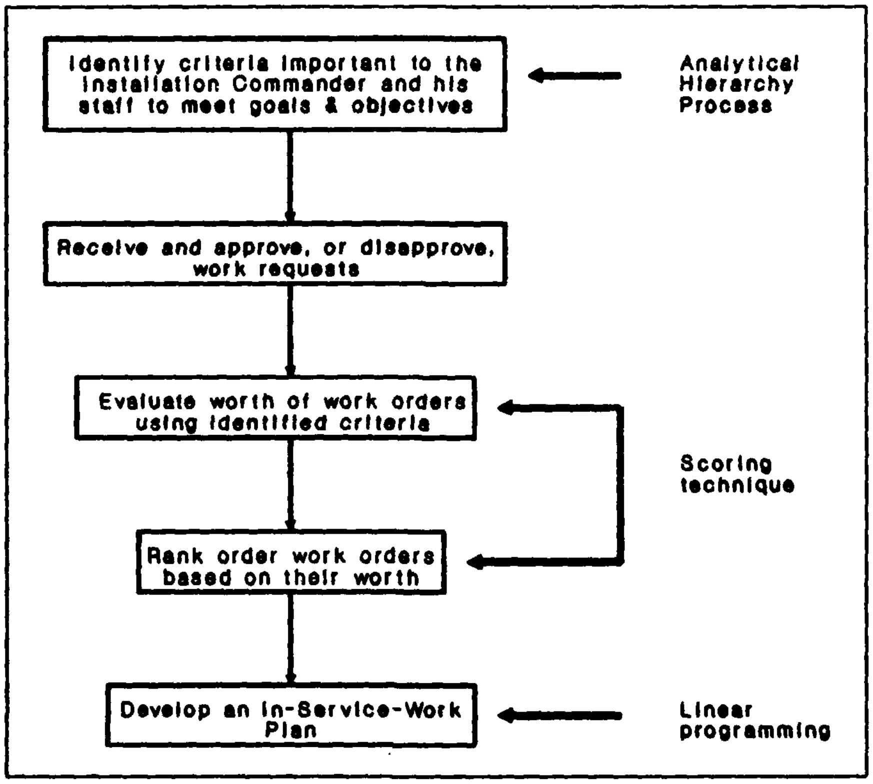


Figure 12. Model for Rank Ordering Work Orders

Finally, rank ordering of the work orders is then completed by sorting on the composite work order scores.

As explained above, it would appear as though the AHP does not meet the above stated criteria of simplicity. However, while the underlying math can be complex, the mathematical mechanics are actually transparent to the user. As a result, the decision makers' tasks are simple. Use of the AHP will insure correct selection of criteria important to the base as a whole and the relative importance of those criteria, as well as engendering a sense of fairness. In addition, the task of identifying and weighting the criteria is essentially a one-time requirement. Once the task has been completed, a simple annual review of the criteria and weights, to confirm their validity, is all that will be required.

The daily work horse of this model is the scoring technique. It is a simple, easy to understand technique that is able to handle large numbers of work orders. In addition, changes can be made to any one particular work order or measurement of the work order on a particular criterion without requiring recomputation of the other composite work order scores. Thus, the automated scoring model will be flexible. In summary, the proposed rank ordering model meets the above criteria of simplicity, a sense of fairness, flexibility, and adaptability for use on the computer.

This chapter reviewed the decision making procedures available concerning the rank ordering problem and presented a possible solution. Chapter III will discuss the approach and steps followed in this study to obtain a "snap shot," or profile, of the methods civil engineering currently uses to prioritize work orders. Chapter III will also discuss how the profile of ranking methods, obtained from the survey, will be compared to the rank ordering model proposed in this chapter.

III. Methodology

Overview

Testing of the research questions required collection of data from Base Civil Engineering squadrons of major CONUS Air Force installations. A search of literature revealed a lack of relevant secondary data available for use as a data base for testing of the research questions. Thus, collection of primary data was necessary. According to William C. Emory's Business Research Methods, there are two choices available for collection of primary data: observation or survey (15:157).

The use of observation as a data collection instrument was ruled out after comparing this study's information requirements with strengths and weaknesses provided by Emory. According to Emory, the observation method is a slow and expensive process requiring human observers or costly surveillance equipment. In addition, the method is limited in determining what existing conditions are at distant locations, and "results are restricted to data that can be determined by overt action or surface indicators" (15:157-158). Since testing of the research questions required collection of data from a wide geographic area and opinions of the Base Civil Engineers concerning the strengths and weaknesses of their W.O. priority systems, using the method of observation to collect data was determined inappropriate for this study.

In contrast to the method of observation, one of the great strengths of questioning (or surveys) as a data collection technique is its versatility. Surveys do not require visual or other objective observation of the desired information. In addition, determination of opinions and attitudes can be gained through questioning, and distance and data collection costs do not normally present a problem when using the medium of telephone or mail (15:158-159). Based on the above discussion, the survey method was chosen as the data collection instrument for this descriptive study.

Population and Sample

Data for this research was collected from the Base Civil Engineering organizations of all major Air Force installations located within the Continental United States (CONUS) and Hawaii. In 1986, the Air Force redefined and classified all Air Force installations into one of four categories: major installations, minor installations, support sites, and other activities; to reflect more accurately actual installation posture. To qualify as a major installation, the site must be operated by an active, Guard, or Reserve unit of group size or larger and have all the organic support to accomplish the unit's mission. Minor installations are those operated by active, Guard, or Reserve units of at least squadron size, these sites do not satisfy all of the criteria for a major installation.

Based on the revised definitions, there are 101 major installations within the United States and possessions, and 39 within foreign countries respectively (1:85). This study surveyed 84 major installations within the Continental United States and Hawaii.

The sample of BCE organizations from within CONUS and Hawaii was a purposive judgment sample. Nonprobability sampling was chosen rather than consensus or probability sampling primarily to avoid the difficulties of time and communication encountered when sampling worldwide. Sampling was restricted to major installations because civil engineering activities of minor installations do not perform all the functions of a normal BCE organization, nor do minor installations exhibit the full range of variables affecting the type of work order priority systems used as those exhibited on major installations.

The factors and procedures used to prioritize in-service work orders identified by this descriptive study cannot be inferred to be representative of those used throughout the Air Force. However, the cross-sectional study does provide a snap shot of how major installations prioritize in-service work orders and what factors they use to set priorities. In addition, the work order prioritization model developed from this survey does contain the best features of the current prioritizing methods.

Data Collection Plan

Interviews and questionnaires were used in this study to solve the research problem. Personal and telephone interviews were conducted for two purposes: 1) to narrow the search for and to identify an appropriate decision making tool for use in prioritizing WOs, and 2) to identify a listing of WO priority systems in use today along with their strengths and weaknesses, and decision factors BCEs are using.

Developing a questionnaire required formulation or identification of tentative answers to the first four investigative questions for inclusion in the questionnaire. Personal interviews were conducted with local experts: one current and four former BCEs and others knowledgeable in the Operations and Maintenance arena of civil engineering.

Specifically, six officers and one civilian at HQ AFLC (Col James G. Zody, Col Jason F. Mayhew, Col R. W. Walters, Col Joe Hicks, Lt Col P. C. Holden, Lt Col W. T. Leitch, and Mr. T. C. Cadogen), the Wright-Patterson AFB BCE (Col Scamblis), and civil engineering's representative of the HQ AFLC IG team (Maj [sel] Michael W. Dronen) were interviewed. Additionally, staff members of the Military Airlift Command civil engineering directorate, Lt Col (sel) Steven Foster and Capt Norman Carod, were interviewed by telephone to supplement information obtained locally.

The personal interviews were semi-structured, meaning a partial listing of WO prioritization factors and procedures was provided to respondents to focus the discussion and initiate thoughts concerning allocation of WOs, and the researcher guided the topical direction and coverage. The telephone interviews were conducted using the same set of questions asked in the personal interviews to insure proper coverage of the research questions. Information obtained from the interviews became the foundation of the questionnaire.

To improve content validity, the questionnaire was pretested using three groups: 1) faculty members (Lt Col Ballard, Lt Col [sel] Holt, Maj Rumsey, Maj Showers, Capt Davis, Capt Streifert, Dr. Shane, and Dr. Steel); 2) students enrolled in the graduate engineering management program of the School of Systems and Logistics, Air Force Institute of Technology (AFIT), Wright-Patterson AFB OH (Capt Randy Eide, Capt Tom Lavery, and Capt Jim Schnoebelen); and 3) 10 students attending the AFIT School of Civil Engineering and Services professional continuing education course for Civil Engineering Squadron Commanders/Deputies, MGT 400 88A. Only deputy BCEs attending MGT 400 88A were pretested to insure BCEs attending the course would not be exposed to the test prior to distribution of the questionnaire to the field.

Questionnaires were distributed to those at the decision making level responsible for allocation of BCE resources: specifically, the Base Civil Engineering commander and the Chief of Operations of each CONUS major installation and Hickam AFB. To the extent possible, questions were closed to make fewer demands on the respondents and to make it easier to analyze. However, many of the measurement questions within the survey contained the category of "other (please specify)" to permit the respondent to provide information not covered in the questionnaire concerning his/her WO priority system (15:218-220). In addition, respondents were asked to provide a copy of written procedures concerning their base WO priority systems (operating instructions, squadron and base regulations, or supplements to regulations).

The purpose of the collection plan was to identify the internal/external factors and procedures used by the BCE to prioritize in-service work orders, and to determine, in the opinion of the respondents, what site-specific factors outside Civil Engineering affect the type of priority system in use and its strengths and weaknesses. A copy of the questionnaire, incorporating the six work order priority systems and the internal and external forces (factors) influencing the choice of a specific priority system, identified through the personal and telephone interviews, is at appendix B.

Data Analysis

Types of Data. Two types of data were collected in this study: nominal and ordinal. Many concepts have characteristics that differ in kind only and are called nominal level data (21:15-19). A nominal scale partitions a set or population into subsets or categories that are mutually exclusive and collectively exhaustive (15:87), meaning that no categories overlap and that each object can be placed in at least one of the categories. These categories are used to classify an object, person, concept, characteristic, or factor. Factors such as major command, position in CE, type of priority system, and yes/no questions are examples of nominal data. Thus, numbers or letters attached to the alternative nominal levels in the questionnaire have no meaning other than as a distinguishing label.

The second type of data collected in this study is ordinal level data. According to Kachigan, if values of a set can be arranged in a meaningful order (rank order), then the factor can be represented by a number on an ordinal scale (21:15-19). Thus, a comparison can be made between the categories and they can be placed in a particular order along a continuum. Examples of ordinal level data in this study include the size of the base, number of tenants on base, MC work orders on backlog when arranged in group sizes, and the familiar Likert scale used in questions 40 through 63 of the questionnaire as reproduced below.

SD	D	N	A	SA
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

According to Kachigan, "The numerical values of an ordinal scale indicate a hierarchy of the levels of the variable in question" (21:16).

However, when using ordinal level data, the researcher must be careful not to make any inference about the degree of difference between values on the scale, since that is not a property of ordinal level data.

Statistical Package. Responses to each question on the questionnaire returned were converted to numerical values, and the complete set of values for each case was entered into a computer data file. The data from the survey questionnaires were then analyzed using the computer program Statistical Package for the Social Sciences (SPSSx, release 2.1). The specific SPSSx subprograms used to answer the research questions are briefly described below.

FREQUENCIES. The procedure FREQUENCIES summarizes data by providing a count of the number of times each value of a variable occurs. The procedure also converts the observed frequencies into percentages based on the total number of observations, called relative frequencies. According to Devore, a frequency distribution or relative frequency distribution provides an effective tabular summary of the data (13:18).

Procedure FREQUENCIES was used for both nominal and ordinal level data in this study to identify trends and to develop an Air Force-wide work order priority system profile and profiles for each specific work order priority system. System specific profiles were developed by using a series of IF statements to assign each case or response to one of the pre-identified methods of prioritizing work orders.

For nominal level data, the mode indicates the category that had the most responses and is the appropriate measure of central tendency and the statistic used in this study. For ordinal level data, the median is the appropriate measure of central tendency. The word "median" is synonymous with "middle" and the sample median is the middle value when the observations are ordered from smallest to largest in magnitude (13:15). However, based on the premise readers would be more interested in which category or characteristic was reported more often than others, the mode is provided for both nominal and ordinal level data in this study.

Technically, the use of the mean and other measures of statistical significance are restricted to interval and ratio level data. However, researchers differ on the question of whether the more powerful parametric significance tests are appropriate with ordinal measures. Researchers such as Siegel argue the use of parametric tests is incorrect on both theoretical and practical grounds (41:32). On the other side of the issue, researchers such as Anderson argue the parametric tests are usually acceptable for ordinal scales on both practical and theoretical grounds (2:315-316). Finally, researchers such as Kerlinger recognize that there are risks in using parametric procedures on ordinal type data but these risks are usually not great (22:427).

The approach of this study was generally a conservative one using nonparametric tests in most cases. However, as will be stated later, a multiple comparison procedure for determining which population means are different will be used for comparison of respondents' opinions concerning the work order priority system they are using (research questions 40-63).

ONEWAY. The procedure ONEWAY produces a one-way analysis of variance (ANOVA). The purpose of ANOVA is to evaluate whether two or more sample means differ more than would be expected by chance.

Scheffe' Test. The SCHEFFE multiple range test was used to analyze those factors with more than two categories of response (questions 40-63). This required the assumption that the six methods of rank ordering WOs are independent and normally distributed with the same variance. The Scheffe' test orders the means from smallest to largest. Pairs of means that are significantly different at the 0.05 level are identified. "The Scheffe' method is conservative for pairwise comparison of means. It requires larger differences between means for significance than most of the other methods" (31:112).

Systematic Procedure

Selection of an appropriate analytical aid involved an initial selection of several "resource allocation" concepts from the body of decision theory by consulting experts within AFIT (LTCs Rowell and Valusek, in the Department of Operations Sciences, and Maj Rumsey, in the Functional Management Division). Chapter II presented the resource allocation techniques identified. Based on a literature review, expert advice of those mentioned above, and the survey results, the Analytical Hierarchy Process and Scoring technique were selected for use in the decision model for this study. In chapter V, the decision model developed in chapter II will be used to demonstrate how it can aid the decision maker in prioritizing work orders.

In summary, this chapter presented the methodology used in this study. The following chapter presents the results of the survey and of the statistical procedures described in this chapter.

IV. Results

Introduction

The first part of this chapter presents the descriptive statistics for the sample population as a whole, computed using the subprogram FREQUENCIES. Descriptive statistics are presented for the responses to appropriate questions in the survey questionnaire. The second part of this chapter breaks the sample population down into profiles of specific work order priority systems by using descriptive statistics computed with the subprogram FREQUENCIES by means of IF statements.

Survey Response

As described in Chapter III, 168 questionnaires were sent to the Base Civil Engineer (BCE) and the Chief of Operations (DEM) of 84 major installations within the Continental United States and Hawaii on 21 Mar 1988 (see Appendix A for a listing of bases surveyed). A follow-up mailing of the questionnaires was initiated on 20 Apr 1988 in an attempt to improve the 50.6 percent return rate. The cut-off date established for tabulation was 15 May 1988. There were 119 usable survey questionnaires returned prior to that date, for a return rate of 70.8 percent; comparing favorably to the average Air Force survey response rate of approximately 60 percent (38:46). Table 6 shows the rate of response for each Major Command that was included in the survey. The number of responses from ATC, MAC, SAC, and TAC were significantly larger than the other commands and thus dominated the results.

Table 6.

Survey Response Frequency by Major Command

Major Command	Questionnaires Distributed	Response Count & (percent)	Major Command	Questionnaires Distributed	Response Count & (percent)
AFLC	12	5 (41.7)	SAC	50	33 (66.0)
AFSPACECOM	2	1 (50.0)	TAC	34	28 (82.4)
AFSC	10	5 (50.0)	AFDW	2	2 (100.0)
ATC	26	21 (80.8)	PACAF	2	1 (50.0)
AU	2	2 (100.0)	USAF Academy	2	0 (0.0)
MAC	26	21 (80.8)			

Demographic Data

Survey Question 1. Table 7 profiles the survey respondents by rank. Majors responded more than any other rank.

Table 7.

Grade of Respondents

Grade	Number of Respondents	Relative Frequency (percent)
0-1 or 0-2	3	2.5
0-3	17	14.3
0-4	39	32.8*
0-5	30	25.2
0-6	15	12.6
Enlisted	4	3.3
Civilian	10	9.3

* Mode

Survey Questions 2 through 6. The questionnaires were addressed to the BCE and Chief of Operations. Twenty six of the respondents were in positions beneath the target population, but their responses were included in the calculation of statistics. Table 8 shows the distribution of respondents by the positions they hold in base civil engineering and the number of months they have been in their current positions. The Chief of Operations, with an average tenure of 22 months, was the mode response.

Table 8.

Respondent's Position & Tenure in Civil Engineering

Current Position	Number of Responses	Relative Frequency (percent)	Tenure			
			Mean	Std Dev	Min	Max
DE	41	34.5	22.55	18.2798	1	56
DED	9	7.6	40.67	27.1109	4	140
DEM*	52	43.7	22.00	19.4062	2	244
DEM Sup	1	0.8	36.00	0.000	36	36
DEMR	13	10.9	11.23	7.0611	3	26
DEMRC	3	2.5	30.33	27.7549	4	60

* Mode

Notes:

DE - BCE
DED - Deputy BCE
DEM - Chief of Operations
DEM Sup - Superintendent of Operations
DEMR - Chief of Requirements
DEMRC - Chief of Production Control

Survey Question 7 through 12. Survey questions 7 through 12 provided a picture of several of the attributes of respondents' installations. Later in this study, these attributes will be considered as factors outside of civil engineering that influence the type of work order prioritizing method used by CE. Table 9 displays these installation attributes. Base sizes were computed using the total civilian and military working population of a base. The particular base size ranges were obtained from a previous thesis written by McKnight and Parker (27:51). The category ranges chosen for the number of senior officers outranking the Installation Commander were based on the personal and telephone interviews reported in Chapter III. The category ranges chosen for the number of tenant organizations on base were based on information provided by the Wright Patterson public affairs officer. Mode responses were medium base size (4,500-7,500); no Major Commands on base; no officers outranked the Installation Commander; one wing on base; and 5 to 15 tenants. Each of these attributes is independent, and relationships between the various attributes cannot be inferred.

Table 9.

Base Attributes

Attribute	Number of Responses	Relative Frequency (percent)
Base size:		
Small	15	12.6
Medium	68	57.1*
Large	36	30.3
No. of MAJCOM/NAF on base:		
None	72	60.5*
1	31	26.1
2	12	10.1
4 or more	4	3.4
No. of ofcrs outranking Base Cmdr on base:		
None	45	38.1*
01 - 05	37	31.4
06 - 10	17	14.4
More than 10	19	16.1
No. of wing size organizations on base:		
0	2	1.7
1	50	42.4*
2	34	28.8
3	13	11.0
4 or more	19	16.1
No. of tenant organizations on base:		
Less than 5	24	20.2
05 - 15	56	47.1*
16 - 25	21	17.6
More than 25	18	15.1

* Mode

Profile of AF Work Order Priority Systems

Survey Questions 13, 14, 26, 27, and 34. Table 10 shows the characteristics of the work order priority systems for Air Force civil engineering as a whole.

Table 10.

Characteristics of Priority Systems Used by Respondents

Characteristic	Number of Responses	Relative Frequency (percent)
Work classification prioritized:		
MC	15	13.0
M/R	0	0.0
M/R & MC	99	86.1*
Other	1	0.8
Infrastructure work orders:		
Compete with requesters' work orders	62	54.4*
Are handled separate from requesters' work orders	41	36.0
Other	11	9.7
Percent work orders generated by Base Commander and higher ranking officers:		
0 percent	1	0.9
01 - 10 percent	53	46.5*
11 - 20 percent	24	20.1
21 - 30 percent	12	10.5
31 - 40 percent	10	8.8
41 - 50 percent	5	4.4
51 - 75 percent	6	5.3
> 75 percent	3	2.6

Characteristic	Number of Responses	Relative Frequency (percent)
Average minor construction WO backlog		
000 - 050	25	22.5
050 - 099	37	33.3*
100 - 199	32	28.8
200 - 299	10	9.0
300 - 399	4	3.6
400 - 499	0	0.0
500 - >	3	2.7
Average maintenance & repair WO backlog		
000 - 050	14	12.5
050 - 099	25	22.3
100 - 199	40	35.7*
200 - 299	18	16.1
300 - 399	6	5.4
400 - 499	2	1.8
500 - >	7	6.3

* Mode

Later, during the analysis, these characteristics will be considered as factors inside and outside of civil engineering that influence the type of work order prioritizing method being used by civil engineering.

The mode responses to these questions were as follows: both maintenance & repair (M/R) and minor construction (MC) work orders are rank ordered by the WO prioritizing system; civil engineering work orders to maintain the base infrastructure compete with requesters' work orders for priority; 1 to 10 percent of the work orders are generated by the Installation Commander or higher ranking officers on base; the average minor construction work order backlog at any one time is 50 to 99 work orders; and the average M/R work order backlog at any one time is 100 to 199 work orders.

