

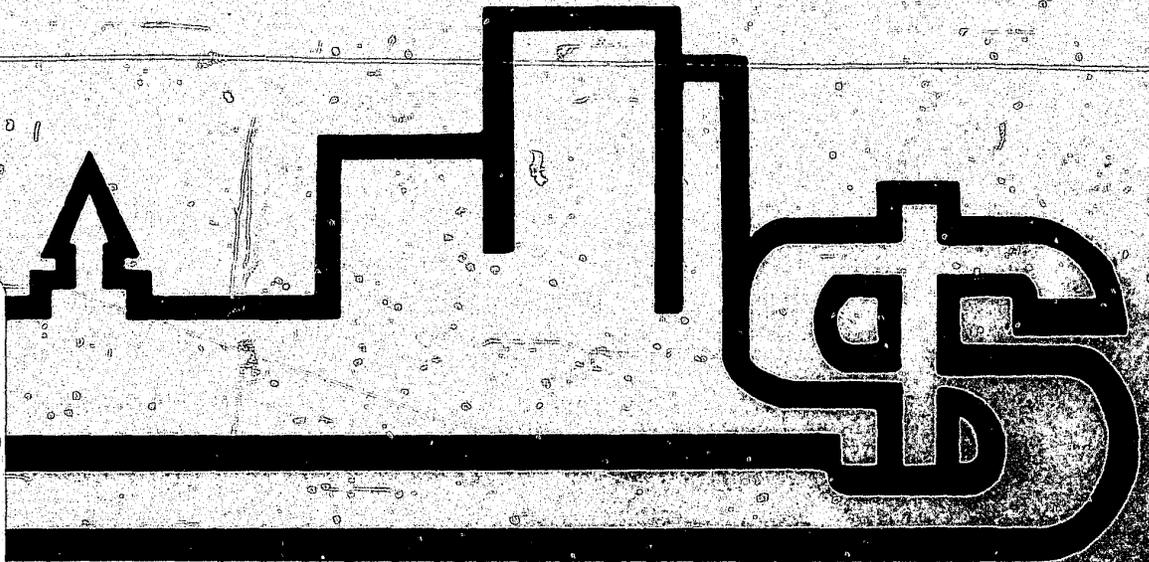


Work Schedule Design Handbook

Capacity Sharing Program

X Methods for
Assigning Employees'
Work Shifts and
Days Off

60697





THE
INSTITUTE
FOR PUBLIC
PROGRAM
ANALYSIS

**WORK SCHEDULE DESIGN
HANDBOOK**

**METHODS FOR ASSIGNING EMPLOYEES'
WORK SHIFTS AND DAYS OFF**

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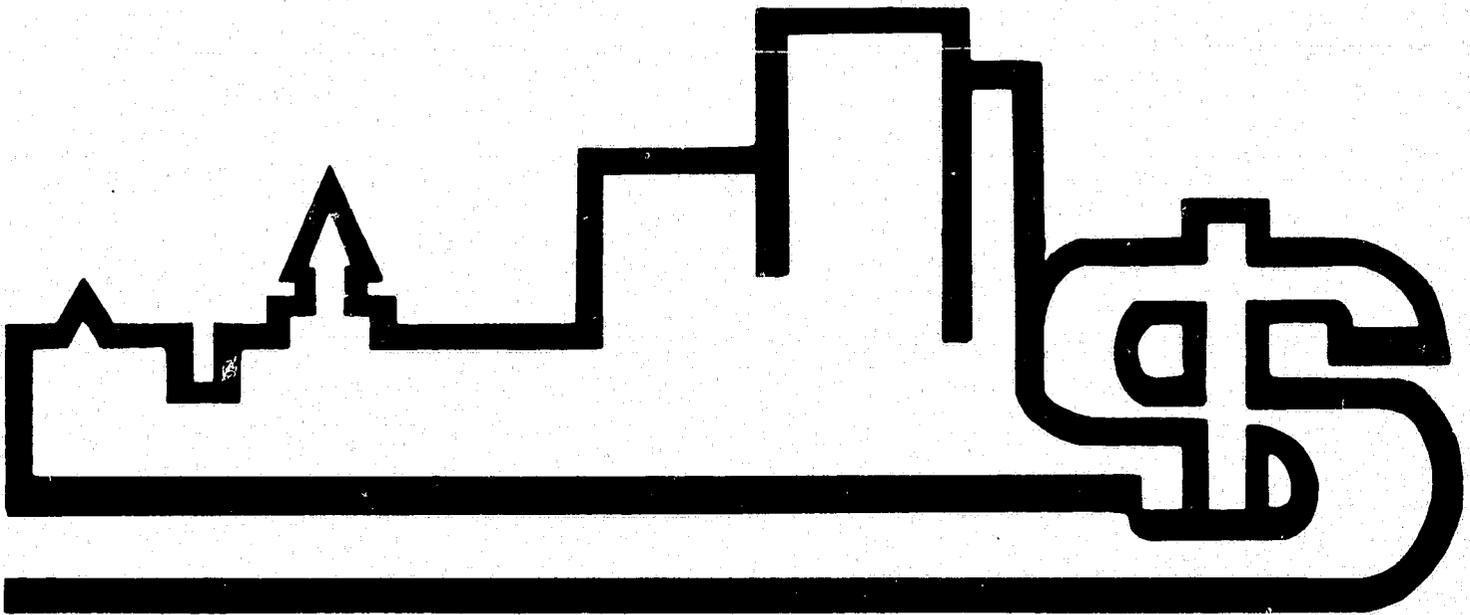