Survey Questions 20 and 21. Table 11 shows the count of the number of times respondents reported their installations used one of the six methods of prioritizing work orders identified in the personal and telephone interviews. The count also includes the report that "no" system was in use. The Checkbook system was the most frequently reported system in use for prioritizing work orders.

The respondents were also presented with a list of the previously identified six work order prioritizing methods and asked to rank order them in the order which seemed most practical for prioritizing work orders. Thus, one would interpret the mode response of "2," for the BCE Panel system, to mean the respondents rated the BCE Panel as the second most practical system for prioritizing work orders when compared to Weighting, Command Driven, Base Panel, Engineering Judgment, and the Checkbook system. Since each system was ranked separately by all

Table 11.

Reported Use of Each Work Order Priority System and Respondents' Ranking of the Practical Value of Each System

Priority System Used	Number of Respondents	Relative Frequency (percent)	Respondents' Ranking of Priority System**
Weighting	2	1.7	4
No System	3	2.5	
Cmd Driven	13	11.2	6
Base Panel	16	13.8	2
BCE Panel	16	13.8	2
Engr Judgment	25	21.6	1
Checkbook	44	37.9	1*

* Overall mode

** Modes based on responses from total sample population (highest rank possible is 1)

respondents, the mode response or ranking for each system could and did match with a ranking of first for both Engineering Judgment and the Checkbook system, and second for the Base Panel and BCE Panel system.

Survey Question 22 and 31. Question 31 addressed the issue of whether or not the respondents' civil engineering organizations had set a quota on the number of approved work orders permitted in the CE work order queue at any one time. The mode response was "No," CE had not established a WO quota. Question 22 attempted to identify the factors used to establish the WO quota as reported by respondents who stated their organization did have a WO quota. Table 12 shows the responses to these two questions.

The following write-in factors were provided by respondents and are listed together under the category of "other" in Table 12: subjective call, unit mission priority, arbitrary, WO backlog by organization,

Table 12.

Answers Concerning how WOs are Allocated

Fact	Number of Responses	Relative Frequency (percent)
Has CE established a WO quota?		
Yes	46	40.0
No	69	60.0*
Factors used to make WO allocations:		
Other	6	5.0
Organization's Top 10/20 WOs	7	5.9
Personnel assigned	15	12.6
More than one factor	21	17.6
WO history & other	2	1.7
Personnel & WO history	2	1.7
Personnel & total sq ft	2	1.7
Total sq ft & WO history	5	4.2
Total sq ft, personnel & other	1	0.8
Total sq ft, WO history, & other	2	1.7
Total sq ft, personnel, & WO history	5	4.2
Total sq ft, personnel, WO history & other	2	1.7
Total assigned sq ft	27	22.7
WO History	34	28.6*

* Mode

manpower authorization savings, and facility type and age. The mode response was that work order quotas were based on each organization's work order history.

Survey Questions 28 through 30. Once a work order is approved, AFR 85-1 provides civil engineering the option to assign the work order to one of four priority categories:

1) Priority I - mission: "Work in direct support of the mission that if not done would reduce operational effectiveness";

2) Priority II - Safeguard of Life and Property: "Work needed to give adequate security to areas subject to compromise; to eliminate health, fire, or safety hazards; or to protect valuable property or equipment. Also includes energy conservation work";

3) Priority III - Support: "Work which supports the mission or prevents a breakdown of essential operating or housekeeping functions";

4) Priority IV - Necessary: "Not qualifying for higher priority" (12:32).

Questions 28 was designed to determine to what extent organizations are permitted to participate in the prioritization of their own work orders. The mode response was that organizations are permitted to prioritize all AFR 85-1 priority categories. Question 29 collected information on how frequently organizations are permitted to update the priorities they have set for their work orders in the CE queue. The mode response was monthly. This was an open ended question and the following frequencies were write-ins: continually, as needed, weekly, every six weeks, every other month, semi-annually, and annually.

Question 30 asked respondents at what stage in the processing of work orders through Civil Engineering customers were no longer permitted to change the priorities they had set for their work orders. The mode response was work order priorities were frozen once they reached Materiel Control and materials had been placed on order. Table 13 summarizes responses to questions 28 through 30.

Survey Questions 32 and 33. Question 32 collected information on how important the concept of first-come first-serve is to the respondent's work order system. The mode response was that the concept of first-come first-serve is "Slightly Important." Question 33 was designed to determine how important professional judgment was to respondents when setting work order priorities. The mode response was that professional judgment is "Very Important" when setting WO priorities. Table 14 presents the responses to these two questions.

Table 13.

Local BCE Procedures for Rank Ordering Work Orders

Procedure	Number of Responses	Relative Frequency (percent)
AFR 85-1 priority categories CE customers can rank order:		
Priority 1	4	3.5
Priority 2	0	0.0
Priority 3	2	1.8
Priority 4	2	1.8
Priority 1-4	89	78.8*
None	16	14.2
Stage in the WO process when CE customers can no longer change WO priorities:		
Not an option	8	7.9
Customer service	4	4.0
Planning	16	15.8
Materiel Control	42	41.6*
Scheduling	11	10.9
Any time	19	18.8

Procedure	Number of Responses	Relative Frequency (percent)
Time frame for CE customer update of WO priority listings:		
Continually	1	1.0
As needed	20	20.2
Weekly	1	1.0
Monthly	41	41.4*
Six weeks	2	2.0
Two months	2	2.0
Quarterly	24	24.2
Semi-annually	4	4.0
Annually	3	3.0

* Mode

Survey Questions 35 and 36. Many civil engineering organizations have recently installed an AF-sponsored management information system designed specifically for civil engineering, called the Work Management Information System (WIMS). Although other CE units do not yet have WIMS, they have personal computers such as the Zenith Z-248. Thus, questions 35 and 36 were designed to determine to what extent computers are used to assign work order priorities and to track them once priorities have been set. The mode responses were that computers

Table 14.

Respondents' Opinions Concerning how Priorities Should be Set

How important is the concept of first-in-first-out to your WO system?

Very Important	Slightly Important	Neutral	Not So Important	Not Important
10 (8.7%)	39 (33.9%)*	23 (20.0%)	21 (18.3%)	22 (19.1%)
		Mean: 3.052	Std Dev: 1.283	

How important is professional judgment when setting WO priorities?

Very Important	Slightly Important	Neutral	Not So Important	Not Important
58 (50.9%)*	34 (29.8%)	13 (11.4%)	6 (5.3%)	2 (1.8%)
		Mean: 1.761	Std Dev: 0.975	* Mode

Scale:
1 - Strongly Disagree
2 - Disagree
3 - Neutral
4 - Agree
5 - Strongly Agree

are not used to assign WO priorities but are used to track the WOs. Table 15 shows responses to these questions.

Table 15.

Computer Use To Manage Work Orders

	Yes	No
Computer is used to assign WO priorities:	30 (26.3%)	84 (73.7%)*
Computer is used to track WO priorities:	97 (85.8%)*	16 (14.2%)

* Mode

Survey Question 37. Forces both internal and external to the base Civil Engineering organization influence the way the BCE chooses to prioritize work orders. Question 37 provided a list of some of these influences (called factors in this study and the questionnaire) and asked respondents to indicate which factors they considered when deciding to continue using their current method of prioritizing work orders. Table 16 shows the frequency of response for each factor.

Table 16.

Factors Influencing Civil Engineering Squadrons' Decisions to Continue Using Their Current Prioritizing System

Factors	Frequency Count & (percent)
Operations funding available to CE	77 (65.3)
Size of CE WO backlog	69 (58.5)
Installation commander's management style	62 (52.5)
BCE's management style	46 (39.0)
BCE's past experience with work order priority systems	44 (37.3)
Base mission	40 (33.9)
Number of senior officers on base outranking the Base Commander	23 (19.5)
Number of wings on base	21 (17.8)
Base size	21 (17.8)
Base relationship with Major Command	11 (9.3)
Geographic dispersion of CE's area of responsibility	6 (5.1)
Other	21 (17.8)
It works	6 (5.1)
Manhours available	5 (4.2)
Miscellaneous	3 (2.6)
Lack of funds	2 (1.7)
Reimburseables	2 (1.7)
Customer satisfaction	2 (1.7)
Reasonable compromise	1 (0.8)

Factors are listed in the order of most to least frequent in response. Thus, "Operating funds available to civil engineering" had the highest response of 77, while "It is a reasonable compromise" had the lowest response of 1. Table 16 also shows the write-in responses to this open ended question under the category of "Other."

<u>Survey Questions 38 and 39</u>. Questions 38 and 39 were designed to collect information on the factors used by Civil Engineering units to consider (weigh) when prioritizing work orders using the Weighting method described in the questionnaire (Appendix B). A list of 29 factors was provided, from which respondents were asked to select the ten most important. Table 17 provides a list of the factors chosen, along with response frequencies. Factors chosen are listed in order of lowest to highest response frequency.

Table 17.

Factors Respondents Reported Important to Consider When Prioritizing WOs

Factor	Frequency Count & (percent)	Factor	Frequency Count & (percent)
Season	1 (8.3)	Command programs	6 (50.0)
Reimburseables	1 (8.3)	Requester's mission	6 (50.0)
Requester's unit population	1 (8.3)	Base infrastructure	6 (50.0)
Equipment availability	1 (8.3)	Environmental issues	6 (50.0)
CE training requirements	1 (8.3)	Command interest	7 (58.3)
Energy conservation measures	2 (16.7)	Prevent reducing essential operational effectiveness	7 (58.3)
Oldest WO first (FIFO)	3 (25.0)	Fire hazards	9 (75.0)
Work classification	3 (25.0)	Prevent breakdown of operations	9 (75.0)
User priority	3 (25.0)	Hazards to safety	10 (83.3)
Shop manning	3 (25.0)	Hazards to health	11 (91.7)
Drop dead date	4 (33.3)	Security requirements	11 (91.7)
Quality of life	5 (41.7)	Funding availability	12 (100.0)
Material availability	5 (41.7)		

Note: n = 12

Having selected the ten most important factors to consider when prioritizing work orders, respondents were then asked to select the top five factors and to rank them in order of importance from one to five (one being the most important). One write-in was received: work order justification. Table 18 shows the factors respondents selected.

Table 18.

How Respondents Ranked Factors Used to Weight and Prioritize Work Orders

Factor	Respondents' Rankings In Order of Importance (from highest of First to lowest of Fifth)				
	First*	Second*	Third*	Fourth*	Fifth*
Prevent reducing essential operational effectiveness	2 (16.7)	1 (8.3)	2 (16.7)	1 (8.3)	
Command interest	3 (25.0)		1 (8.3)		
Requester's mission	2 (16.7)	1 (8.3)		1 (8.3)	1 (8.3)
Prevent breakdown of operations		3 (25.0)	1 (8.3)		1 (8.3)
Hazards to safety	1 (8.3)	2 (16.7)			2 (16.7)
Fire hazards			2 (16.7)	2 (16.7)	1 (8.3)
Funding availability			2 (16.7)	2 (16.7)	
Command programs	1 (8.3)	1 (8.3)			1 (8.3)
Drop dead date	1 (8.3)			2 (16.7)	
Hazards to health		1 (8.3)	1 (8.3)	1 (8.3)	
Quality of life	1 (8.3)				1 (8.3)
Shop manning		1 (8.3)		1 (8.3)	
Security requirements			1 (8.3)	1 (8.3)	
WO justification	1 (8.3)				
Work order history		1 (8.3)			
Environmental issues		1 (8.3)			
Facility condition			1 (8.3)		
Base infrastructure			1 (8.3)		
User priority					2 (16.7)
Material availability					2 (16.7)
Work classification				1 (8.3)	
Season					1 (8.3)

* Count (percent)

Note: n = 12

To help with interpretation of the table, a weighting scheme was used to determine in what order to list the factors. The category of "First" was assigned 5 points, "Second" 4 points, "Third" 3 points, "Fourth" 2 points. and "Fifth" 1 point. To determine the order, the number of responses for each category was multiplied by the category points.

Survey Questions 40 through 63. Questions 40 through 63 collected respondents' opinions concerning the work order prioritizing systems they were currently using. A Likert scale ranging from "Strongly Disagree" to "Strongly Agree" was used for questions 40 through 59. A sixth response of "NA" (not applicable) was added for questions 60-64. Table 19 shows both the mode and the mean response for each question.

System Specific Profiles

The previous section of this chapter provided descriptive statistics for the sample population as a whole and was based on responses from the entire sample. The following section provides descriptive statistics for six specific methods of prioritizing work orders: 1) the Checkbook system, 2) the Base Panel system, 3) the Weighting system, 4) the BCE Panel system, 5) the Engineering Judgment system, and 6) the Command Driven system. Statistics were computed with the subprogram FREQUENCIES and the use of IF statements, by instructing SPSSx to provide the frequencies for respondents using each specific prioritizing method for select survey questions. In summary, the descriptive statistics reported in the following section were not based on responses from the entire sample but, rather, only on responses from the sub-population of respondents who reported using the specific prioritizing method.

Table 19.

Respondents' Opinions About the Work Order Prioritizing System Currently Used By Their Organizations

Characteristic	Mode	Frequency Count & (percent)	Mean	Std Dev
Simple to use	Agree	58 (51.3)	4.000	0.982
Requires few CE manhours to keep current	Agree	51 (45.1)	3.478	1.166
Ensures equity among base organizations	Agree	44 (39.3)	3.366	1.193
Easily permits users to change priorities when needed	Agree	50 (44.2)	3.664	1.131
Insures base infrastructure work requirements are given equal priority with other WO requirements	Agree	47 (42.0)	3.411	1.242
Minimizes WO insertions and In-Service-Work Plan disruptions	Agree	36 (31.9)	2.796	1.262
Helps the BCE identify controversial work orders	Agree	47 (41.6)	3.646	1.093
Limits the number of WOs to a manageable size	Agree	44 (39.6)	3.396	1.288
Permits BCEs to direct resources as they see fit	Agree	39 (34.8)	3.196	1.153
Minimizes the warehouse/storage space required for work orders awaiting manhours	Agree	39 (34.8)	3.286	.043
Makes it easy to defend assigned priorities	Agree	50 (44.6)	3.875	0.969
Lets the BCE set priorities based on professional engineering knowledge	Agree	34 (30.4)	3.089	1.212
Requires personal involvement of BCE or Chief of Operations in setting work order priorities	Agree	46 (39.7)	3.397	1.126
Wastes manhours managing the system	Disagree	49 (42.2)	2.284	1.028
Results in complaints the system is unfair	Disagree	46 (40.0)	2.417	1.051
Is flexible enough to meet the new short fused requirements	Agree	73 (63.5)	3.991	0.884
Lets the backlog of WOs grow	Agree	38 (33.0)	2.878	1.229
Lets the political power dominate the setting of WO priorities	Agree	44 (38.3)	3.078	1.171

Scale:
1 - Strongly Disagree
2 - Disagree
3 - Neutral
4 - Agree
5 - Strongly Agree

Table 19.

Respondents' Opinions About the Work Order Prioritizing System Currently Used By Their Organizations (contd)

Characteristic	Mode	Frequency Count & (percent)	Mean	Std Dev
Wastes too much time accommodating short-fused requirements	Disagree	54 (46.6)	2.621	1.077
Lets requesters "game" the system to their advantage	Disagree	52 (45.2)	2.409	1.107
Allows the user to set his/her own priorities	Strongly Agree	49 (42.2)	4.190	1.164
Provides "visibility" through publication and distribution of priority listings to customers	Agree	41 (35.7)	4.061	1.293
Gives DCS primary responsibility for determining WO priorities	Strongly Agree	36 (31.0)	3.948	1.497
Is unable to show the "real" WO backlog due to the WO quota imposed on requesters	Disagree	36 (31.3)	3.496	1.672

Scale:
1 - Strongly Disagree
2 - Disagree
3 - Neutral
4 - Agree
5 - Strongly Agree

<u>Checkbook</u> <u>System</u>. The description of the Checkbook method of prioritizing work orders provided for respondents in the questionnaire is reproduced below.

> A block of manhours is allocated to each organization monthly based on factors such as organization size and total facility square footage occupied by the unit. As with a checkbook, the unit is free to request and have work accomplished up to the amount allocated to them monthly. Typically, units are free to negotiate with each other to make up deficits for desired work. Variations of the checkbook method may allocate number of work orders rather than manhours.

Survey question 18 asked the respondents to describe how their current methods differed from the above description. Several respondents indicated their method of prioritizing work orders was a combination of the Checkbook method and one or more of the other five methods to be described later in this chapter. Although many respondents provided a written response to this question, none significantly differed from the above description.

One refinement that consistently appeared though was the grouping of organizations under a directorate, usually headed by a colonel. Each of these directorates prioritized and controlled the numbers of work requests submitted from within their organizations. Respondents reported as few as four to as many as eight directorate groupings. Typically, civil engineering was treated as a separate directorate and given its own block of work orders/manhours to accomplish base infrastructure repair and maintenance. Many respondents indicated civil engineering worked the top 5 or 10 work order priorities from each of the directorates.

Table 20 provides the frequencies of responses to survey questions 8-14, 20-22, 26, 27, 29-32, 34-36, 64, and 65 by respondents using the Checkbook system.

Questions 64 and 65 were open ended and were designed to solicit respondents' opinions concerning the strongest advantage and the primary disadvantage of the respondents' current system. The following is a partial listing of the strongest advantage reported by respondents to questions 64 and 65:

- Allows CE to manage the WO system and to meet commitments to the customer.
- Improves communication between CE and the customer.
- CE is able to do something for each commander each month, and not just have work orders in Planning or Materiel Control.
- Directorates set their own priorities and understand the requirement to program work in advance to meet their needs.
- Key decision makers are involved from the onset and funding is rarely an issue.

Table 20.

Profile of the Checkbook Work Order Priority System

Variable	Mode	Frequency Count & (percent)
Base Size	4,000-7,500	29 (65.9)
Number of MAJCOM/NAF on base	None	26 (59.1)
Number of wings on base	1	23 (52.3)
Number of tenants on base	5-15	24 (54.5)
Number of officers outranking the Installation Commander	None	20 (45.5)
Average number of minor construction work orders on backlog at any one time	50-99	14 (34.1)
Average number of maintenance and repair work orders on backlog at any one time	100-199	12 (28.6)
Type work classification prioritized	MC & M/R	32 (74.4)
Respondent's rating of system effectiveness	Effective	22 (50.0)
Of the six prioritizing systems, how did respondents rank the checkbook system	First	28 (68.3)
CE WOs to maintain the base infrastructure compete with requesters' work orders	No	23 (52.3)
How often does CE request customer update of the work order priority listing	Monthly	19 (43.2)
Step in the WO process where priorities are frozen	at Materiel Control	25 (59.5)
Installations have WO quotas	Yes	29 (65.9)
How important is concept of first-in-first-out	Not important at all	13 (29.5)
Percent of total WOs generated by Base Commander or higher	1% - 10%	20 (45.5)
A computer is used to assign WO priorities	No	31 (70.5)
A computer is used to track WO priorities	Yes	41 (93.2)
What is the one strongest advantage of the checkbook system	Customer participation	11 (25.0)
What is the one primary disadvantage of the checkbook system	None	5 (11.6)

Note: n = 44

- Directorates have the responsibility to screen their organizations' work requests.
- The system is flexible.
- Keeps the work order backlog to a manageable level.
- Minimizes work order insertions.
- The system accurately reflects desires of the customer while taking care of the base infrastructure.

- The system is visible, meaning customers know how it works and perceive it to be an equitable system.
- The system takes the heat off of CE because now each Commander decides what will be done, not CE. This is as it should be, as colonels should decide what really needs to be done in their areas, not a captain or major in civil engineering.

The following is a partial listing of the primary disadvantage reported by respondents:

- Command interest projects must be handled separately and override the priority list.
- Inability to plan ahead since WOs arrive in a random fashion.
- CE cannot accommodate all requirements--thus the WO backlog grows.
- Requires great flexibility and hinders mid- and long-range planning.
- Gives organizations too much influence over what work CE does.
- Allows too much disruption in the work schedule.
- Some commanders select only large and costly work orders for their top priorities--thereby getting more than their "fair share" of civil engineering manhours and supply dollars.
- Nice to have quality of life type work often is completed in lieu of very important infrastructure work.
- Does not allow for orderly insertions of last minute requirements (whether they are last minute because of oversight, lack of customer awareness of CE procedures, or valid last minute requirements).
- Too many manhours required to keep the system current.
- The WO quota masks the real backlog.
- Commanders change their priorities too often.

Corporate Base Panel System. The description of the Corporate Base Panel method of prioritizing work orders provided for respondents in the questionnaire is reproduced below.

> The Installation commanding officer establishes a corporate board (other than the Facilities Board) to review, approve, and prioritize work requests. The Panel is often chaired by the Deputy to the Installation Commanding Officer (such as the Vice wing commander). Squadrons may or may not have the option to prioritize their work orders within the base priority listing. Starting point for Panel prioritization is usually AFR 85-1 category recommendations of Priorities 1 through 4.

In response to survey question 18, respondents described how their current method differed from the above description. Similar to responses from those using the Checkbook system, several respondents using the Base Panel system reported their method of prioritizing work orders was a combination of the Corporate Base Panel method and one or more of the other five methods. One significant difference to the above description was reported: normally, the corporate base panel established to prioritize work orders was subordinate to the Facilities Board (FB). The FB gave final approval of the Panel's prioritized WO list. In addition, base organizations were normally given the opportunity to prioritize their work orders in the queue and often major organizations were given work order quotas.

In addition to the above description, the following three versions of the Corporate Base Panel were different enough to warrant a discussion of each.

- The first version permits each organization on base to rank order and list their "Top 10" work orders in backlog. The Operations Branch then uses these "Top 10" inputs to draft sample future and second future month In-Service-Work Plans for work orders with material complete and a separate list of WOs to fund that are planning complete. The Base Panel then reviews Operation's draft lists, negotiates changes, and submits the lists to the Facilities Board for approval.

- The second version establishes three separate Corporate Base Panels: One for each major base organization (the home wing and the tenant wing) and a third for civil engineering. A quota of 40/20/20 work orders was established for the home/tenant/CE Panel. After an in-house Civil Engineering Work Request Review Board (WRRB) has reviewed and approved each work request for in-house CE work force accomplishment, each Panel is then permitted to prioritize their own work orders by whatever method they choose. Only the "Top 80" work orders are funded, planned, and scheduled for accomplishment. However, each organization can have an unlimited number of work requests from which to select their quota. Each Panel releases new work requests to civil engineering monthly when work orders are scheduled, on a one-for-one basis. In other words, when one work order is scheduled, another can be selected by the Panel to be planned.

- The third and final version established a single corporate Base Panel called the Facility Board Working Group. Panel membership is limited to each DCS and two major tenants. The Panel is chaired by the Base Commander. Each of these members is permitted to list their "Top 5" work orders in order of priority. Civil engineering then commits funds to order materials for the organizations' "Top 5." The actual order of accomplishment is determined by the Panel using the organizations' "Top 5" as a starting point for discussion.

Table 21 shows responses to survey questions 8-14, 20-23, 26, 27, 29-32, 34-36, 64, and 65 of those using the Corporate Base Panel method of prioritizing work orders.

In response to survey question 64, the following is a partial listing of the strongest advantage reported by respondents using the Corporate Base Panel system:

- The system ensures the most critical work is done.
- Provides clear direction on priority and what work is to be done in this very manageable system.
- Able to control and accomplish DCS primary work requirements.
- User inputs are screened by their DCS.
- The system is equitable.
- Stops the growth of work order backlog.
- The wing commander prioritizes work.
- All base organizations have an input as to how CE in-house resources are expended.

Below is a partial listing of the primary disadvantage reported by respondents:

- Work orders to maintain the base infrastructure do not get done. Almost all the work orders completed are minor construction.
- Encourages duplication of work.
- Vocal organizations can get a higher share of available work order manhours.
- Does not allow programmers to program work orders to match in-house available manhours.
- A perception of inequity.
- System has not been computerized.

Weighting System. The description of the Weighting method of prioritizing work orders provided for respondents in the questionnaire is reproduced on page 74.

Table 21.

Profile of the Base Panel Work Order Priority System

Variable	Mode	Frequency Count & (percent)
Base Size	4,000-7,500	7 (43.8)
Number of MAJCOM/NAF on base	None	8 (50.0)
Number of wings on base	1	8 (50.0)
Number of tenants on base	5-15	7 (43.8)
Number of officers outranking the Installation Commander	1-5	7 (43.8)
Average number of minor construction work orders on backlog at any one time	50-99 100-199	5 (33.3) 5 (33.3)
Average number of maintenance and repair work orders on backlog at any one time	50-99	6 (40.0)
Type work classification prioritized	MC & M/R	15 (93.8)
Respondent's rating of system effectiveness	Effective	11 (68.8)
Of the six prioritizing systems, how did respondents rank the Base Panel system	First	10 (62.5)
CE WOs to maintain the base infrastructure compete with requesters' work orders	Yes	8 (53.3)
How often does CE request customer update of the work order priority listing	Monthly	6 (50.0)
Step in the WO process where priorities are frozen	at Materiel Control	6 (46.2)
Installations have WO quotas	No	12 (75.0)
How important is concept of first-in-first-out	Neutral	5 (31.3)
Percent of total WOs generated by Base Commander or higher	1% - 10%	6 (37.5)
A computer is used to assign WO priorities	No	10 (62.5)
A computer is used to track WO priorities	Yes	13 (81.3)
Chairperson of Base Panel	Wing/CC Base/CC	5 (33.3) 5 (33.3)
What is the one strongest advantage of the Base Panel system	Customer gets their high priority WOs	4 (30.8)
What is the one primary disadvantage of the Base Panel system	Infrastructure suffers	3 (23.1)

Note: n = 16

Work order priorities are typically established by weighting factors (such as the categories of Priority [Mission, Fire/Safety, Support, and Necessary] as given in AFR 85-1, Command Interest [Wing Commander, Base Commander, BCE, and others], and Location [Scheduling, Materiel Control, Planning, Backlog]) on a pre-determined scale against each work order. The weights assigned to each factor are then totalled to determine the priority for that work order. Work orders are sorted by total score, and may be sorted in a number of other ways, to develop a base priority list.

Only two respondents reported using the Weighting method and no variation of the above description was provided.

One respondent indicated their base was preparing to implement a "Priority Matrix System" with no variation from the operating characteristics described above. However, documentation returned with the questionnaire was thorough and to make this study as complete as possible, several features of the system will be presented.

In this Weighting system, extra points are assigned to WOs that have been in the WO process system for excessive amounts of time to prevent CE from deferring jobs they may not want to do. Also, extra points can be assigned to allow for the "real world" of command pressure. This system provides organization commanders with a means to push their top priority work orders. Finally, "bonus points" can be assigned by CE to permit efficient use of shop manhours. For example, when a particular shop needs work, extra points can be given. Or, if there is a period of very limited funds for material acquisition, then WOs that are manpower intensive can be given extra points (5). The decision matrix used by the respondent's base is reproduced in Table 22.

Table 23 shows responses to survey questions 8-14, 20-22, 26, 27, 29-32, 34-36, 64, and 65 of those using the Weighting method of prioritizing work orders.

Table 22.

Priority Matrix Decision Factors (5)

Decision Factors	Factor Points			
Safety	5	10	15	20
Security	5	10	15	20
Fire Deficiency	5	10	15	20
Bioenvironmental	5	10	15	20
Life/Equipment Support (HVAC)	5	10	15	20
Mission:				
a. Facility	5	10	15	20
b. Base		10	15	20
c. Command			15	20
Command Interest				
a. BCE (SII) or any O-6	10	15	20	25
b. Base Commander		15	20	25
c. Center Commander			20	25
d. ALC/AF				25
Facility Degradation/upgrade	1	3	5	7
Customer satisfaction	1	3	5	
Base appearance	3	5	7	

Decision Factors	Factor Points			
Reduce cost of operation	2	4	6	8
Prime BEEF exercise Project	2	3	4	5
Promote efficiencies	4	6	8	10
Improve working conditions				5
Provide maint. to utility services				15
Self-help				100
Welfare and recreation				20
Surface transport system degradation	2	4	6	8
Time in System	0	25	50	75
WO is labor intensive				25*
WO is material intensive				25*

Note: * For scheduling purposes only. To be assigned only when determined necessary for good CE work force management.

In response to survey question 64, the following is a listing of the strongest advantage reported by respondents using the Weighting system:

- Customer satisfaction.
- Visibility, customers know the priority of all projects.

Below is a listing of the primary disadvantage reported by respondents using the Weighting system in response to survey question 65:

- Too many short fused project insertions disrupt the In-Service-Work Plan.
- CE does not always know the validity of all work requirements.

Table 23.

Profile of the Weighting Work Order Priority System

Variable	Mode	Frequency Count & (percent)
Base Size	4,000-7,500	2(100.0)
Number of MAJCOM/NAF on base	None	2(100.0)
Number of wings on base	1	1 (50.0)
	2	1 (50.0)
Number of tenants on base	16-25	1 (50.0)
	> 25	1 (50.0)
Number of officers outranking the Installation Commander	6-10	1 (50.0)
	> 10	1 (50.0)
Average number of minor construction work orders on backlog at any one time	50-99	1 (50.0)
	100-199	1 (50.0)
Average number of maintenance and repair work orders on backlog at any one time	100-199	2(100.0)
Type work classification prioritized	MC & M/R	2(100.0)
Respondent's rating of system effectiveness	Neutral	1 (50.0)
	Somewhat Ineffective	1 (50.0)
Of the six prioritizing systems, how did respondents rank the Weighting system	First	2(100.0)
CE WOs to maintain the base infrastructure compete with requesters' work orders	Yes	2(100.0)
How often does CE request customer update of the work order priority listing	As needed	1 (50.0)
	Annually	1 (50.0)
Step in the WO process where priorities are frozen	at Materiel Control	1 (50.0)
	Any time	1 (50.0)
Installations have WO quotas	No	1 (50.0)
	Yes	1 (50.0)
How important is concept of first-in-first-out	Neutral	1 (50.0)
	Not important at all	1 (50.0)
Percent of total WOs generated by Base Commander or higher	11% - 20%	1 (50.0)
	51% - 75%	1 (50.0)
A computer is used to assign WO priorities	Yes	1 (50.0)
	No	1 (50.0)
A computer is used to track WO priorities	Yes	12(100.0)
What is the one strongest advantage of the Weighting system	Customers satisfied	1 (50.0)
	Visibility	1 (50.0)
What is the one primary disadvantage of the Weighting system	Insertions	1 (50.0)
	Masks validity of WOs	1 (50.0)

Note: n = 2

Internal BCE Panel. The description of the internal BCE Panel method of prioritizing work orders provided for respondents in the questionnaire is reproduced below.

> An internal BCE panel prioritizes work orders for approval of a senior base official. Typically, work orders are prioritized on the basis of AFR 85-1 guidance. Who chairs the panel varies from base to base (BCE, Deputy BCE, or Chief of Operations).

Written responses to survey question 18, describing system differences, did not vary significantly from the above description. Similar to the previous WO priority methods, several respondents reported their method of prioritizing WOs was a combination of the BCE Panel and one or more of the other five methods.

Table 24 shows responses to survey questions 8-14, 20-22, 24, 26, 27, 29-32, 34-36, 64, and 65 of those using the internal BCE Panel method of prioritizing work orders.

The following is a partial listing of the strongest advantage reported by respondents using the internal BCE Panel method in reply to survey question 64:

- All decision making is kept in-house where Civil Engineering has a better feel for such factors as funding levels, equipment availability, backlog in specific crafts, and command interest.
- DCS commanders set their own WO priorities with confidence WOs high in priority will be completed within six months of placing it in the CE queue.
- System is fair, mission oriented, and follows AF guidance.
- System is flexible, able to handle unexpected important work requirements.
- The system works.
- Controls the number of work orders in the system.
- The system is simple to understand.

Beginning on page 78 is a partial listing of the primary disadvantage reported by respondents using the Internal BCE Panel system in reply to survey question 65:

Table 24.

Profile of the BCE Panel Work Order Priority System

Variable	Mode	Frequency Count & (percent)
Base Size	4,000-7,500	10 (62.5)
Number of MAJCOM/NAF on base	None	12 (75.0)
Number of wings on base	2	5 (33.3)
Number of tenants on base	5-15	8 (50.0)
Number of officers outranking the	None	5 (33.3)
Installation Commander	1-5	5 (33.3)
Average number of minor construction work	50-99	4 (28.6)
orders on backlog at any one time	200-299	4 (28.6)
Average number of maintenance and repair work orders on backlog at any one time	100-199	5 (35.7)
Type work classification prioritized	MC & M/R	15 (93.8)
Respondent's rating of system effectiveness	Effective	9 (56.3)
Of the six prioritizing systems, how did respondents rank the BCE Panel system	First	12 (75.0)
CE WOs to maintain the base infrastructure compete with requesters' work orders	Yes	13 (81.3)
How often does CE request customer update of	Monthly	4 (33.3)
the work order priority listing	Quarterly	4 (33.3)
Step in the WO process where priorities are frozen	at Planning	3 (25.0)
Installations have WO quotas	No	12 (75.0)
How important is concept of first-in-first-out	Slightly Important	9 (56.3)
Percent of total WOs generated by Base Commander or higher	1% - 10%	8 (53.3)
A computer is used to assign WO priorities	No	13 (81.3)
A computer is used to track WO priorities	Yes	11 (73.3)
What is the one strongest advantage of the BCE Panel system	Simple to understand	3 (21.4)
	CE prioritizes work orders	3 (21.4)
What is the one primary disadvantage of the BCE Panel system	Requesters not involved	2 (7.7)
	None	2 (7.7)
Chairperson of BCE Panel	Chief of Ops	6 (37.5)

Note: n = 16

- There are times when base officials do not feel the system is responsive enough.
- The system limits flexibility of the customers.

- WOs with lower priorities become backlogged for long periods of time.
- Does not allow for all factors to be considered before priorities are set.
- Work to maintain the base infrastructure suffers at the expense of minor construction work.
- The system does not involve requesters and commanders in the prioritizing process. Thus, it lacks their support.

Engineering Judgment System. The description of the Engineering Judgment method of prioritizing work orders provided for respondents in the questionnaire is reproduced below.

> The BCE combines prior experience and professional judgment to set work order priorities using the four category priority system recommended by AFR 85-1. Typically, BCE uses First-in-first-out (FIFO) and reacts to Commander's special interests within each category. A variation of this system permits the Chief of Operations or Requirements to do most prioritizing, usually using AFR 85-1 guidance, FIFO and professional judgment.

Similar to responses for the priority methods already discussed in this chapter, several respondents using the Engineering Judgment method report their organizations are using a combination of the Engineering Judgment method and one or more of the other five methods. The only significant variation to the above description reported by several respondents was the imposition of work order quotas on each major organization which they are permitted to prioritize prior to submission to CE.

For example, at one respondent's base, CE has established a "Top-20 Work Order Program." Eleven major organizations and tenants are each limited to 20 work orders in the system at any one time. Each organization is responsible for establishing, prioritizing, and updating its own top-20 list. Top-20 priority lists are updated monthly, and work is accomplished by priority sequence of each organization: however, those WOs with materials on hand are completed first. When there is more than one WO ready to be scheduled, the following factors are used:

1) Priority of work requests assigned by organizations.

2) Scope of work (large versus small WO) for labor-hour availability.

3) Seasonal work.

4) Work site availability.

5) Distribution of work among organizations (45:1-2)

A critical comment on the use of work order quotas was provided by a respondent in reply to open ended survey question 66 and is provided below.

> Using quotas is a way of alleviating managers of doing their jobs. There needs to be a time when the BCE can look a DCS in the eye and say "Sorry, Colonel, I can't do that" and get the Installation Commander's backing. Using the system places the blame on the system, and is an easy way out.

Table 25 shows responses to survey questions 8-14, 20-22, 25-27, 29-32, 34-36, 64, and 65 of those using the Engineering Judgment method to prioritize work orders.

The following is a partial listing of the strongest advantage reported by respondents using the Engineering Judgment method in reply to survey question 64:

- Meets the requirements of the Base Commander.
- Permits Civil Engineering to determine work requirements.
- Chief of Operations involvement in prioritization.
- The system is fair to all organizations on base, regardless of size or power.
- Allows work orders to be worked in a timely manner.
- System is flexible; it has the latitude to accommodate special interest requirements and still maintain CE work order infrastructure support.
- CE management of the system is simplified through organization commanders' involvement and prioritization of their own limited number of work requests.
- Simple to understand.

Table 25.

Profile of the Engineering Judgment Work Order Priority System

Variable	Mode	Frequency Count & (percent)
Base Size	4,000-7,500	10 (40.0)
Number of MAJCOM/NAF on base	None	15 (60.0)
Number of wings on base	1	8 (32.0)
	2	8 (32.0)
Number of tenants on base	5-15	12 (48.0)
Number of officers outranking the Installation Commander	None	12 (48.0)
Average number of minor construction work orders on backlog at any one time	50-99	9 (37.5)
Average number of maintenance and repair work orders on backlog at any one time	100-199	11 (45.8)
Type work classification prioritized	MC & M/R	23 (92.0)
Respondent's rating of system effectiveness	Effective	12 (48.3)
Of the six prioritizing systems, how did respondents rank Engineering Judgment	First	17 (70.8)
CE WOs to maintain the base infrastructure compete with requesters' work orders	Yes	21 (87.5)
How often does CE request customer update of the work order priority listing	As needed	9 (42.9)
Step in the WO process where priorities are frozen	Any time	7 (33.3)
Installations have WO quotas	No	20 (83.3)
How important is concept of first-in-first-out	Slightly Important	13 (54.2)
Percent of total WOs generated by Base Commander or higher	1% - 10%	15 (62.5)
A computer is used to assign WO priorities	No	20 (87.0)
A computer is used to track WO priorities	Yes	17 (73.9)
What is the one strongest advantage of the Engineering Judgment system	Flexibility	5 (20.8)
What is the one primary disadvantage of the Engineering Judgment system	Perception of inequity	4 (16.7)
	Insertions	4 (16.7)
Primary person within CE setting WO priorities	Chief of Ops	11 (45.8)

Note: n = 25

On page 82 is a listing of the primary <u>disadvantage</u> reported by respondents using the Engineering Judgment system in response to survey question 65:

- The WO list is in a constant flux, resulting in lost manhours for items that had been started and then dropped in priority.
- Not visible to customers, since the prioritized lists of what is in the queue and competing for scarce resources are only published base-wide occasionally.
- System approves too much work.
- Lack of customer satisfaction.
- Delays completion of priority 4 work orders by 10 months or more.
- Can have misdirected effort if organization commanders aren't sure of their requirements and continually change their priorities.
- Requesters game the system.
- System generates a perception of unfairness as some organization missions are less important than others, and they tend to have fewer WOs completed.
- The BCE is not directly involved with the prioritizing of work and will not defend the "necessary" against the "nice to have" work.
- System requires too many manhours to manage.

Command Driven System. The description of the Command Driven method of prioritizing work orders provided for respondents in the questionnaire is reproduced below.

> Priorities are set by command interest with the balance of the program filling in around the command interest program. The central concept is that senior commanders (such as Major Command general officers) continually generate command interest work orders, making it unnecessary to develop a formal work order priority system.

In response to survey question 18, respondents described how their current method differed from the above description. Similar to responses from those using the other systems, several respondents using the Command Driven system reported their method of prioritizing work orders was a combination of the Command Driven method and one or more of the other five methods. One reported difference to the above description was that several respondents' organizations set quotas to allocate work orders among wing commanders/equivalents or higher level organizations.

Table 26 shows responses to survey questions 8-14, 20-22, 26, 27, 29-32, 34-36, 64, and 65 of those using the Command Driven method of prioritizing work orders.

Table 26.

Profile of the Command Driven Work Order Priority System

Variable	Mode	Frequency Count & (percent)
Base Size	4,000-7,500	8 (61.5)
Number of MAJCOM/NAF on base	None	6 (46.2)
	1	6 (46.2)
Number of wings on base	1	6 (46.2)
Number of tenants on base	5-15	5 (38.5)
Number of officers outranking the Installation Commander	1-5	7 (53.8)
Average number of minor construction work orders on backlog at any one time	100-199	7 (58.3)
Average number of maintenance and repair work orders on backlog at any one time	100-199	5 (41.7)
Type work classification prioritized	MC & M/R	7 (58.3)
Respondent's rating of system effectiveness	Effective	6 (46.2)
Of the six prioritizing systems, how did respondents rank the Command Driven system	First	4 (33.3)
CE WOs to maintain the base infrastructure compete with requesters' work orders	No	6 (46.2)
How often does CE request customer update of the work order priority listing	Monthly	4 (44.4)
Step in the WO process where priorities are frozen	at Materiel Control	5 (45.5)
Installations have WO quotas	No	9 (69.2)
How important is concept of first-in-first-out	Slightly Important	5 (38.5)
Percent of total WOs generated by Base Commander or higher	1% - 10%	4 (30.8)
A computer is used to assign WO priorities	No	9 (69.2)
A computer is used to track WO priorities	Yes	13(100.0)
What is the one strongest advantage of the Command Driven system	Satisfies the boss	7 (52.8)
What is the one primary disadvantage of the Command Driven system	Perception of inequity	3 (25.0)

Note: n = 13

The following is a partial listing of the strongest advantage reported by respondents using the Command Driven method in reply to survey question 64:

- System is flexible, able to meet short-fused requirements.
- Able to follow a complex, detailed master plan of improvements for the base, including many relocations of units.
- Responds best to the wing commander.
- When wing commander gives his approval, there is little disagreement.
- Makes work order backlog visible.