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August 1978
Grant Number H-2576-RG

Methods for
Assigning Employees'
Work Shifts and
Days Off



The views, conclusions and recommendations in this report are those of the contractor or author, who are solely responsible for the accuracy and completeness of all information herein. The contents of this report do not reflect necessarily the official views and policies, expressed or implied, of the U. S. Department of Housing and Urban Development or the United States Government.

ABSTRACT

This Handbook is a product of the project "Improved Work Schedules for Urban Service Delivery System Personnel," sponsored by the U. S. Department of Housing and Urban Development (grant number H-2576-RG). The project was implemented by the City of Santa Clara, California, in cooperation with The California Innovation Group (CIG) and The Institute for Public Program Analysis (TIPPA). CIG--now known as the Southwest Innovation Group (SIG)-- is an urban technology transfer consortium funded jointly by its member cities and the National Science Foundation. TIPPA is a not-for-profit research institute based in St. Louis, Missouri.

The Handbook is intended as a practical guide to manual methods for designing work schedules which specify the time of day and days of the week each employee is scheduled to work. The Handbook describes specific procedures for: analyzing an existing schedule to determine its properties; determining how many employees are needed on the basis of on-duty staffing requirements; allocating employees' on-duty assignments by time of day and day of week; determining what type of schedule and design method should be used, based on required properties in the schedules to be designed; and using the selected design method to construct a work schedule with specific properties.

Schedule properties that can be explicitly controlled with the procedures described in the Handbook include: fixed or rotating shift assignments; lengths of shift assignments; fixed or rotating days off; number of consecutive days off; number of consecutive work days; and variable or uniform staffing levels by shift and day of week.

FOREWORD

To schedule the work hours of municipal employees in inefficient or inappropriate ways is to waste money and erode morale. No government, no matter what its size, can afford to do either.

This immensely practical handbook gives specific instructions on how to design extended-hour work schedules in money- and morale-saving ways. Even mathematical duffers can use them without difficulty.

Neither the schedules themselves nor the techniques used to design them are new. As the handbook explains, the newness lies in the comprehensiveness of the coverage and in the demonstration that schedules initially developed for specific purposes -- for fire and police needs, for example -- can be extended to meet the needs of many other municipal services.

If we recall that personnel costs constitute the largest single expense in public budgets, we can well appreciate how improved scheduling can result in a better use of people's time and, ultimately, in a better use of the tax dollar. The Government Capacity Building Division of HUD's Office of Policy Development and Research is happy to make this handbook available to you.



Donna E. Shalala
Assistant Secretary for Policy
Development and Research

PREFACE

This Handbook is a product of the project "Improved Work Schedules for Urban Service Delivery System Personnel," sponsored by the U. S. Department of Housing and Urban Development as part of its Government Capacity Sharing Program, Office of Policy Development and Research (grant number H-2576-RG). The project was implemented by the City of Santa Clara, California, in cooperation with The California Innovation Group (CIG) and The Institute for Public Program Analysis (TIPPA). CIG--now known as the Southwest Innovation Group (SIG)--is an urban technology transfer consortium funded jointly by its member cities and the National Science Foundation. TIPPA is a not-for-profit research institute based in St. Louis, Missouri.

Available under separate cover is an executive summary of the Handbook entitled Summary and Introduction to "Work Schedule Design Handbook: Methods for Assigning Employees Work Shifts and Days Off." This report contains the same summary information found in the first chapter of the Handbook itself, and is available from TIPPA and the National Technical Information Service (5285 Port Royal Road, Springfield, Virginia, 22161).

The authors gratefully acknowledge the assistance and support of the following persons:

- Mr. Robert Baumgardner, HUD project monitor;
- Mr. Del DelaBarre, Executive Director, California Innovation Group;
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The authors also wish to acknowledge the cooperation and assistance of the agencies, located in Anaheim, Fresno, Pasadena, San Diego, San Jose, and Santa Clara, which participated in field testing the schedule design methods described in the Handbook. A list of agency contact persons and their addresses and telephone numbers is contained in Appendix B of the Handbook.

A special note of thanks is extended to Mrs. Vicki O'Dell, who typed much of the material contained in the Handbook and supervised the typing of the remainder.