The following write-in response to survey question 65 expanded on the benefits of the Command Driven system:

> A Command Driven system is most likely to get full cooperation of all contributors: contracting, supply, transportation, and customers. The potential benefit is a greater volume of work accomplished, and ultimately, more satisfied customers. Most CE squadrons do not know how productive they can be until really pushed. Therefore, some systems actually limit the productive capacity of CE squadrons.

Below is a listing of the primary disadvantage reported by respondents using the Command Driven system in response to survey question 65:

- Base infrastructure suffers because of politics. Glamor work wins out over less visible work such as sewer maintenance.
- Lets the backlog of work orders grow.
- Organizations with little clout never gets his work requirements completed.
- Customer dissatisfaction.
- BCE has no control over the resources he/she is responsible for.
- Results in frequent disruption of the In-Service-Work Plan.

Summary

The first part of this chapter provided a profile of how the Air Force prioritizes work orders as a whole and what internal and external factors influence the type of WO prioritizing system used. This profile included demographic data about the respondents, installation attributes impacting the type of prioritizing system used, and characteristics of the priority systems used by respondents.

The work order prioritizing method reported to be used most frequently was the Checkbook method (37.9 percent of the respondents). At 21.6 percent of the sample population, Engineering Judgment was the next most popular system. Finally, the three methods of Base Panel, BCE Panel, and Command Driven were reported to be used about the same frequency of 13.8, 13.8, and 11.2 percent of the sample population respectively.

The second part of this chapter provided a profile of each specific work order prioritization system identified in the personal and telephone interviews. While no new prioritizing system was reported by respondents, several significant variation were identified. Each of the system profiles addresses the same general variables or factors for comparison and system specific factors when applicable. Also provided in the second part of this chapter is the strongest advantage and the primary disadvantage reported by respondents for each system.

This chapter has presented the descriptive statistics for the sample population as a whole and each specific method of prioritizing work orders. In the next chapter, Analysis and Discussion of Results, these descriptive statistics will be used to answer the research questions.

V. Analysis and Discussion of Results

Introduction

This chapter contains an analysis and discussion of the results presented in Chapter IV. Each research question is analyzed separately, based on the results presented in Chapter IV and the computer subprograms FREQUENCIES, ONEWAY, AND SCHEFFE' TEST described in Chapter III. The final part of this chapter will synthesize the model presented in Chapter II with the work order priority systems discussed in Chapter IV.

Research Question 1

> How do Air Force Civil Engineering organizations allocate in-service work order accomplishment among base organizations?

There is a two-part answer to this research question. First, on a micro level, what specific work order prioritizing methods did respondents report using? Second, on a macro level, how does CE prioritize work orders Air Force-wide?

The six work order priority system profiles (Checkbook, Corporate Base Panel, Weighting, Internal BCE Panel, Engineering Judgment, and Command Driven) developed by modes and frequencies in Chapter IV provide useful information about the methods used by respondents to prioritize work orders for in-service accomplishment. Since the respondents did not report using any other rank ordering method, it is assumed the above list is exhaustive for the sample population. When looked at individually, these profiles are self-explanatory. To facilitate comparison, Table 27 summarizes mode responses for each of the six specific rank ordering methods.

Table 27.

Comparison of Mode Responses for Work Order Priority System Profiles

Variable	Checkbook	Base Panel	Weighting	BCE Panel	Engineering Judgment	Command Driven
Major command	TAC	SAC	SAC	MAC	ATC	SAC
Base size	4000-7500	4000-7500	4000-7500	4000-7500	4000-7500	4000-7500
Number of MAJCOM/NAFs on base	None	None	None	None	None	None
Number of wings on base	1	1	1 or 2	2	1 or 2	1
Number of tenants on base	5-15	5-15	16-25	5-15	5-15	5-15
Number of officers outranking the Base Commander	None	1-5	6-10	None	None	1-5
Average number of MC WOs on backlog at any one time	50-99	50-99 100-199	50-99 100-199	50-99 200-299	50-99	100-199
Average number of M/R WOs on backlog at any one time	100-199	50-99	100-199	100-199	100-199	100-199
Work classification rank ordered by priority system	MC & M/R	MC & M/R	MC & M/R	MC & M/R	MC & M/R	MC & M/R
Respondent's rating of system effectiveness	Effective	Effective	Neutral	Effective	Effective	Effective
CE WOs to maintain the base infrastructure compete w/requester's WOs	No	Yes	Yes	Yes	Yes	No
Periodic CE request for customer update of WO priority listing	Monthly	Monthly	Annually As needed	Monthly Quarterly	As needed	Monthly
Step in the WO process where priorities are frozen	Matl Cntl	Matl Cntl	Matl Cntl	Planning	Not Frozen	Matl Cntl
Installations have work order quotas	Yes	No	No Yes	No	No	No
Percent of total WOs generated by Installation Commander or higher	1% - 10%	1% - 10%	11% - 20% 51% - 75%	1% - 10%	1% - 10%	1% - 10%
WO priorities assigned by a computer	No	No	No Yes	No	No	No
WO priorities tracked by a computer	Yes	Yes	Yes	Yes	Yes	Yes

Although Table 27 is self-explanatory, it is useful to note that the table reveals the following mode responses are the same across all six methods:

- the base size is medium (4,000 to 7,500);
- there is no Major Commands or Numbered Air Force headquarters on base;
- both Minor Construction and Maintenance & Repair work orders are prioritized using the rank ordering method;
- except for those using Weighting, respondents consider their current rank ordering system effective;
- all systems use a computer to track work orders.

Table 28 shows the frequency distribution of each work order priority system across Major Commands.

Table 28.

Summary of Work Order Priority System Use - by Major Commands

	Frequency Count (percent) for Each WO Priority System						
Major Command	Check-book	Engr Judg	Base Panel	BCE Panel	Command Driven	No System	Weight-ing
AFLC	2 (1.7)		2(1.7)	1(0.9)			
AFSPACECOM			1(0.9)				
AFSC		4(3.4)		1(0.9)			
ATC	5 (4.3)	8(6.9)	3(2.6)	4(3.4)	1(0.9)		
AU					2(1.7)		
MAC	7 (6.0)	7(6.0)		6(5.2)	1(0.9)		
SAC	9 (7.8)	5(4.3)	6(5.2)	2(1.7)	7(6.0)	3(2.6)	1(0.9)
TAC	20(17.2)	1(0.9)	4(3.4)	1(0.9)	2(1.7)		
PACAF	1 (0.9)						
AFDW				1(0.9)			1(0.9)
Total	44(37.9)	25(21.6)	16(13.8)	16(13.8)	13(11.2)	3(2.6)	2(1.7)

n = 119

Figure 13 graphically displays the column totals in Table 28 to emphasize the different rates of use for each prioritizing method across the entire sample population.

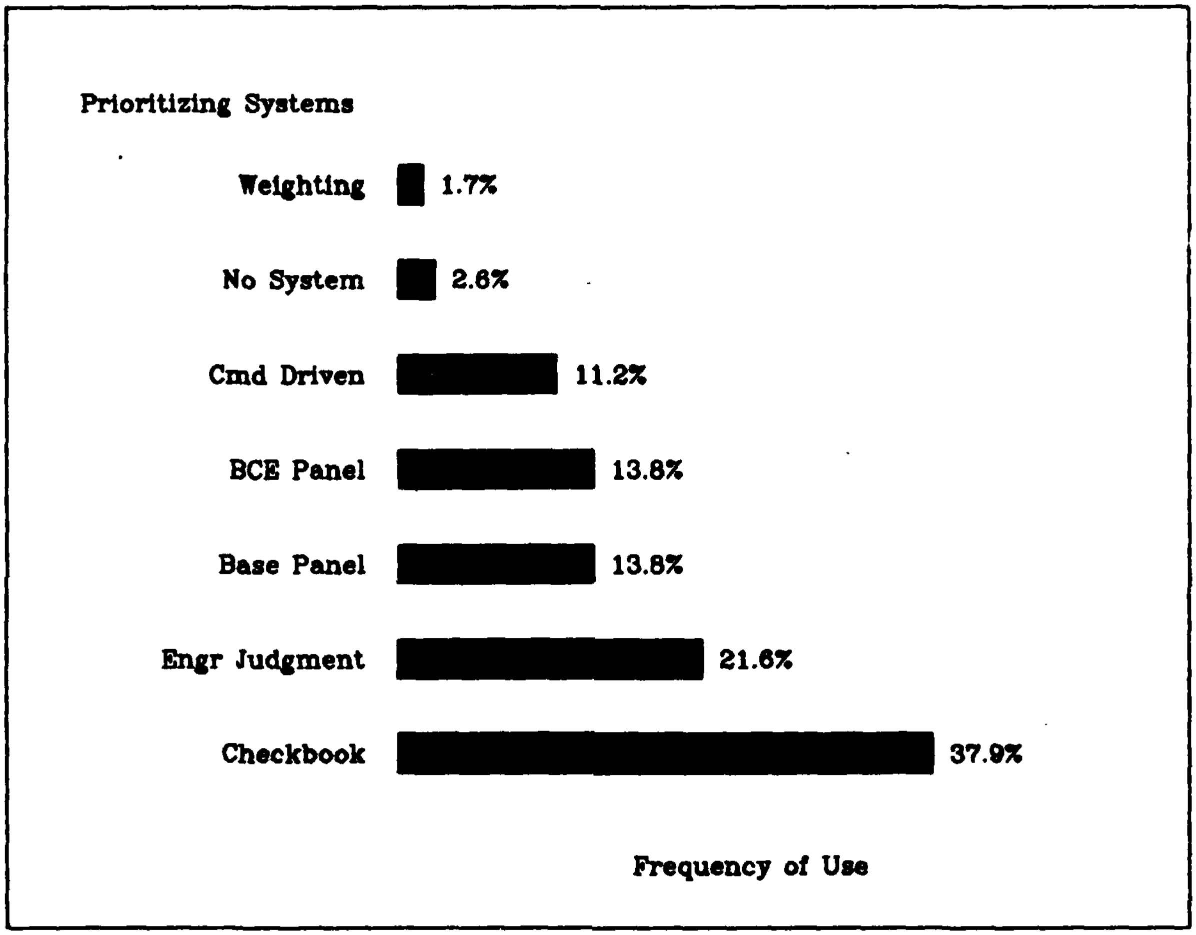


Figure 13. Use of Priority Systems as Reported by Respondents

Inspection of Figure 13 shows the Checkbook system has a response frequency of 37.9 percent and is clearly the priority system used most frequently. In fact, 71.4 percent of the respondents from TAC, 40 percent of AFLC, 33.3 percent of MAC, 27.3 percent of SAC, and 23.8 percent of ATC reported using the Checkbook system. The next most frequently used priority system is Engineering Judgment with 21.6 percent of the sample population reporting its use. An analysis of the use of Engineering Judgment shows 80 percent of the respondents from AFSC, 38.1 percent of ATC, 33.3 percent of MAC, 15.2 percent of SAC, and 3.6 percent of TAC reported using the system. Registering 24.1 percent behind the Checkbook system, both the Corporate Base Panel and the Internal BCE Panel were reported to be used by 13.8 percent of the respondents. The last system with a significant response rate was the Command Driven system with 11.2 percent of the respondents reporting its use. Only 1.7 percent of the respondents reported using the Weighting system.

Figure 14 graphically displays the row totals from Table 28 to emphasize the rate of use for each prioritizing method within each major command surveyed.

Based on the findings, this research concludes there are six different methods used in the Continental United States by Air Force Civil Engineering to prioritize work orders for in-service accomplishment: Checkbook, Corporate Base Panel, Weighting, Internal BCE Panel, Engineering Judgment, and Command Driven. Furthermore, research shows the most frequently used work order priority system is the Checkbook method.

Research Question 2

What factors internal to the Civil Engineering organization are considered when making decisions about the priority of in-service work order accomplishment?

Contained within Tables 10, 14, 16, and 17 are factors or forces internal to the base Civil Engineering organization that influence the

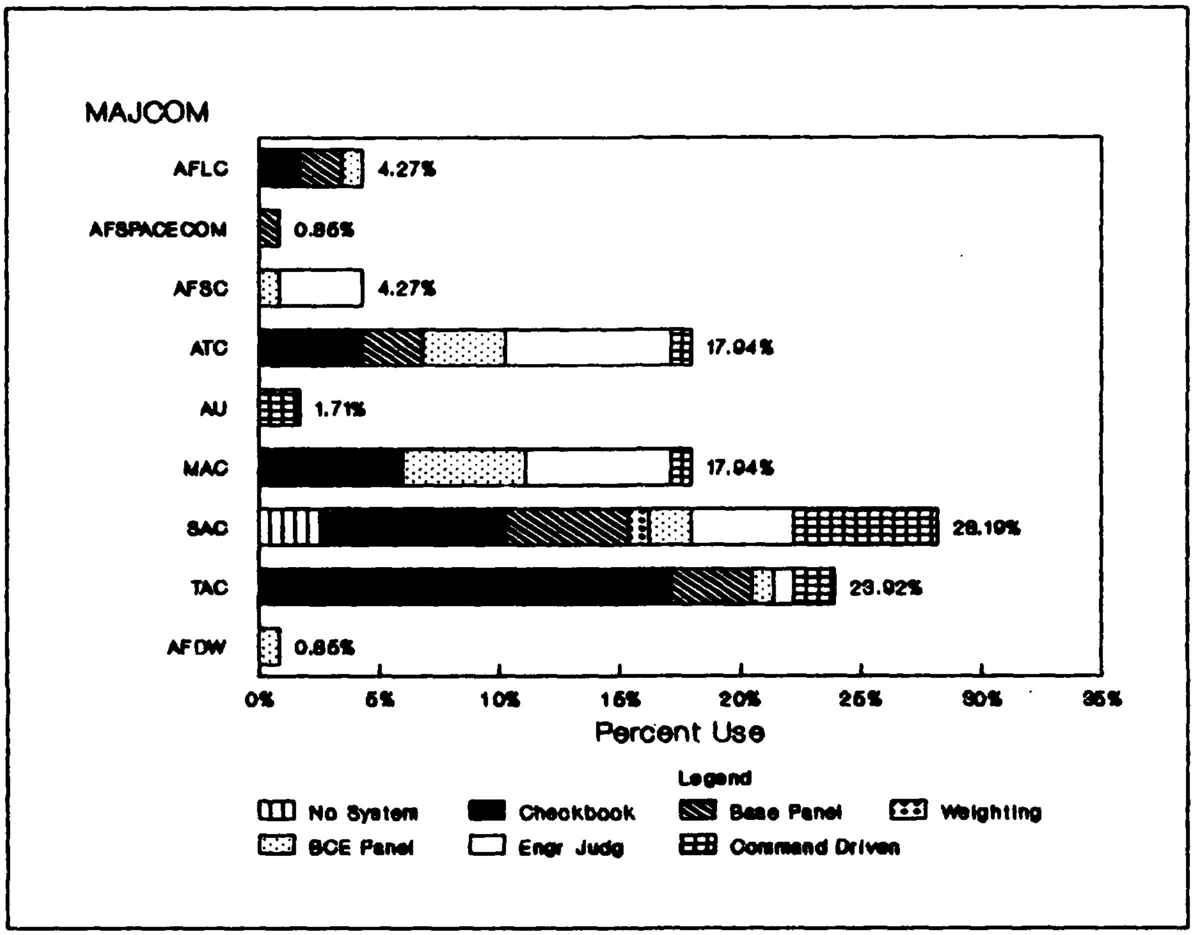


Figure 14. Reported Use of Priority Systems by Major Command

way the BCE chooses to prioritize work orders. Causal inferences are not possible based on the level of data collected. In addition, only respondents using the Weighting system were asked to answer survey question 38. Thus, frequencies in Table 17 are based on a small sample population size of 12. The factors internal to CE, listed below, are those which respondents indicate they consider when making decisions about rank ordering work orders for in-service accomplishment.

1. Work order backlog. The size of work order backlog was the second most frequently reported factor influencing CEs' decision to continue using their current prioritizing system (58.5 percent).

2. Professional engineering judgment. The mode response to the question of "How important is professional judgment when setting WO priorities?" was "Very Important" (50.9 percent).

3. Concept of first-in-first-out (FIFO). Since this factor is an operating procedure set by the BCEs and under their control, it can be considered an internal factor. The mode response to the question "How important is the concept of FIFO to your WO system?" was it is "Slightly Important" (20.0 percent).

4. Base Civil Engineer's management style. The BCE's management style was the fourth most frequently reported factor influencing CEs' decision to continue using their current prioritizing system (39.0 percent).

5. Equipment availability. This factor refers to the availability of equipment needed by the craftsman to perform the work. Only 8.3 percent responding to survey question 38 choose this factor as important to consider when prioritizing WOs.

6. CE training requirements. This factor includes both Prime BEEF and craftsman training requirements. Only 8.3 percent responding to survey question 38 chose this factor as important to consider when prioritizing WOs.

7. Energy conservation measures. Table 26 shows that 16.7 percent of those responding to survey question 38 choose this factor as important to consider when prioritizing WOs.

8. Shop manning. The response frequency of 25.0 percent to survey question 38 shows this is an important factor to consider when prioritizing WOs.

9. Base infrastructure. Table 26 shows that 50.0 percent of the respondents answering survey question 38 chose this factor as important to consider when prioritizing WOs.

Results are limited and the above cannot be considered to be an exhaustive list of factors internal to Civil Engineering considered when making decisions about the priority of in-service work order accomplishment.

Research Question 3

What factors external to the Civil Engineering organization are considered when making decisions about the priority of in-service work order accomplishment?

Tables 10, 16, 17, and 18 provide an insight into the factors or forces external to the Civil Engineering organization that influence the way the BCE chooses to prioritize work orders. Causal inferences are not possible based on the level of data collected. The factors external to CE, listed below and taken from Tables 10 and 16, are those which respondents indicate they consider when deciding to continue using their current prioritizing system. By inference these factors are considered when making decisions about rank ordering work orders for in-service accomplishment. Percents given are the response frequencies from a sample population size of 119.

1. Operating funds available to CE (65.3 percent).
2. Installation commander's management style (52.5 percent).
3. Base mission (40 percent).
4. Number of senior officers on base outranking the Installation Commander (19.5 percent).
5. Number of wings on base (17.8 percent).
6. Base size (17.8 percent).
7. Base relationship with its parent Major Command (9.3 percent).
8. Geographic dispersion of CE's area of responsibility (5.1 percent).
9. Manhours available (4.2 percent, as a write-in response).
10. Percent of work orders generated by the Installation Commander and higher ranking officers on base. (This factor was obtained from Table 8.)

In addition to the above list, Tables 16 and 17 provide a list of factors considered by those answering survey questions 38 and 39 to be important when rank ordering work orders. Below are external factors, extracted from Tables 16 and 17, that influence the way Civil Engineering prioritizes work orders for in-service accomplishment. Percents given are the response frequencies from a sample population size of 12.

1. Funding availability (100.0 percent).
2. Security requirements (91.7 percent).
3. Hazards to health (91.7 percent).
4. Prevent breakdown of operations (75.0 percent).
5. Fire hazards (75.0 percent).
6. Prevent reducing essential operational effectiveness (58.3 percent).
7. Command interest (58.3 percent).
8. Environmental issues (50.0 percent).
9. Requesters' mission (50.0 percent).
10. Command programs (50.0 percent).
11. Material availability (41.7 percent).
12. Quality of life projects (41.7 percent).
13. Work completion drop dead dates (33.3 percent).
14. Requester's unit population size (8.3 percent).
15. Reimbursement for work performed (8.3 percent).
16. Season (8.3 percent).

Results are limited and the above cannot be considered to be an exhaustive list of factors external to Civil Engineering considered when making decisions about the priority of in-service work order accomplishment.

Research Question 4

In the opinions of Base Civil Engineers, what are the shortcomings and advantages of the work order decision priority systems they currently use?

Table 19 shows the mode, frequency count for the mode, the mean and the standard deviation for the respondents' opinions about the work order prioritizing system used by their organizations. In addition, open ended responses to survey questions 64 and 65 provide the strongest advantage and the primary disadvantage reported by respondents.

As discussed in Chapter III, the procedure ONEWAY was used to determine whether the mean responses for the rank ordering methods were significantly different for each of the opinion gathering survey questions #40 through #63. The analysis of variance (ANOVA) established that the opinions expressed in nine survey questions were significantly different among the six rank ordering methods. Table 29 shows the nine opinions, the F ratios, and the significance levels obtained from the ANOVA. The Scheffe' multiple comparisons test shows which of the ranking methods are significantly different from each other.

Table 29.

Significant Analysis of Variance Tests for WO Ranking Methods

Opinion	F Ratio	Level of Significance	Ranking Methods Which Differ
Ensures equity among base organizations	3.9311	0.0053	Checkbook
Easily permits users to change priorities when needed	3.8484	0.0060	Checkbook
Limits the number of WOs to a manageable size	5.8380	0.0003	Checkbook Base Panel
Permits BCEs to direct resources as they see fit	10.3659	0.0000	Base Panel Engr Judg
Lets the BCE set priorities based on professional engineering knowledge	14.2238	0.0000	Engr Judg
Requires personal involvement of BCE or Chief of Operations in setting work order priorities	5.6508	0.0004	Engr Judg BCE Panel
Lets the political power dominate the setting of WO priorities	3.1903	0.0165	Cmd Driven
Wastes too much time accommodating short-fused requirements	3.2790	0.0144	Cmd Driven
Allows the user to set his/her own priorities	4.5476	0.0021	Checkbook

Scale:
1 - Strongly Disagree
2 - Disagree
3 - Neutral
4 - Agree
5 - Strongly Agree

As stated above, significant differences existed for the opinions shown in Table 29. Table 30 shows the mean response for the prioritizing method(s) that differs significantly from the others and provides the overall mean response (sample size 119) for comparison. Also provided, is an indication of whether the differing respondents felt stronger or less strong than those using the other methods. Responses were based on a scale of from 1 to 5 (1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, and 5-Strongly Agree).

Table 30.

How Opinions of Those Using Prioritizing Methods Identified by the Scheffe' Test Differ With Opinions of Those Using the Other Methods

Opinion	Method That Differs	Differing Method's Mean	Over-all Mean	Difference in Opinion
Ensures equity among base organizations	Checkbook	3.814	3.366	Stronger
Easily permits users to change priorities when needed	Checkbook	4.023	3.664	Stronger
Limits the number of WOs	Checkbook	3.705	3.396	Stronger
to a manageable size	Base Panel	4.067	3.396	Stronger
Permits BCEs to direct	Base Panel	2.875	3.196	Less Strong
resources as they see fit	Engr Judg	4.167	3.196	Stronger
Lets the BCE set priorities based on professional engineering knowledge	Engr Judg	4.250	3.089	Stronger
Requires personal involvement of BCE or Chief of Operations in setting	BCE Panel	4.188	3.397	Stronger
work order priorities	Engr Judg	3.880	3.397	Stronger
Lets the political power dominate the setting of WO priorities	Cmd Driven	3.846	3.078	Stronger
Wastes too much time accommodating short-fused requirements	Cmd Driven	3.308	2.621	Stronger
Allows the user to set his/her own priorities	Checkbook	4.591	4.190	Stronger

Scale:
1 - Strongly Disagree   3 - Neutral   4 - Agree
2 - Disagree   5 - Strongly Agree

To summarize significant differences among work order prioritizing methods as determined by this study, below is a synopsis of the opinions for each method that were statistically different.

- Checkbook system: Respondents felt stronger than those using the other methods that their system ensures equity; easily permits users to change priorities; limits the number of WOs to a manageable size; and allows users to set their own priorities.

- Corporate Base Panel: Respondents felt stronger than those using the other methods that their system limits the number of WOs to a manageable size, and requires personal involvement of the BCE or Chief of Operations in setting WO priorities; and, less strongly, that their system permits BCEs to direct resources as they see fit.

- Engineering Judgment: Respondents felt stronger than those using the other methods that their system permits BCEs to direct resources as they see fit; lets the BCE set priorities based on professional engineering judgment; and requires personal involvement of the BCE or Chief of Operations in setting WO priorities.

- Command Driven: Respondents felt stronger than those using the other methods that their system lets the political power dominate the setting of WO priorities; and wastes too much time accommodating short-fused requirements.

Survey question 64 asked the respondents to list the strongest advantage of their work order prioritizing systems. The answers were grouped into similar categories and presented in Table 31. Results indicate customer participation in setting work order priorities and customer satisfaction are believed to be the primary advantages of the Checkbook system. Flexibility to meet sudden work requirements and command interest work was reported to be the primary advantage of the Engineering Judgment system. "It 'satisfies the boss,' the Installation Commander," was reported to be the primary advantage of the Command Driven System. Frequency counts for the other WO ranking methods were not high enough to identify consensus on a category.

Table 31.

The Reported Strongest Advantage of Respondents' Current Prioritizing Methods Grouped Into Similar Subject Areas

Advantage	Frequency Count: Check-book	Base Panel	Weight-ing	BCE Panel	Engr Judg	Cmd Driven	Row Total
DCS participation	15	3	-	1	-	-	19
Satisfaction	8	3	1	2	-	-	14
Participation	12	1	-	-	-	-	13
Flexible	1	-	-	1	7	2	11
Satisfies boss	-	1	-	-	2	7	10
Visible	2	-	1	3	1	1	8
CE sets priorities	1	-	-	3	3	-	7
Equitable	1	2	-	1	3	-	7
Effective	-	2	-	-	2	-	4
Quota	-	1	-	1	2	-	4
It works	1	-	-	2	-	-	3
Time savings	2	-	-	-	1	-	3
DE involvement	-	-	-	-	2	-	2
None	1	-	-	-	1	-	2
CC dominance	-	1	-	-	-	-	1
Communication	1	-	-	-	-	-	1
Planning	-	-	-	-	-	1	1
Minimizes insertions	1	-	-	-	-	-	1

Survey question 65 asked the respondents to list the primary disadvantage of their work order prioritizing systems. The answers were grouped into similar categories and presented in Table 32. Results indicated there is no consensus for any particular category for any of the rank ordering methods. However, comparison of Tables 31 and 32 reveals that an advantage reported by one respondent is reported as a disadvantage by another respondent. For example: participation, satisfaction, equitable, and effective are listed as advantages; while discourages participation, dissatisfaction, inequitable, and ineffective

Table 32.

The Reported Primary Disadvantage of Respondents' Current Prioritizing Methods Grouped Into Similar Subject Areas

	Frequency Count						
Advantage	Check-book	Base Panel	Weight-ing	BCE Panel	Engr Judg	Cmd Driven	Row Total
None	6	-	-	2	3	-	11
Inequitable	3	1	-	-	3	3	10
Infrastructure suffers	2	4	-	1	-	3	10
Insertions	4	-	1	1	3	1	10
Backlog grows	4	1	-	1	-	1	7
Priorities vary	4	1	-	-	2	-	7
Gaming	4	1	-	-	1	-	6
Dissatis-faction	1	-	-	1	3	1	6
Manpower to manage	5	-	-	-	1	-	6
CC dominance	2	-	-	-	3	-	5
Masks backlog	3	1	-	-	-	-	4
Ineffective	1	2	-	1	-	-	4
Lacks visibility	-	1	-	-	2	-	3
Discourages participation	-	-	-	2	-	-	2
No planning	1	-	-	1	-	-	2
Too liberal	-	-	-	1	1	-	2
DE involvement	1	-	-	-	1	-	2
Doesn't work	-	-	-	-	1	-	1
No control	-	-	-	-	-	1	1
Inflexible	-	-	-	1	-	-	1
New system	1	-	-	-	-	-	1
Not computerized	-	1	-	-	-	-	1
Politics	-	-	-	-	-	1	1
Validity uncertain	-	-	1	-	-	-	1

are listed as disadvantages. The same dichotomy exists for responses between different systems. This dichotomy of responses is not disturbing. In fact, since this study is dealing with opinions, a diversity of perceptions on the same subject is expected.

To summarize the findings for research question 4, significant differences have been found on the opinions of respondents for survey questions 42, 43, 47, 48, 51, 52, 57, 58, and 60. In general, the mode responses to the opinion gathering survey questions 40 through 63 were the same across all WO ranking methods. In addition, responses to several categories shown in Table 31 indicate a consensus of opinion concerning advantages of the Checkbook, Engineering Judgment, and Command Driven methods. No consensus of opinion concerning disadvantages of the WO ranking methods could be identified in Table 32.

Research Question 5

What common features exist among the reported strengths and weaknesses of the current system?

The common features that exist among the reported strengths and weaknesses of the current systems discussed below are based on the researcher's analysis of open ended questions, personal and telephone interviews conducted to develop the survey questionnaire, and frequency distributions found in Chapter IV. Only the reported common strengths will be discussed in this section. However, since the absence of a common strength in a system would indeed be a weakness, the issue of common weaknesses is sufficiently covered.

One common feature is the concept of allocating a set number of manhours or work orders to organizations, a quota. Setting a work order quota is a central element of the Checkbook system and reported by 46 respondents to be used by their base. Below is a summary of the respondents' reported use of work order quotas:

Work Order Prioritizing System	Frequency Count (percent)
Checkbook	29 (65.9)
Base Panel	4 (25.0)
Weighting	1 (50.0)
BCE Panel	4 (25.0)
Engineering Judgment	4 (16.0)
Command Driven	4 (30.8)

Several benefits can be realized through the use of quotas: first, aggregate planning, the process of devising a plan for providing a productive capacity scheme to support work order requirements, can be enhanced by the steady, relatively nonchanging, work load provided by quotas. Second, greater customer satisfaction can be achieved since each organization can count on having its quota of work completed each month. Finally, limiting the number of work orders to a manageable size prevents system overload and the inefficiencies overload can cause. One disadvantage of quotas is they prevent Civil Engineering from accurately tracking the work backlog.

A second common feature is the use of the Air Force hierarchical structure to give commanders the authority to aggregate, scrutinize, validate, and prioritize work orders for organizations within their Directorate. Responses to survey question 60 indicated 31 percent of the respondents "Strongly Agreed" with the statement their system "gives DCS primary responsibility for determining WO priorities." This feature not only gives the commanders more control over their own work order priorities, but it also frees civil engineering Operations management to concentrate on other Production & Operation issues.

A third common feature is the characteristic of progressively making it more difficult to change work order priorities as the work order moves through various stages in the work order processing system, closing in on the start of work. In the development of a master production schedule (MPS), in Production & Operations management,

> . . . the early weeks are understood to be frozen, the middle weeks are described as firm, and the later weeks are said to be full or open. The early weeks are frozen so that production departments can depend on this portion of the plan to the extent that material can be ordered, personnel can be scheduled to work, and machine changeovers can be scheduled to support the MPS. If the early weeks of the MPS were allowed to be changed, material orders, personnel work schedules, and machine changeover schedules would also need to be changed. Such changes cause chaos in production departments and material control departments (16:513).

This frozen character applies when setting a policy concerning the ability to change work order priorities and must be observed to allow for rational and systematic acquisition of material flows to support civil engineering's In-Service-Work Plan. Several respondents using the Checkbook, Corporate Base Panel, and Engineering Judgment systems reported using the Top 5, Top 10, or Top 20 work orders in backlog to create a frozen block of work orders as described above.

A fourth common feature is the built-in flexibility of the work order priority system to quickly react to urgent, unexpected work requirements. With a response of 73 or 63.5 percent of the respondents, the question addressing system flexibility received the highest response frequency of survey questions 40 through 63. These results emphasize the importance of a flexible system.

A fifth common feature is the system must be transparent to both operators and users. Coupled with the ease of understanding is the need to regularly publish the work order priority list for all to see.

Table 19 shows that 41 respondents or 35.7 percent "Agreed" their system "Provides 'visibility' through publication and distribution of priority listings to customers." Table 27 shows that most systems publish a work order priority listing monthly. In addition, 58 respondents or 51.3 percent stated their system is "Simple to use." Thus, this research supports incorporation of the common features of transparency and visibility into a work order prioritizing system.

The last common feature to be discussed is the idea that in the operational environment, very few situations exist where the work order prioritizing system is a purebred as described in Chapter IV. As reported in each of the specific system profiles in Chapter IV, most prioritizing systems are a combination or blend of two or more of the six prioritizing methods. Thus, the reader can expect to find features of various systems in use at most civil engineering organizations.

The above common features that exist among reported strengths of current systems is not an exhaustive list. However, when evaluating a particular work order prioritizing system, the decision maker should include these features as important elements to consider.

Research Question 6

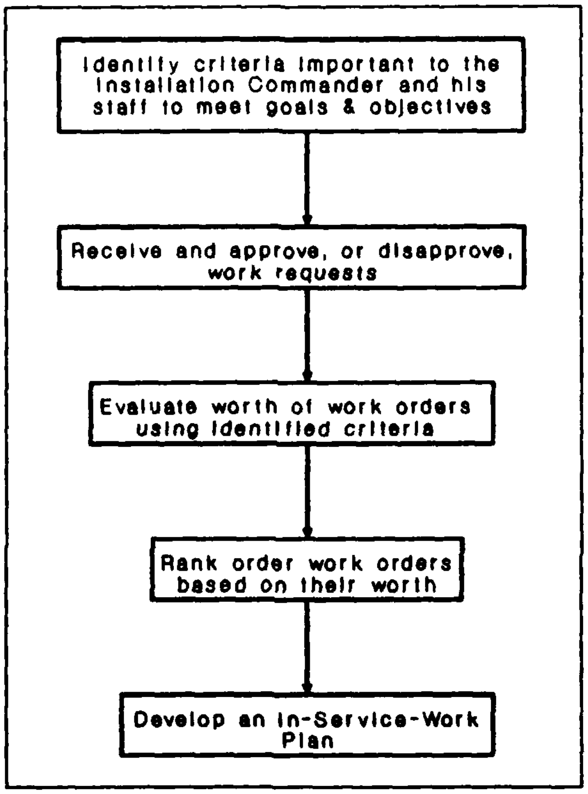
> **Having identified the commonalities among the current systems, what is required to combine the best features or strengths into a generic priority method that will avoid repeating the reported shortcomings?**

This research question is really a two-part question: First, is there a method to prioritize work orders that can be used by civil engineering Air Force-wide? Second, can an analytical technique be found that will aid the decision maker in the determination of work order priorities?

This research has shown there is no unanimous method of prioritizing work orders being used by the Air Force within the Continental United States. In addition, given the diversity of base operating characteristics and given the diversity of the work order prioritizing methods used, it seems unlikely any single prioritizing method would evolve naturally. It is equally reasonable to assume that the requirement to implement any one method Air Force-wide would cause the majority of bases to change the procedures they now use.

Nevertheless, the Checkbook system has been found to be the most frequently used work order ranking method of the six identified by this study. Also, this study has shown that in general the mode responses to opinion-gathering survey questions 40 through 63 concerning system advantages and disadvantages were the same across all WO ranking methods. Thus, Checkbook users reported at least the same level of agreement concerning system advantages/disadvantages, and felt stronger than the other respondents that their system ensures equity, easily permits users to change priorities, limits the number of WOs to a manageable size, and allows the users to set their own priorities. Additionally, the Checkbook system embodies the common strengths of transparency, visibility, flexibility, permitting CE to consolidate requests by directorates, using WO quotas, and allowing CE to freeze WOs as identified in research question five. For the above reasons, the Checkbook method will be used to determine whether the work order prioritizing model developed in Chapter II can be used to aid the decision maker in the determination of work order allocations.

As presented in Chapter II and shown below in Figure 4, the first task in the work order prioritizing model is to identify the criteria important to the Installation Commander and his staff to meet established goals and objectives.



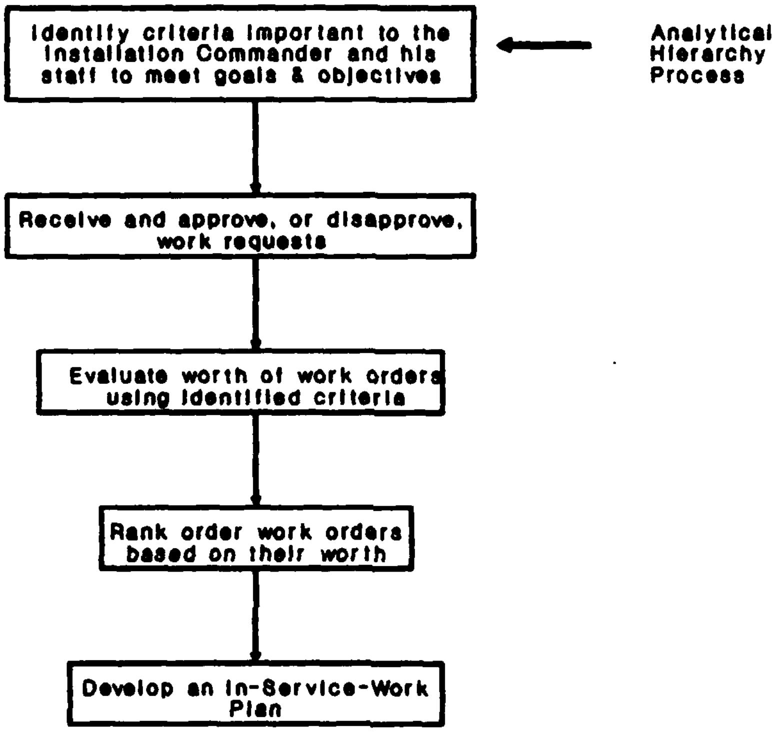
Reprint of Figure 4. Work Order Decision Flow Model

Next, Civil Engineering validates the work requests by determining if each is a valid requirement and a BCE responsibility. After having approved the request for in-service accomplishment, the next decision task is to evaluate the worth of the work order using the identified criteria. Then a rank ordered list is developed based on the worth assessments. Finally, CE develops an In-Service Work Plan for accomplishment of the work orders in the order given by the work order priority list.

It is well known that problem definition is one of the most difficult and yet important tasks in the problem solving process. For the problem of how to fairly allocate work orders, identifying and weighting criteria is the most difficult and important task. The criteria identified to measure the worth of work orders determines how successful CE will be in meeting the Installation Commander's goals and objectives since it drives everything that occurs beyond step one in the rank ordering process shown in Figure 4. Analysis of the literature in Chapter II leads to the conclusion that the Analytical Hierarchy Process is well suited to aid in the important decision of identifying criteria used to order priorities and determine what criterion outweighs another.

To demonstrate the utility of the AHP in the work order ranking problem, the next section will show how the AHP can be used to aid in the work order allocation decision users of the Checkbook system must make. For purposes of illustration, the example will posit a typical medium size TAC installation with one wing and a tri-deputate command structure.

As described in the survey questionnaire and Chapter IV, the Checkbook method allocates work orders or manhours to each organization or directorate for their use, similar to distributing a sum of money among different bank accounts. Thus, civil engineering must determine how to allocate available in-service manhours among the directorates it serves. This decision task is equivalent to the task of "Identifying criteria important to the Installation Commander and his staff to meet goals and objectives." As discussed above, and as shown below in the reprint of figure 11, this is the decision the AHP can aid the decision maker in making.



The Analytical Hierarchy Process can aid the decision maker in allocating work orders or in-service manhours among the directorates. The following section will explain step-by-step how the Analytical Hierarchy Process serves this purpose.

<u>Application of Decision Model to the Checkbook Method</u>.

<u>Step 1</u>. Define the problem and determine what you want to do. For example, on a TAC installation the Installation Commander may simply state his goal to "fairly allocate work orders among my directorates."

Step 2. Break down the decision problem of how to allocate work orders into a hierarchy with each level consisting of a few manageable elements. There are no inviolable rules for constructing hierarchies. However, here are some general guidelines from one successful implementer of the AHP:

- Each set of elements occupies a level of the hierarchy.
- The focus or top level consists of only one element--the broad overall objective.
- Subsequent levels may each have several elements, although their number is usually small (between five and nine).
- Elements in each level must be of the same order of magnitude (35:28).

When constructing a hierarchy where the goal is to fairly allocate resources (work orders) among the alternatives (directorates) the next step is to place the names of the directorates on the bottom level, level three in this example: Under a Tri-deputate command structure, the directorates would normally include a Deputy Commander of Operations (DCO), a Deputy Commander of Maintenance (DCM), a Combat Support Group Commander (CSG), a Deputy Commander of Resources (DCR), the USAF Hospital Commander (H), all tenants combined (T), and the Civil Engineering Commander (BCE). Although not a directorate, civil engineering has been separated from the CSG to permit the BCE to perform the functions of maintaining and repairing the base infrastructure independent of the CSG.

The next level, level two in this example, consists of the criteria for judging the alternatives or basing the allocations on and might include

- contribution to the base mission,
- directorate size,
- facilities occupied by the directorate, (include only facilities with condition code 1-3 as defined in AFM 300-4, Volume 1),
- and directorate work order history over the past three years.

In effect, the criteria are those things the decision maker thinks are important to consider when allocating work orders. Figure 15 below illustrates a hierarchy with the last two levels in place.

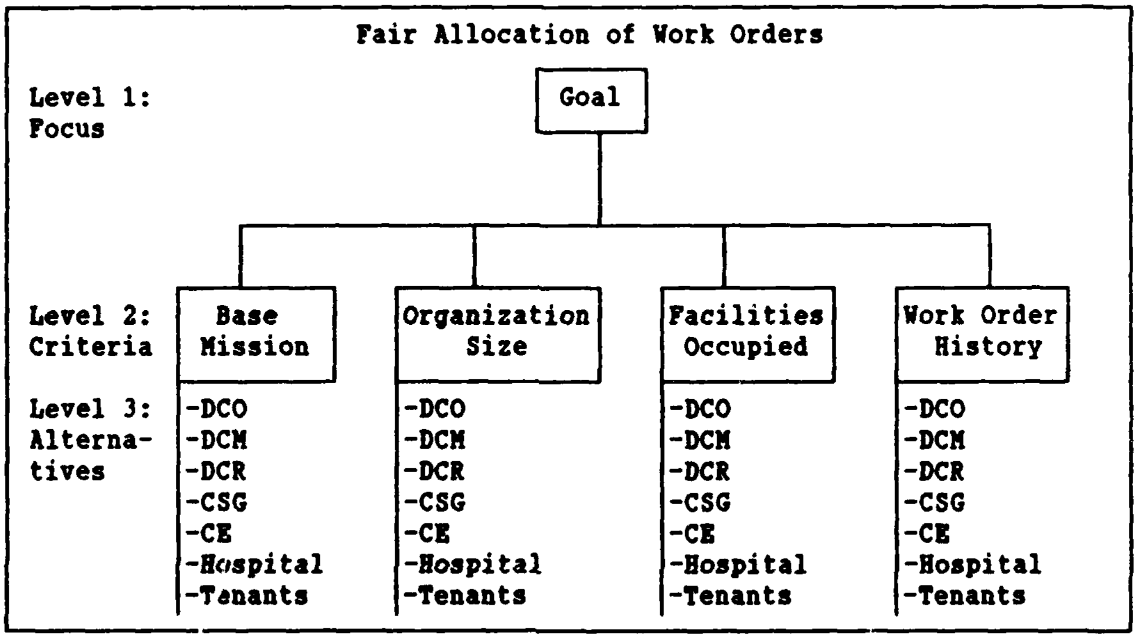


Figure 15. Hierarchy for Fair Allocation of Work Orders

At the top level, level one, is a single element, the focus or overall purpose of "allocating work orders fairly," in terms of which the criteria can be compared according to the importance of their contribution. Figure 15 shows the hierarchical tree with all three levels of this example in place.

<u>Step 3</u>. The third step in the AHP is to collect input data by pairwise comparisons of decision elements. This is done by constructing a set of pairwise matrices for each of the lower levels--one matrix for each element in the level immediately above. Starting at the top of the hierarchy, select the criterion to be used for making the first

comparison. Referring to Figure 15, the top element of the hierarchy is the goal of fairly allocating work orders. Then, take the elements to be compared from the level immediately below, level two, and arrange them in a square matrix as shown below in Table 33.

Table 33.

Matrix for Pairwise Comparison of Criteria Used to Allocate WOs

Allocate WOs Fairly	B	O	F	W
B: Base Mission	1	1	1/2	1/3
O: Org. Size	1	1	1/2	1/3
F: Facilities	2	2	1	1/2
W: WO History	3	3	2	1
Column Totals	7	7	4	2.167

Numbers are used to fill in the matrix of pairwise comparisons. Each number represents the relative importance of one element over another with respect to the property. Table 5, shown in Chapter II and reproduced below, provides the scale for pairwise comparisons. In the matrix, the elements in the column on the left are compared to the elements in the top row with respect to the property in the next higher level (fair allocation of WOs). "To compare elements, ask: How much more strongly does this element (or activity) possess--or contribute to, dominate, influence, satisfy, or benefit--the property than does the element with which it is being compared" (35:77)?

Always compare the first element of a pair (the element of the left hand column) with the second (the element in the top row) and estimate the numerical value from the scale in Table 5.

Reprint of Table 5.

The Pairwise Comparison Scale (35:78)

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the property
3	Slight importance of one element over another	Experience and judgement slightly favor one element over another
5	Essential or strong importance of one element over another	Experience and judgment strongly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above non-zero numbers	If an activity has one of the above numbers assigned to it when compared with a second activity, then the second activity has the reciprocal value when compared to the first.	

To illustrate completion of a matrix, Table 33 shows that when using the criteria of "Fair Allocation of WOs," "WO History" is slightly more important than "Base Mission." Thus, the value of 3 is entered in row 4, column 1. To perform the comparison between "WO History" and "Base Mission," the decision maker would ask how much more strongly does the element of "WO History" influence the "Fair Allocations of WOs" than does the element of "Base Mission"?

The reciprocal value is used for the comparison of the second element with the first. Thus, in Table 33, the value of 1/3 is entered in row 1, column 4 for the comparison of "Base Mission" to "WO History." If the elements being compared are equal, a one is assigned to both positions. The comparison of one element in a matrix with itself--for example, "Facilities" in Table 33--must give unity (1). Therefore, the diagonal of the square matrix will always be 1s.

Referring to Table 33, the first step in determining the criteria priorities or weights for each matrix is to add the values in each column. Next, normalize the matrix to permit meaningful comparison among elements, by dividing each entry in each column by the total of that column. For example, divide each entry in the "B" column of Table 33 by the column total of 7. Finally, average across each row of the normalized matrix by adding the column values in each row and dividing by the number of entries. Thus, the "Base Mission" priority value or weight would be calculated as follows:

$$\frac{1/7 + 1/7 + 1/8 + 2/13}{4} = 0.1411$$

Table 34 shows the normalized pairwise comparison matrix with respect to the focus of allocating work orders among the directorates. The last column gives the priority vector. In Table 34, work order history turns out to be the most important criterion, followed by facilities occupied by the directorates. Next, four matrices must be developed for comparing the seven directorates with respect to each of the four criteria: base mission, organization size, facilities occupied,

Table 34.

Normalized Matrix Used to Determine Criteria Weights

Allocate Work Orders Fairly	B	O	F	W	Priority Vector (eigenvector)
B: Base Mission	1/7	1/7	1/8	2/13	0.1411
O: Org. Size	1/7	1/7	1/8	2/13	0.1411
F: Facilities	2/7	2/7	1/4	3/13	0.2631
W: WO History	3/7	3/7	1/2	6/13	0.4547

and work order history. Table 35 shows these matrices and the resulting priority vectors.

Step 4. When judgments are provided by others, obtain and synthesize all judgments required to develop the set of matrices in step 3. An appropriate group decision process could be used to obtain a base *corporate agreement* on the judgments. There are n(n-1)/2 judgments required to develop the set of matrices in step three. Values representing the researcher's judgments, shown in Tables 33 and 35 are for illustrative purposes only and do not represent findings based on a survey.

Judgments on the relative importance of each element in the hierarchy will be made by officers who are knowledgeable about their installation, organization missions, needs of the organizations and in the case of CE officers, infrastructure needs. However, as Saaty points out, even experts can make mistakes in setting up a hierarchy or discriminating between pairs of elements to judge priorities. "The AHP tests the consistency of judgments; too great a departure from the perfectly consistent value indicates a need to improve the judgments or

Table 35.

Four Matrices for Comparing Seven Directorates

Base Mission	DCO	DCM	CSG	CE	DCR	H	T	Priority Vector (eigenvector)
DCO	1	3	4	4	4	5	6	0.368
DCM	1/3	1	3	3	3	4	5	0.223
CSG	1/4	1/3	1	1	1	3	4	0.107
CE	1/4	1/3	1	1	1	3	4	0.107
DCR	1/4	1/3	1	1	1	3	4	0.107
H: Hospital	1/5	1/5	1/3	1/3	1/3	1	3	0.055
T: Tenants	1/6	1/5	1/4	1/4	1/4	1/3	1	0.033
lambda max								7.353
Consistency Index (C.I.)								0.059
Consistency Ratio (C.R.)								0.045

Organization Size	DCO	DCM	CSG	CE	DCR	H	T	Priority Vector (eigenvector)
DCO	1	1/3	1/3	3	3	3	1	0.133
DCM	3	1	2	6	6	6	3	0.357
CSG	3	1/2	1	3	3	3	2	0.211
CE	1/3	1/6	1/3	1	1	1	1/3	0.054
DCR	1/3	1/6	1/3	1	1	1	1/3	0.054
H: Hospital	1/3	1/6	1/3	1	1	1	1/3	0.054
T: Tenants	1	1/3	1/2	3	3	3	1	0.138
lambda max								7.141
Consistency Index (C.I.)								0.024
Consistency Ratio (C.R.)								0.018

Facilities Occupied	DCO	DCM	CSG	CE	DCR	H	T	Priority Vector (eigenvector)
DCO	1	1/2	1/3	1/7	1/3	5	1/2	0.056
DCM	5	1	3	1/3	3	7	3	0.218
CSG	3	1/3	1	1/2	1	5	2	0.108
CE	7	3	5	1	5	9	6	0.417
DCR	3	1/3	1	1/2	1	5	2	0.108
H: Hospital	1/2	1/7	1/5	1/9	1/5	1	1	0.031
T: Tenants	2	1/3	1/2	1/7	1/2	1	1	0.060
lambda max								7.519
Consistency Index (C.I.)								0.086
Consistency Ratio (C.R.)								0.065

Continued

Table 35.

Four Matrices for Comparing Seven Directorates (contd)

Work Order History	DCO	DCM	CSG	CE	DCR	H	T	Priority Vector (eigenvector)
DCO	1	1/3	1/3	1/7	1	3	1	0.064
DCM	3	1	1	1/5	3	5	3	0.154
CSG	3	1	1	1/2	3	5	3	0.154
CE	7	5	5	1	7	9	7	0.477
DCR	1	1/3	1/3	1/7	1	3	1	0.064
H: Hospital	1/3	1/5	1/5	1/9	1/3	1	1	0.035
T: Tenants	1	1/3	1/3	1/7	1	1	1	0.053
lambda max								7.240
Consistency Index (C.I.)								0.040
Consistency Ratio (C.R.)								0.030

to restructure the hierarchy." (35:16) Saaty goes on to further explain the concept of consistency:

> The consistency is perfect if all the judgments relate to each other in a perfect way. If you say that you prefer spring to summer three times more and that you prefer summer to winter twice more, then when you give the judgment comparing your preference of spring to winter it should be six and not anything else. The greater your deviation from six, the greater your inconsistency. This observation applies to relations among all the judgments given. We would have perfect consistency, then, if all the relations checked out correctly (35:16).

The AHP measures the overall consistency of judgments by means of a consistency ratio (C.R.). The value of the consistency ratio should be 10 percent or less. If it is greater than 10 percent, the judgments may be somewhat random and should be revised or the problem should be more accurately structured by grouping similar elements under more meaningful criteria (35:16).

<u>Step 5</u>. Having made all the pairwise comparisons and entered the data, the consistency index (C.I.) and consistency ratio (C.R.) are

computed for each judgment matrix of each hierarchical level. To determine the C.R., the consistency index for each matrix must be computed. To calculate the C.I., first multiply the judgment values contained within the matrix by the column of priorities (eigenvector). For example, the entry in row one, column one of Table 36 was determined by multiplying the value judgment of 1 (Table 33, row one, column one) times the column priority of 0.1411 (Table 34, Base Mission):

$$(1) \times (0.1411) = 0.1411$$

Next, total the entries for each row (Table 36, Row Totals). Then divide each of the row totals in the column by the corresponding entry from the priority vector, shown in the column headings. This yields the new column of Row Total/Priority Vector. Now average the Row Total/Priority Vector column to obtain lambda max:

$$\text{lambda max} = \frac{4.004 + 4.006 + 4.010 + 4.020}{4} = 4.0104$$

Table 36.

Determining the Degree of Inconsistency

Fair Allocation of Work Orders	B (0.141)	O (0.141)	F (0.263)	W (0.455)	Row Totals	(Row Total)/(Pri Vector)
Base Mis.	1(0.141)	+1(0.141)	+1/2(0.263)	+1/3(0.455)	= 0.57	0.57/0.141
Org. Size	1(0.141)	+1(0.141)	+1/2(0.263)	+1/3(0.455)	= 0.57	0.57/0.141
Fcltys	2(0.141)	+2(0.141)+	1(0.263)	+1/2(0.455)	= 1.05	1.05/0.263
WO History	3(0.141)	+3(0.141)+	2(0.263)+	1(0.455)	= 1.83	1.83/0.455
Column Total						16.041
Lambda max (n = 4) = 16.041/4 =						4.010
Consistency Index = (4.010 - 4)/(4 - 1) =						0.003
Consistency Ratio = 0.004/0.9 =						0.004

Then, the consistency index is calculated as follows:

$$C.I. = \frac{\text{lambda max} - n}{n - 1} = \frac{4.0104 - 4}{4 - 1} = 0.0035$$

The consistency index of a randomly generated reciprocal matrix from the scale of 1 to 9, with reciprocals forced, is called the random index (R.I.). The ratio of C.I. to R.I. for the same order matrix is called the consistency ratio (C.R.). As stated earlier, a C.R. of 0.10 or less is considered unacceptable. A short table of R.I. follows:

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The R.I. for n = 4 is 0.90. Thus, the consistency ratio for level one of the hierarchy is 0.0035/0.90 = 0.0038, which indicates good consistency. Table 36 summarizes the results for determining the degree of inconsistency for level one of the hierarchy.

<u>Step</u> <u>6</u>. Steps 3, 4, and 5 are performed for all levels and clusters in the hierarchy. Table 35 summarizes the results for determining the degrees of inconsistency for level two of the hierarchy.

<u>Step</u> <u>7</u>. Hierarchical composition is now used to weight the priority vectors by the weights of the criteria, and the sum is taken over all weighted priority vectors entries corresponding to those in the next lower level of the hierarchy.

For this example of determining how to fairly allocate work orders among the directorates, all seven entries in the priority vector column (Table 35) obtained in each of the four matrices are multiplied (weighted) by the priority of the corresponding criterion. These values are shown in Table 37.

Table 37.

Determining the Overall Priorities

	Base Mission (0.141)		Organization Size (0.141)		Facilities Occupied (0.263)		Work Order History (0.454)		Vector of Overall Priorities
DCO	0.141(0.368)	+	0.141(0.133)	+	0.263(0.056)	+	0.455(0.064)	=	0.115
DCM	0.141(0.223)	+	0.141(0.357)	+	0.263(0.218)	+	0.455(0.154)	=	0.209
CSG	0.141(0.107)	+	0.141(0.211)	+	0.263(0.108)	+	0.455(0.154)	=	0.143
CE	0.141(0.107)	+	0.141(0.054)	+	0.263(0.417)	+	0.455(0.477)	=	0.349
DCR	0.141(0.107)	+	0.141(0.054)	+	0.263(0.108)	+	0.455(0.064)	=	0.080
H	0.141(0.055)	+	0.141(0.054)	+	0.263(0.031)	+	0.455(0.035)	=	0.039
T	0.141(0.033)	+	0.141(0.138)	+	0.263(0.060)	+	0.455(0.053)	=	0.064
Total								=	1.0

The results of this operation are then added to yield the overall priorities for the directorates, which can be used as percentages for allocation of available work orders or manhours: DCO = 11.5 percent, DCM = 20.9 percent, CSG = 14.3 percent, CE = 34.9 percent, DCR = 8.0 percent, the Hospital = 3.9 percent, and tenants = 6.4 percent.

<u>Step 8</u>. The consistency of the entire hierarchy is found by multiplying each consistency index by the priority of the corresponding criterion and adding the results together. The sum is then divided by the same type of expression using the random consistency index corresponding to the dimensions of each matrix weighted by the priorities as before. Thus, the overall consistency of the hierarchy is given by:

$$\frac{0.003(1) + 0.059(0.141) + 0.024(0.141) + 0.086(0.263) + 0.040(0.455)}{0.9(1) + 1.32(0.141) + 1.32(0.141) + 1.32(0.263) + 1.32(0.455)}$$

for a consistency ratio of 0.025, which indicates good consistency. Table 38 shows the consistency indexes, composite priorities, and random indexes determined previously that are used to determine the hierarchy consistency ratio calculated above.

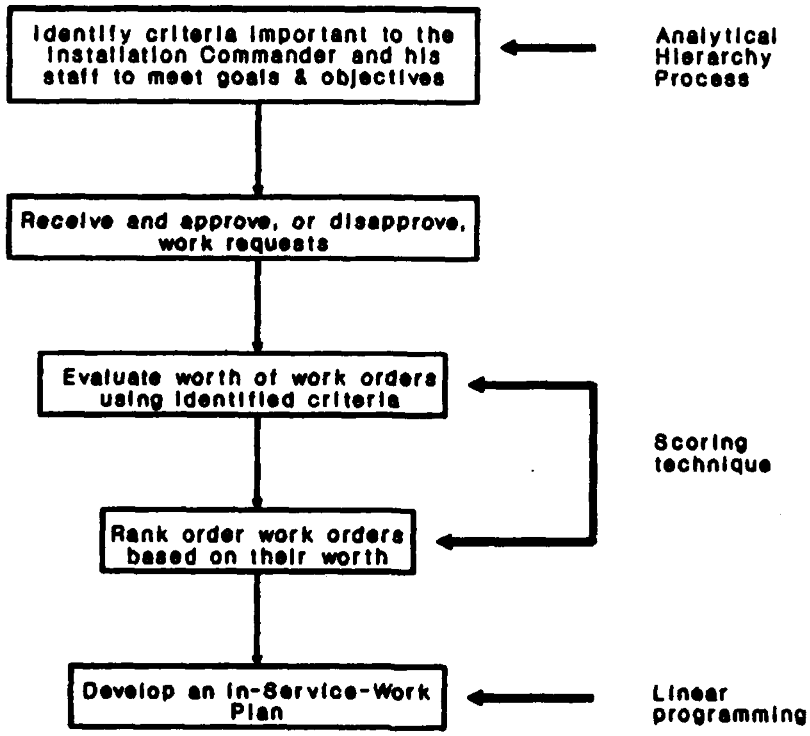
Table 38.

Determining the Hierarchy Composite Ratio

Criterion	(A) C.I.	(B) Composite Priority	(C) R.I.	A x B	C x B
Level One	0.003	1.0	0.90	0.003	0.90
Level Two					
Base Mission	0.059	0.141	1.32	0.008	0.186
Org Size	0.024	0.141	1.32	0.003	0.186
Facilities	0.086	0.263	1.32	0.023	0.347
WO History	0.040	0.455	1.32	0.018	0.600
Total				0.056	2.220
Hierarchy Composite Ratio (C.R.) = 0.056/2.220 = 0.025					

<u>Application of Decision Model to the Other Prioritizing Methods</u>. For those who prefer to continue using a work order prioritizing method other than the Checkbook method, the model developed in Chapter II and shown below can be used to aid the decision maker in determining work order priorities by providing a prioritized first cut list.

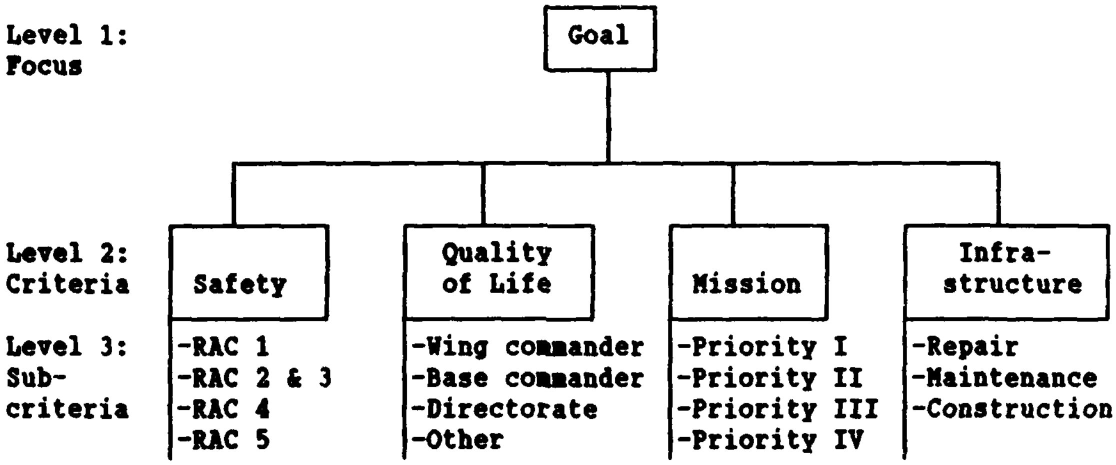
Similar to the Checkbook WO allocation problem, when used to rank order WOs the AHP provides a vehicle for the decision maker(s) to



identify criteria important to the Installation Commander and his staff to meet goals and objectives. For criteria identified by the decision maker(s), the AHP also calculates coefficients <u>for use by the scoring technique</u> to measure the relative "worth" of each work order in the form of a composite work order score. Finally, the "strawman" prioritized list can be assembled by sorting on the composite work order scores.

To see how this process works, consider a BCE on the same TAC installation as described earlier; this time the BCE is using one of the other five methods though. Figure 10, shown in Chapter II and reproduced below, shows how the BCE might structure the elements of the problem and arrange them in a hierarchy when identifying criteria and determining the priorities to be <u>used as coefficients</u> in the scoring technique.

Best Use of Resources



Level 1, the focus, is the best use of resources. Level 2 comprises the criteria that contribute to best use of resources and includes elimination of safety hazards; improvements in the quality of life; contribution to the base mission; and maintenance, repair, and improvement of the base infrastructure. Level 3 consists of the subcriteria to be used as coefficients in the scoring technique and are explained below:

- Subcriteria used for "Safety" are the risk assessment codes (RAC) 1-5 as explained in AFR 127-12 or fire safety deficiency codes (FDSC) I-III explained in AFR 92-1.

- Subcriteria used for "Quality of Life" provides a means to account for the level of senior management support a work order might have.

- Subcriteria used for "Mission" reflect the contribution a work order has in support of the base mission and uses the description of work order priorities I-IV as explained in AFR 85-1 and chapter IV, pages 58-59.

- Subcriteria used for "Infrastructure" permits emphasis to be placed on civil engineering's primary mission of maintaining and repairing the base infrastructure.

Note that an element in a given level does not have to function as a criterion for all the elements in the level below. Thus a hierarchy can be divided into subhierarchies sharing only a common topmost element. Each element in a level is evaluated in terms of all the elements in the next higher level (35:36).

Once the hierarchy is in place, the next step is to compare the level 2 criteria in pairs with respect to best use of resources and judge the relative importance of each criterion. In this hypothetical example, the decision maker judged that mission was slightly more important than infrastructure in contributing to best use of resources, and was moderately more important than safety. Table 39 shows the pairwise comparison matrix of the criteria with respect to the focus. The last column gives the priorities: Mission turns out to be the most important criterion, followed by infrastructure and quality of life.

Table 39.

Best Use of Resources

Best Use of Resources	M	I	Q	S	Priority Vector (eigenvector)
M: Mission	1	2	1/2	3	0.424
I: Infrastructure	1/2	1	1	2	0.227
Q: Quality of Life	1/2	1	1	2	0.227
S: Safety	1/3	1/2	1/2	1	0.122

Next, four matrices for comparing the subcriteria of level three with respect to the criterion of level two are developed (Table 40). All entries in the vector of priorities obtained in each of the four matrices and listed in the last column of each matrix are multiplied (weighted) by the priority of the corresponding criterion. The results

Table 40.

Four Matrices for Comparing Subcriteria

Mission	I	II	III	IV	Vector of Priorities
I: Priority I	1	2	3	5	0.463
II: Priority II	1/2	1	3	4	0.313
III: Priority III	1/3	1/3	1	3	0.152
IV: Priority IV	1/5	1/4	1/3	1	0.071
Infrastructure	**M**	**R**	**C**		**Vector of Priorities**
M: Maintain	1	1/2	3		0.333
R: Repair	2	1	3		0.528
C: Construct	1/3	1/3	1		0.140
Quality of Life	**W**	**B**	**D**	**O**	**Vector of Priorities**
W: Wing Commander	1	2	3	4	0.467
B: Base Commander	1/2	1	2	3	0.277
D: Directorate	1/3	1/2	1	2	0.160
O: Other Commander	1/4	1/3	1/2	1	0.095
Safety	**RAC 1**	**RAC 2&3**	**RAC 4**	**RAC 5**	**Vector of Priorities**
Risk assessment code 1	1	3	5	7	0.565
Risk assessment code 2&3	1/2	1	2	3	0.262
Risk assessment code 4	1/3	1/2	1	2	0.118
Risk assessment code 5	1/4	1/3	1/2	1	0.055

(Table 41) are weighted subcriteria that can be used as the coefficients in the scoring technique.

Once criteria has been identified and weighted, a raw work order score is determined by assigning a score of "1" to WOs possessing a criterion characteristic and a score of "0" to WOs not possessing the criterion characteristic. The raw work order score is then multiplied by the criterion importance score determined previously using the AHP to

Table 41

Determining the Overall Priorities for Subcriteria

Subcriteria	Mission (0.424)	infrastructure (0.227)	Quality of Life (0.227)	Safety (0.122)	Vector of Overall Priorities
Priority I	0.424(0.463)				= 0.196
Priority II	0.424(0.313)				= 0.133
Priority III	0.424(0.152)				= 0.064
Priority IV	0.424(0.071)				= 0.030
Maintenance		0.227(0.333)			= 0.120
Repair		0.227(0.528)			= 0.075
Construction		0.227(0.140)			= 0.032
Wing Commander			0.227(0.467)		= 0.106
Base Commander			0.227(0.277)		= 0.063
Directorate			0.227(0.160)		= 0.036
Other Commander			0.227(0.095)		= 0.022
RAC 1				0.122(0.565)	= 0.069
RAC 2 & 3				0.122(0.262)	= 0.032
RAC 4				0.122(0.118)	= 0.014
RAC 5				0.122(0.055)	= 0.007
Total					= 1.000

obtain a criterion score. Finally, criterion scores are added to obtain the work order composite score used to rank order WOs.

In this example, WIMS could be programmed to actually assign the value of "1" or "0" for each criterion based on information entered by the Production Control Specialist as he entered the work order data into the computer. WIMS would then be programmed to perform the calculations as described above to determine the work order composite score. Table 42 shows how the work order composite score would be determined for a hypothetical work order requested by the Base Commander to construct a wall dividing his secretary's room into a waiting room and an administrative space.

Table 42.

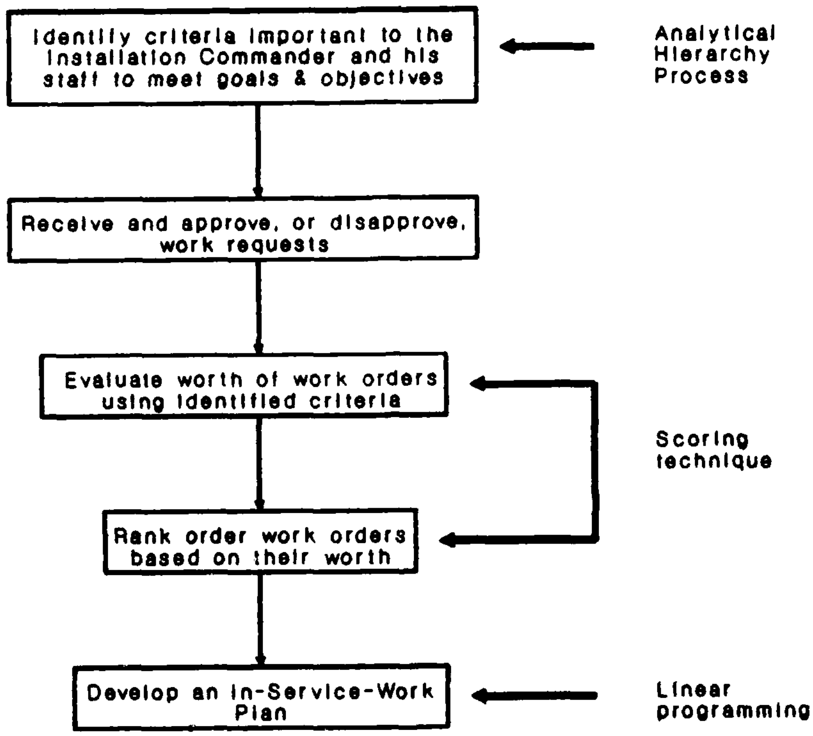
Calculation of a Composite Work Order Score Using the Scoring Method

Criteria	Project Score		Criterion Weight		Criterion Score
Priority I	0	x	0.196	=	0.000
Priority II	0	x	0.133	=	0.000
Priority III	0	x	0.064.	=	0.000
Priority IV	1	x	0.030	=	0.030
Maintenance	0	x	0.120	=	0.000
Repair	0	x	0.075	=	0.000
Construction	1	x	0.032	=	0.032
Wing CC	0	x	0.106	=	0.000
Base Commander	1	x	0.063	=	0.063
Directorate	0	x	0.036	=	0.000
Other Commanders	0	x	0.022	=	0.000
RAC 1	0	x	0.069	=	0.000
RAC 2 & 3	0	x	0.032	=	0.000
RAC 4	0	x	0.014	=	0.000
RAC 5	0	x	0.007	=	0.000
Composite Work Order Score				=	0.095

For convenience, the composite scores could be multiplied by 1000, resulting in a composite score of 95 for this work order. After the program described above has been developed and loaded into WIMS, and all work order records have been entered, the first cut prioritized work order list can be developed by instructing the computer to sort the values in the composite work order score field and list them in descending numerical order.

Model Application Overview. Having examined the mathematical operations of the Analytical Hierarchy Process, it will be useful to step back outside the technique to gain a broader perspective. From within the process, the mathematics seem complex and time consuming. However, software has already been developed for micro computers that automates the AHP calculations, so that the math is transparent to the user.

A review of the model developed in Chapter II for rank ordering work orders will help connect the potential value of the AHP to the rank ordering decision process.



At implementation, the decision makers must tackle the most difficult task of identifying criteria that are important to consider when allocating or actually rank ordering work orders. These criteria must support the goals and objectives important to the Installation Commander and his staff. It is important to note that the task of identifying these criteria is essentially a one-time requirement. Once the task has been completed, a simple annual review of the criteria and weights to confirm their validity is all that will be required.

It is certainly true that BCEs do not have the time to work through the calculations associated with the AHP, as presented in this chapter, each time they need to prioritize work orders. Fortunately, these calculations can readily be incorporated into an electronic spreadsheet or a programming language such as Basic, Fortran, APL, or COBOL to create an interactive program. One such package, Expert Choice™, was used by the author in the preparation of this report. Expert Choice™ and similar interactive programs permit the decision maker to enter the number of levels in the hierarchy and the number of elements or criteria in each level. The program then presents the choices in pairwise fashion to the decision maker. After the decision maker enters pairwise, subjective estimates of the relative worth of each element, the program then calculates priorities for each criterion, the consistency index, the consistency ratio, and the hierarchy consistency. Using such an interactive program, the BCE can perform "if-then" analysis with regard to the criteria weights and resulting work order allocations or work order scores.

To evaluate the worth of work orders, it is only a simple matter of entering the criteria weights calculated by the AHP software into WIMS for the scoring technique to use as coefficients. The process of establishing the relative worth of each work order has now been automated. Each time Customer Service enters a new work order into WIMS, the computer matches entered work order data with the appropriate criteria weights and calculates a composite work order score. Thereafter, the decision maker has instant access to a rank ordered WO list that was developed from criteria important to the decision maker.

It is unlikely that a decision maker would want to use the automated priority list without modification to actually accomplish work orders. In all likelihood, the "first cut" automated priority list will serve as a valuable spring board for further discussion, thereby aiding the Base Civil Engineer in making the actual rank ordering decision.

Finding. Based on the above example, this research concludes the AHP can be used to aid the decision maker in the determination of work order allocations or work order priorities. Additionally, although the results were not unanimous, the checkbook is the preferred work order prioritizing method.

Summary. This study has identified six methods used by civil engineering to prioritize work orders for in-service accomplishment. It has also shown that while users of each system articulate varying degrees of satisfaction and believe their systems to be effective, they also recognize their systems have certain disadvantages. It is reasonable to assume that if offered a tool that could eliminate or lessen the impact of these disadvantages while conserving human energy, the BCE would use the tool.

This chapter discussed the importance of selecting and weighting criteria used to formulate a work order quota and demonstrated how the Analytical Hierarchy Process could be applied by a BCE or Installation Commander on a typical TAC base using the Checkbook method. It also discussed how the AHP could be used to hierarchically structure and weight criteria, used in a scoring technique, to compare and rank work orders for users of the other five prioritizing methods. The value of the resulting rank ordered work order list is to serve as a "strawman" or decision aid helping the BCE to determine the relative worth of work orders based on those things the BCE deemed important to consider. In other words, the AHP helps the BCE process through the reams of work order information available on WIMS, which are difficult to use in their raw form to compare WOs with one another and not very effective as a decision support mechanism, and convert the raw data to a more usable form--a "strawman" prioritized list.

The most important finding of this study is that the Checkbook method of prioritizing work orders for in-service accomplishment is used the most often and for the reasons stated in this chapter, the Checkbook system should be considered first when a change in or startup of a new system is required. Additionally, regardless of the type of prioritizing system used, the Analytical Hierarchy Process can be used by the BCE to replace intuitive decision making with an analytical technique designed to systematically aid in selecting and weighting the criteria used to base work order allocations on or to determine work order priorities.

VI. Summary, Conclusions, and Recommendations

Summary

The objective of this research was two fold: 1) to develop a profile of the methods used by civil engineering to prioritize work orders for in-service accomplishment; and 2) to determine if an analytical aid could be found to assist decision makers in the rank ordering decision process.

This study examined six rational and systematic methods used by CE organizations throughout the Continental United States to equitably distribute limited in-service resources by prioritizing the order of work orders accomplishment. The methods identified were:

- Checkbook (37.9): blocks of work orders are allocated to organizations for use at their discretion. Organizations prioritize their own work orders.
- Engineering Judgment (21.6): an engineering staff sets work order priorities based on prior experience and professional judgment.
- Base Panel (13.8): a corporate installation board reviews, approves and prioritizes work orders.
- BCE Panel (13.8): a corporate civil engineering board prioritizes work orders for approval of the senior installation commander.
- Command Driven (11.2): senior commanders continually generate command interest work orders, making it unnecessary to develop a formal WO priority program.
- Weighting (1.7): work orders priorities are set by computing an overall dimensionless project score based on ratings assigned to each WO for relevant decision criterion.

The above list is arranged from the most to the least frequently used method reported in the survey. The numbers shown in parenthesis are the percent of respondents reporting use of the systems. Specific characteristics of each prioritizing system are detailed in the system specific profiles in Chapter IV.

To assist in the rank ordering decision process, a decision model that functions more like a decision support system was developed in Chapter II. The model is actually a hybrid using several analytical techniques:

- First, the Analytical Hierarchy Process is used to encourage decision makers to develop a hierarchical approach to modeling the problem environment. The process requires developing criteria to assess the relative worth of each work order to the goals and objectives set by the decision makers. The result of this process is a set of relative weights for criteria that can be used to allocate work orders among organizations (checkbook method) or to evaluate the worth of each work order (other five methods).

- Second, the scoring technique is used to evaluate the relative worth of work orders by measuring them on the criteria and associated weights determined using the AHP. The resulting rank ordered list can be used as a "strawman" to aid in the rank ordering decision process.

- Finally, if desired, the work order scores, obtained from the scoring technique, can be used as the payoff values needed for linear programming to automate the development of a first cut In-Service-Work Plan, as proposed by Belyeu and Kuhn, and Bush and Richardson in their research.

A demonstration of how this model works is provided in Chapter V.

Conclusions

Discussion of the Primary Research Objective. This study began with a search for "one best" work order prioritizing system for Air Force-wide implementation. However, just as Frederick Taylor's Scientific Management could not find "the one best way" of management, neither did this study find "the one best" prioritizing method. There was no unanimous method of prioritizing work orders. This is probably to be expected, given the diversity of base operating characteristics and given the diversity of the work order prioritizing methods in use. In addition, many respondents reported using a combination of several methods. Thus, in the real world of operations, it is likely no "pure" system exists as described in the questionnaire.

Nevertheless, four methods of prioritizing WOs were reported to be in use most frequently: Checkbook, Engineering Judgment, BCE Panel, and Base Panel. Of the four, Checkbook was clearly used the most often and exhibited to a greater degree than the other methods the reported advantages of ensuring equity, easily permitting users to change priorities, limiting the number of WOs to a manageable size, and allowing the customers to set their own priorities. Besides the above advantages, Checkbook users reported at least the same level of agreement concerning system advantages/disadvantages, contained in opinion gathering questions 40 through 63, as did the other respondents. In addition, the Checkbook system embodies the common strengths of transparency, visibility, flexibility, permitting CE to consolidate requests by directorates, using WO quotas, and allowing CE to freeze WOs as identified in research question five. Respondents also reported customer participation in setting work order priorities and customer satisfaction to be the primary advantages of the Checkbook method.

When asked to rank order their prioritizing method against the others, in the order which seemed most practical for prioritizing work orders, respondents ranked Checkbook and Engineering Judgment first, and Base Panel and BCE Panel second. For the reasons listed above, this study concludes the Checkbook system should be considered first when a change in systems or startup of a new system is required.

Engineering Judgment was clearly the second most popular work order prioritizing method and also ranked first by respondents as most practical for prioritizing work orders. Engineering Judgment exhibited to a greater degree than the other methods the reported advantages of permitting BCEs to direct resources as they see fit, letting the BCE set priorities based on professional engineering judgment, and requiring personal involvement of the BCE or Chief of Operations in setting WO priorities. Another advantage reported by respondents was flexibility to meet sudden mission and command interest work requirements. Similar to the Checkbook method, Engineering Judgment can possess the common strengths of visibility, flexibility, permitting CE to consolidate requests by directorates, using WO quotas, and allowing CE to freeze WOs as identified in research question five. Thus, Engineering Judgment would make a logical second choice, should the Checkbook system not fit the base operating environment, when a change in systems or startup of a new system is required.

After Checkbook and Engineering Judgment; Base Corporate Panel and BCE Panel should be considered as a third option since they have about the same reported use and degree of satisfaction.

In contrast to the above methods, respondents rated Command Driven the least practical of the six methods for prioritizing work orders. Also, respondents using the Command Driven method felt stronger than those using the other methods that their system lets the political power dominate the setting of WO priorities and wastes too much time accommodating short-fused requirements. The primary reported advantage of the Command Driven system was it "satisfies the boss." Undeniably, it is important to satisfy the boss. However, based on the above findings, the Command Driven system should be considered as a last option when a change in systems or startup of a new system is required.

Response of those using the Weighting system was limited, which makes it difficult to draw conclusions from. As stated in Chapter I, Hickam AFB, HI, was included in the survey because CE at Hickam had been known to be using a Weighting system that was integrated with WIMS. However, in a telephone interview, the civil engineering deputy reported the system had been changed in favor of the Checkbook system. The reason for this change was the version of the Weighting system they used was complicated enough that only one person in Requirements could assess priorities. Similar to the matrix shown in Table 22, Hicham's former system contained thirteen criteria to assess the worth of work orders by. The conclusion drawn from this limited information is when using the Weighting method, it is wise to use as few criteria as necessary and to make the system as simple as possible.

Discussion of the Second Research Objective. The second research objective was to determine if an analytical aid could be found to assist decision makers in the rank ordering decision process.

> Since management is not likely to use any model to actually decide among projects, the model's true value will most probably be found in the wide range of information it can generate for use in making selection decisions (28:91).

Using Moore's advice as guidance, the objective pursued when developing the decision model in Chapter II was to provide a decision aid that was simple to understand, perceived to be equitable, flexible, and readily adaptable to automation, and most importantly would facilitate systematic comparison of work orders to determine their relative worth.

As described in Chapter V, this objective was addressed only on a conceptual level and no actual field demonstration of feasibility has been accomplished. However, the logical basis for the conceptual argument in support of this research question is sound. As shown, the AHP can be used to aid in both work order allocation decisions for determining quotas and for determining the weights for use in a scoring system. Both applications assist the decision maker in hierarchically structuring the problem and in identifying criteria and criteria weights for making allocations or to compare work orders by.

Other Related Conclusions. In addition to the above conclusions, there were two other conclusions reached by this researcher that are considered noteworthy.

1. This study attempted to determine what factors internal and external to civil engineering influenced the way the BCE chooses to prioritize work orders. The decision maker could select from this list the factors pertinent to his base environment to measure the worth of work orders on. Response to survey questions addressing this issue was insufficient to provide a statistically sound list. However, the factors discussed in answer to research questions two and three ,in Chapter V, provide a good springboard for decision makers to start with when developing criteria to compare work orders, regardless of the method used to prioritize work orders.

2. This study also attempted to identify common features among the reported *strengths of* the reported prioritizing methods. As a result of the researcher's analysis and synthesis of the data, several common strengths were identified that decision makers should consider incorporating into their method of prioritizing work orders if the features are not already present.

As discussed in Chapter V, research question five, these common features include the following:

1. Set a quota of work orders, perceived to be equitable by the customers, for each organization which CE earnestly strives to complete based on a promised completion date.

2. Aggregate organization work requirements by directorates and permit the directorate to prioritize their own work orders.

3. Create a block of work orders within which priorities can no longer be changed. When a WO moves up far enough up in priority to enter this block, its priority is frozen.

4. Build flexibility into the system so that confusion, inefficiencies, and general upheaval are not the norm when an urgent, unexpected work requirement surfaces.

5. Make the system as transparent as possible. Transparent means it should be easy to understand how the system works and it is highly visible through publication and distribution of work order priority lists to customers.

Recommendations

This research effort has identified six methods civil engineering uses to prioritize work orders for in-service accomplishment. The study has also shown that the AHP can be used to aid decision makers in the process of identifying criteria important to the installation Commander and his staff to meet goals and objectives for use in evaluating the worth of each work order. However, limited research time did not allow for field testing of the model using data from actual BCE organizations using the six prioritizing methods. Therefore, the foremost recommendation is to operationalize the model presented in Chapter II by developing a program for WIMS and testing the model. The object of the test would be to develop a prioritized "strawman" list for an actual BCE organization over a suitable period of time as a means of validation. In addition to this recommendation, there are several other issues that warrant further research.

First, develop a measurement instrument enabling the decision maker considering changing to one of the six identified work order prioritizing methods to predict the success of the method under various base operating conditions. Such an instrument would help the decision maker avoid selecting a less than optimal prioritizing method. In addition, the instrument could be used as a decision support system permitting the decision maker to perform "what-if" analysis.

Second, develop an expert system to assist the decision maker in prioritizing work orders. An expert system uses rules of inference to duplicate the decision-making processes of experts by integrating the expert's heuristic knowledge with their informal styles of reasoning. Once developed, the expert system would permit "if-then" analysis with regard to prioritizing work orders.

Third, investigate the feasibility of using the AHP model to prioritize construction projects. When Requirements determines a work order is beyond in-house capabilities, the WO is sent to Programming to become a construction project. The Engineering & Environmental Planning Branch then uses the WO inputs to develop a base five-year construction program. Similar to work orders, projects must be prioritized to properly allocate scarce construction dollars. Thus, the model developed in Chapter II could readily be adapted to aid the decision maker in making the construction project prioritizing decision.

Fourth, conduct a study to determine what scientific management tools and Production and Operation Management techniques BCE organizations are using. This study will provide the researcher with a base from which to identify and recommend existing or new techniques to replace intuitive decision making for civil engineering's many large, complex problems.

Appendix A: Installations Surveyed

Small (less than 4,000)

Installation	Command	Installation	Command	Installation	Command
Bolling	AFDW	Reese	ATC	Whiteman	SAC
McClellan	AFLC	Vance	ATC	Wurtsmith	SAC
Brooks	AFSC	Hurlburt	MAC	England	TAC
Columbus	ATC	Blytheville	SAC	Moody	TAC
Goodfellow	ATC	Grissom	SAC	Myrtle Beach	TAC
Laughlin	ATC				

Medium (4,000-7,500)

Installation	Command	Installation	Command	Installation	Command
Hanscom	AFSC	Castle	SAC	Pease	SAC
USAF Academy	USAFA	Dyess	SAC	Plattsburg	SAC
Mather	ATC	Ellsworth	SAC	Bergstrom	TAC
Williams	ATC	F.E. Warren	SAC	Cannon	TAC
Maxwell	AU	Fairchild	SAC	Davis-Monthan	TAC
Altus	MAC	Grand Forks	SAC	George	TAC
Dover	MAC	Griffis	SAC	Holloman	TAC
Little Rock	MAC	K.I. Sawyer	SAC	McDill	TAC
McChord	MAC	Loring	SAC	Mountain Home	TAC
Pope	MAC	Malmstrom	SAC	Seymour Johnson	TAC
Hickam	PACAF	March	SAC	Shaw	TAC
Barksdale	SAC	McConnel	SAC	Tyndall	TAC
Beale	SAC	Minot	SAC	Peterson	AFSPACE-COM
Carswell	SAC				

Large (more than 7,500)

Installation	Command	Installation	Command	Installation	Command
Hill	AFLC	Keesler	ATC	Norton	MAC
Kelly	AFLC	Lackland	ATC	Scott	MAC
Robins	AFLC	Lowry	ATC	Travis	MAC
Tinker	AFLC	Randolph	ATC	Offutt	SAC
Wright-Pat	AFLC	Sheppard	ATC	Vandenberg	SAC
Edwards	AFSC	Andrews	MAC	Homestead	TAC
Eglin	AFSC	Charleston	MAC	Langley	TAC
Patrick	AFSC	Kirtland	MAC	Luke	TAC
Chanute	ATC	McGuire	MAC	Nellis	TAC

Other

Installation	Command
Cheyenne Mt.	SAC

Appendix B: Survey Instrument

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OH 45433-6583

18 APR 1988

REPLY TO ATTN OF: LSR

SUBJECT: Civil Engineering Work Order Priority System Questionnaire (USAF Survey Control No. 88-34)

TO: Base Civil Engineers and Chiefs of Operations

1. On 21 March, we sent you and your Chief of Operations a questionnaire concerning methods civil engineers use to prioritize in-service work orders. The answers to the questionnaire will be used by Capt Steve Lillemon to develop an Air Force-wide profile of these methods and to develop a prototype system that will automate this important activity as a decision aid.

2. To date, we have had a good response rate from civil engineers in most commands, and we appreciate that support. However, a few commands are still under-represented in the responses. Since we want to be sure that Capt Lillemon's prototype and profile take into account the needs of the largest number of potential users, we are sending this follow-up.

3. If the first mailing reached you safely and you have already returned it, please accept our thanks. If we have not yet had input from you, we would very much appreciate hearing from both you and your Chief of Operations by 29 April. Two copies of the questionnaire are enclosed.

4. Thank you.

JAMES T. LINDSEY, Lt Col, USAF
Head, Department of Communication
and Organizational Sciences
School of Systems and Logistics

1 Atch
Questionnaire (2)

USAF Survey Control No. 88-34
Expires 31 May 88

SURVEY OF CE WORK ORDER PRIORITY SYSTEMS

The purpose of this survey is to gather information on methods Air Force civil engineers use to prioritize work orders for **in-service work force** accomplishment.

General Instructions

1. Please mark your answers directly on the questionnaire by circling the appropriate response. Select only one answer to each question unless instructed otherwise. To save you time, the questionnaire is designed so that you skip sections that do not apply to your method of prioritizing work orders.

2. To standardize terms used in the questionnaire, we have developed brief descriptions of six methods used to prioritize work orders for in-service accomplishment. This "Method Definitions" factsheet is the last page of the questionnaire. Please detach this page for convenient reference throughout the questionnaire.

3. Please use the comments section to fill in details or add any information and to give us feedback on this survey.

4. When you have completed the questionnaire, please return it in the self-addressed, prepaid envelope provided.

5. If you have **locally produced, written guidelines for prioritizing work orders** (such as a local regulation or OI), please send us a copy. To ensure anonymity of survey responses, the mailing label enclosed with this package is provided for your use to send the guidelines in a separate envelope.

PART 1. This section asks demographic questions for comparative purposes.

1. What is your grade?
   a. 0-1 or 0-2
   b. 0-3
   c. 0-4
   d. 0-5
   e. 0-6
   f. Other ______

2. What is your current position?
   a. Chief of Operations
   b. Base Civil Engineer (BCE)
   c. Other ______________________

3. How many <u>months</u> have you been in your current position? ______ months

4. How many years experience do you have as a BCE?
   a. haven't been a BCE
   b. less than 1 year
   c. 1 but less than 3 years
   d. 3 but less than 4 years
   e. 4 or more years

5. How many years experience do you have as a Chief of Operations?
   a. haven't been a Chief of Ops
   b. less than 1 year
   c. 1 but less than 3 years
   d. 3 but less than 4 years
   e. 4 or more years

6. How many years experience do you have as a Chief of Requirements?
   a. haven't been a Chief of Req
   b. less than 1 year
   c. 1 but less than 3 years
   d. 3 but less than 4 years
   e. 4 or more years

7. To which major command does your base belong?
   a. AFCC
   b. AFLC
   c. AFSPACECOM
   d. AFSC
   e. ATC
   f. AU
   g. ESC
   h. MAC
   i. SAC
   j. TAC
   k. Other (Specify) ______________

8. What is the working population of your base (military and civilian combined)?
   a. less than 4000
   b. 4000-7500
   c. more than 7500

9. How many Major Command and/or Numbered Air Force Headquarters are located on your base?
   a. none
   b. 1
   c. 2-3
   d. 4 or more

10. How many wings or organizations equivalent to wings do you have on your base?
    a. 0
    b. 1
    c. 2
    d. 3
    e. 4 or more

11. How many tenant units do you have on your base?
    a. less than 5
    b. 5-15
    c. 16-25
    d. more than 25

12. Approximately how many senior officers on your base outrank the installation commander?

a. None   b. 1-5   c. 6-10   d. more than 10

PART 2. This section requests information about how your base selects work orders for **in-service** work force accomplishment. **Please take a minute at this time to look at the work order priority Method Definitions on page 9.**

13. On the average, how many **MINOR CONSTRUCTION** work orders do you have on backlog at any one time?

a. less than 50	c. 100-199	e. 300-399	g. 500 or more
b. 50-99	d. 200-299	f. 400-499	

14. On the average, how many **MAINTENANCE AND REPAIR** work orders do you have on backlog at any one time?

a. less than 50	c. 100-199	e. 300-399	g. 500 or more
b. 50-99	d. 200-299	f. 400-499	

15. Do you currently use any system to prioritize work orders?

a. No   b. Yes (If yes, please skip to Question 17.)

16. If no system is used to prioritize work orders, please describe briefly in the space below how you determine which work orders CE will accomplish and what the order of accomplishment will be.

(After completing Question 16, if you use no system to prioritize work orders, please answer Question 20. Then skip the remaining questions and return the questionnaire in the postpaid envelope. Your response is important.)

17. Does one of the six methods described on the attached "Method Definition" sheet (page 9) closely resemble your current system?

a. No (If no, please go to Question 19.)

b. Yes (Please circle which one)

Checkbook	BCE Panel
Base Panel	Engr Judgement
Weighting	Cmd Driven

18. Briefly describe how your current method differs from the method you identified in Question 17.

a. No differences; exactly like description
b. Differences as follows:

(After describing the differences, please go to Question 20.)

19. If your system is <u>not</u> similar to one of the six defined on page 9 (Method Definitions), please describe it briefly in the space below.

20. On the following scale, please rate the overall effectiveness of your current system.

a. Very effective
b. Effective
c. Neutral
d. Somewhat ineffective
e. Very ineffective

21. Following is a list of the six methods defined on the attached "Method Definition" sheet. The word "Other" is provided in case your current method does not closely resemble one of the predefined six.

Please use the numbers 1 through 6 (or 7) to rank these systems in the order which seems most practical foı prioritizing work orders.

System	**Rank Order (Number 1 is highest.)**
Checkbook	________
Base Panel	________
Weighting	________
BCE Panel	________
Engr Judgement	________
Cmd Driven	________
Other (your own if not one of these)	________

22. If you use a system that allocates work orders or manhours to major organizations or directorates, what factors do you use to make the distribution (circle as many as apply)?

a. Do not use a system that allocates work orders or manhours
b. Total square feet occupied by the organization
c. Total number of personnel assigned to the unit
d. Work order history
e. Other (Please specify) ____________________

23. If your base uses a Corporate Base Panel (Method 2), who chairs it?

a. Do not use a corporate base panel
b. Wing commander
c. Wing vice-commander
d. Base commander
e. Other (Please specify) ____________________

24. If your base uses an Internal BCE Panel (Method 4), who chairs it?

a. Do not use an internal BCE Panel
b. Base Civil Engineer (BCE)
c. Deputy BCE
d. Chief of Operations
e. Other (Please specify) ____________________

25. If work orders are prioritized by an individual within CE, who is he/she?

a. A single individual does not prioritize work orders
b. Base Civil Engineer (BCE)
c. Chief of Operations
d. Chief of Requirements
e. Other (Please specify) ____________________

26. What type work classifications does your work order priority system prioritize? (Choose one answer only.)

a. Minor construction (MC)
b. Maintenance and repair (M/R)
c. Both MC and M/R

27. How are CE work orders to maintain the base infrastructure prioritized?

a. They compete for priority with requesters' work orders.
b. They are handled separate from requesters' work orders.
c. Another method (Please specify) ____________________

28. Please complete this statement by circling one or more responses: "Organization commanders are permitted to periodically review and rank order those work orders their units have submitted to CE within the following AFR 85-1 priority categories . . ." (Circle all that apply)

a. Priority 1
b. Priority 2
c. Priority 3
d. Priority 4
e. All
f. None (If none, skip to question 31.)

29. How often are these unit work order listings prioritized?

a. Monthly b. Quarterly c. Other (Please specify) ____________

30. At what point in the work order process do you no longer permit the requester to change the rank order he established previously for the work order?

a. Requester does not have the option
b. At Customer Service
c. At Planning
d. At Materiel Control
e. At Scheduling
f. Can change at any time

31. At your base, is there a limit (quota) on the number of approved work orders permitted in the CE queue at any one time?

a. Yes   b. No

32. How important is the concept of first-in first-out (oldest WOs are done first) to your work order system?

a. Very important
b. Slightly important
c. Neutral
d. Not so important
e. Not important at all

33. How important is the professional judgement of CE in setting priorities in any prioritizing system?

a. Very important
b. Slightly important
c. Neutral
d. Not so important
e. Not important at all

34. Approximately what percent of your work orders are generated by senior officers such as the base or wing commander, or general officers higher than base level?

a. 0 percent
b. 1-10 percent
c. 11-20 percent
d. 21-30 percent
e. 31-40 percent
f. 41-50 percent
g. 51-75 percent
h. more than 75 percent

35. Do you use a computer to assign work order priorities? a. Yes b. No

36. Do you use a computer to track work order priorities? a. Yes b. No

37. Which of the following influence your decision to continue using your current prioritizing system? (Circle as many as apply.)

a. Installation commander's management style
b. Size of CE work order backlog
c. Base mission
d. Geographic dispersion of CE's area of responsibility
e. Base relationship with Major Command
f. Number of wings on base
g. Number of senior officers on base outranking the Base Commander.
h. Operations funding available to CE
i. Base Civil Engineer's management style
j. BCE's past experience with work order priority systems
k. Base size
l. Other (specify) ______________________________

Question 38 applies only to bases using a weighting system (Method 3 on the "Method Definition" sheet). If you do not use a weighting system, please skip to PART 3.

38. Circle the ten most important factors to consider (weigh) when prioritizing work orders.

a. Self help
b. Command programs
c. Work order history
d. Hazards to health
e. Season
f. Quality of life
g. Command interest
h. User priority
i. Facility condition
j. Drop dead date
k. Fire hazards
l. Reimburseables
m. Shop manning
n. Hazards to safety
o. Requester's mission
p. Base infrastructure
q. Requester's unit population
r. Prevent breakdown of operations
s. Security requirements
t. Facility square footage
u. Environmental issues
v. Energy conservation measures
w. Equipment availability
x. Oldest WO first (FIFO)
y. Material availability
z. CE Training requirements
aa. Funding availability
ab. Work classification
ac. Prevent reducing essential operational effectiveness
ad. Other (specify) ____________________

39. Referring again to Question 38, use the numbers 1, 2, 3, 4, and 5 to indicate your judgement of the top five factors from the ten you chose above that seem most important when assigning weights and prioritizing work orders. Write the rank order number in front of the above circled factors. (Number 1 is highest).

PART 3. Please answer the following questions in relation to the system you now use to prioritize work orders. Circle the letter abbreviations to indicate your answer.

"The system we currently use to prioritize work orders..."	Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree
40. is simple to use.	SD	D	N	A	SA
41. requires few CE manhours to keep current.	SD	D	N	A	SA
42. ensures equity among base organizations.	SD	D	N	A	SA
43. easily permits users to change priorities when needed.	SD	D	N	A	SA
44. insures base infrastructure work requirements are given equal priority with other WO requirements.	SD	D	N	A	SA
45. minimizes WO insertions and IWP disruptions.	SD	D	N	A	SA
46. helps the BCE identify controversial work orders.	SD	D	N	A	SA
47. limits the number of work orders to a manageable size.	SD	D	N	A	SA
48. permits BCEs to direct resources as they see fit.	SD	D	N	A	SA
49. minimizes the warehouse/storage space required for work orders awaiting manhours.	SD	D	N	A	SA
50. makes it easy to defend assigned priorities.	SD	D	N	A	SA
51. lets the BCE set priorities based on professional engineering knowledge.	SD	D	N	A	SA

"The system we currently use to prioritize work orders..."

		Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree	
52.	requires personal involvement of the BCE or Chief of Operations in setting work order priorities.	SD	D	N	A	SA	
53.	wastes manhours managing the system.	SD	D	N	A	SA	
54.	results in complaints that the system is unfair.	SD	D	N	A	SA	
55.	is flexible enough to meet new short-fused requirements.	SD	D	N	A	SA	
56.	lets backlog of work orders grow.	SD	D	N	A	SA	
57.	lets political power dominate the setting of work order priorities.	SD	D	N	A	SA	
58.	wastes too much time accommodating short-fused requirements.	SD	D	N	A	SA	
59.	lets requesters "game" the system to their advantage.	SD	D	N	A	SA	

The following questions also provide for an answer of Not Applicable (NA).

60.	allows the user to set his/her own priorities.	SD	D	N	A	SA	NA
61.	provides "visibility" through publication and distribution of priority listings to customers.	SD	D	N	A	SA	NA
62.	gives DCS primary responsibility for determining work order priorities.	SD	D	N	A	SA	NA
63.	is unable to show the "real" work order backlog due to the WO quota imposed on requesters.	SD	D	N	A	SA	NA

64. What is the <u>one</u> strongest <u>advantage</u> of your current prioritizing method?

65. What is the <u>one</u> primary <u>disadvantage</u> of your current method?

66. Please provide any other information you feel is important concerning the topic of work order priority systems which was not covered on this questionnaire.

METHOD DEFINITIONS

Here are brief definitions of six methods that other bases use to prioritize work orders that are to be accomplished by the civil engineering **in-service work force.** Please detach this page and refer to the definitions when they are called for in the questionnaire.

Checkbook System: A block of manhours is allocated to each organization monthly based on factors such as organization size and total facility square footage occupied by the unit. As with a checkbook, the unit is free to request and have work accomplished up to the amount allocated to them monthly. Typically, units are free to negotiate with each other to make up deficits for desired work. Variations of the checkbook method may allocate number of work orders rather than manhours.

Corporate Base Panel: Base commanding officer establishes a corporate board (other than the Facilities Board) to review, approve, and prioritize work requests. Panel is often chaired by Deputy to Installation Commanding Officer. Squadrons may or may not have the option to prioritize their work orders within the base priority listing. Starting point for Panel prioritization is usually AFR 85-1 category recommendations of Priorities 1 through 4.

Weighting System: Work order priorities are typically established by weighting factors (such as the categories of Priority [Mission, Fire/Safety, Support, and Necessary] as given in AFR 85-1, Command Interest [Wing Commander, Base Commander, BCE, and others], Location [Scheduling, Materiel Control, Planning, Backlog], etc.) on a predetermined scale against each work order. The weights assigned to each factor are then totalled to determine the priority for that work order. Work orders are sorted by total score, and may be sorted in a number of other ways, to develop a base priority listing.

Internal BCE Panel: An internal BCE panel prioritizes work orders for approval of senior base official. Typically, work orders are prioritized on the basis of AFR 85-1 guidance. Who chairs the panel varies from base to base (BCE, Deputy BCE or Chief of Operations).

Engineering Judgment: The BCE combines prior experience and professional judgment to set work order priorities using the four category priority system recommended by AFR 85-1. Typically, BCE uses First-in-first-out (FIFO) and reacts to Commander's special interests within each category. A variation of this system permits the Chief of Operations or Resources to do most prioritizing, usually using AFR 85-1 guidance, FIFO and professional judgment.

Command Driven System: Priorities are set by command interest with balance of program filling in around the command interest program. The central concept is that senior commanders (such as Major Commands) continually generate command interest work orders, making it unnecessary to develop a formal work order priority system.

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Vita

Captain Steven K. Lillemon was born and raised in [redacted] where he graduated from [redacted] High School in 1969. He attended Minot State College for two years before serving in the U.S. Navy for four years as an enlisted Vietnamese interpreter. Upon graduation from North Dakota State University in 1978 with a Bachelor of Science in Civil Engineering, he was commissioned in January 1979 in the USAF through the ROTC. Following his first assignment as a design engineer and the Chief of Construction Management with the 18th Civil Engineering Support Squadron at Kadena AB, Okinawa, Japan, he joined the 15th Air Base Squadron at Wheeler AFB, Hawaii, as the Base Civil Engineer in January 1982. In February 1985, he moved to Holloman AFB, as the Chief of Operations for the 4449th Mobility Support Squadron, keepers of Harvest Bare/Falcon, until entering the AFIT Graduate Engineering Management program in June 1987.

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Often the materials, money, and manpower available for work order (WO) accomplishment are limited. Thus, an important task the Base Civil Engineer (BCE) must perform is to prioritize work orders to determine the order in which they will be accomplished and--equally important--to determine which work orders will not be accomplished because of limited resources.

This study examined six methods used by BCEs of major Air Force installations within the Continental United States to prioritize work orders: Checkbook, Engineering Judgment, Corporate Base Panel, Internal BCE Panel, Command Driven, and Weighting. Based on survey questionnaire responses, both an Air Force-wide profile and system specific profiles were developed for the rank ordering process. Of the six methods, the Checkbook system was used the most often. The study also identified several common features among the reported strengths of the six prioritizing methods.

Based on analysis of the survey data, a pairwise comparison technique called the Analytical Hierarchy Process (AHP) was shown to be a useful aid for developing criteria to assess the relative worth of each work order to the goals and objectives set by the Installation Commander and his staff. BCEs using the Checkbook prioritizing method can use the AHP to develop a set of relative weights for criteria that can be used to allocate work orders among organizations. The AHP can also aid users of the other prioritizing methods by generating weighting coefficients for an automated scoring technique that can be used to generate a "strawman" prioritized work order list.

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WILLIAM A. MAUER 17 Oct 88
Associate Dean
School of Systems and Logistics
Air Force Institute of Technology (AU)
Wright-Patterson AFB OH 45433