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CHAPTER I

INTRODUCTION AND SUMMARY

A. Purpose of the Handbook

The Work Schedule Design Handbook is intended for persons who design, review, or administer work schedules for services which are provided more than eight hours per day or more than five days per week. Such extended-hours service is routinely provided by many agencies in the public sector: police, fire service, emergency medical care, public utilities, refuse collection, libraries, toll collections, lifeguards, and airport operations. (Many types of extended-hours services are also found in the private sector.) Work schedules described in the Handbook specify the pattern of work and off-duty days for each employee (i.e., the time of day and day of the week each employee is scheduled to work).

The Handbook is not intended for use as a textbook on the theoretical foundations of work schedule design, but rather, has been written to be used as a practical guide for designing work schedules. Accordingly, the major topics of the Handbook provide specific "how to" procedures for answering the kinds of work scheduling questions that often arise. These procedures include how to:

- analyze an existing work schedule to determine its properties;
- determine how many employees are needed on the basis of on-duty staffing requirements;
- allocate employees' on-duty assignments by time of day and day of week;
- determine what type of schedule and design method should be used based on required properties in the schedules to be designed; and

- use a selected design method to construct a work schedule with specific properties.

All of the design methods presented in the Handbook can be performed manually and do not require the user to be skilled in advanced mathematics or to have access to a computer. Schedule properties that can be explicitly controlled with these procedures include:

- fixed or rotating shift assignments,
- lengths of shift assignments,
- fixed or rotating days off,
- lengths of off-duty periods (i.e., consecutive days off duty),
- lengths of on-duty periods (i.e., consecutive work days), and
- variable or uniform staffing by time of day and day of week.

The kinds of schedules described in the Handbook are not new--they have been used for years to schedule fire fighters, police, and personnel of other extended-hours services. Often in the past, however, scheduling for these services has been a hit or miss proposition with little documentation on the underlying principles or procedures for designing schedules to satisfy different constraints. What is new is the comprehensive and flexible schedule design technology presented in this handbook. This technology is based largely on work done by The Institute for Public Program Analysis (TIPPA) on scheduling methods in the fire and police services.*

The feasibility of transferring this technology to other types of extended-hours services was field-tested in public agencies in

*A list of scheduling-related publications produced by The Institute for Public Program Analysis and others is presented in the Bibliography.

six California cities during the development of the Handbook. The agencies which participated in the field test project represented different work settings, management environments, and scheduling needs; their combined experience illustrates the benefits to be derived from using the work scheduling methods. These benefits include:

- improved matching of on-duty staffing levels to workload patterns by shift and day of the week;
- improved ability to revise work schedules to meet changing workload patterns;
- improved ability to balance management's need for efficient allocation of agency personnel and employees' need for satisfactory schedule properties; and
- reduced administrative time required to design schedules.

A brief description of the work scheduling project and a summary of project results in one agency are presented in later sections of this chapter. Case studies for all field test agencies are presented in Appendix B.

B. Work Scheduling, Productivity, and the Cost of Public Service

The Impact of Work Schedules

Few observers would argue with the thesis that the kinds of work schedules used by public agencies affect both the cost and quality of the services provided. Work schedules impact virtually every agency employee, and labor costs usually represent the largest budget item for most public agencies. That there are significant management questions to be addressed within the context of work scheduling is not in doubt, and many of these scheduling issues have long been recognized as having potentially significant productivity impacts. Unfortunately, little has yet

been accomplished in quantifying the relationships between work schedule properties and service costs and quality. Two of the more obvious relationships are discussed in the following paragraphs.

Non-proportional schedules. Agencies which provide service on demand, and which use work schedules which are not proportional to cyclic workload variations by shift and day of week experience productivity losses by having an excess of on-duty staff during low workload periods, and by having too few on-duty employees during high workload times. The latter situation not only degrades services to clients but also generates additional personnel costs if temporary staff is obtained on an overtime basis.

Unattractive work schedule properties. Although the attractiveness of many schedule properties is a subjective issue, a poorly-designed schedule may contribute to fatigue and boredom with the attendant problems of absenteeism and lower productivity. Schedule properties which have contributed to these problems in some agencies include:

- long assignments on the same shift,
- frequent shift reassignments,
- inadequate time off between on-duty assignments on different shifts,
- long periods of consecutive work days,
- short off-duty periods,
- few weekends off, and
- schedules which result in an unequal distribution of desirable schedule properties among employees.

Problems of Work Schedule Design

Despite the apparent relationships between work schedules,

agency costs, and productivity, many agencies continue to use schedules that do not match staffing levels to workload variations or that contain undesirable properties. Reasons cited for the reluctance of agencies to adopt new work schedules include the following:

- Lack of awareness. Often the agency and personnel responsible for schedule design are unaware of alternative scheduling methods and their benefits.
- Absence of resources. Few scheduling-related resources in the form of training, technical assistance, or printed materials have been available.
- Limited technology transfer. There are few opportunities for agencies which have designed successful schedules to share their experience with similar agencies in other communities. Also the personnel who design such schedules often do not understand the underlying principles of the schedule design procedure well enough to adapt their schedules to different work environments.
- Resistance to change. Uncertainty of the impact of new schedules and of the cost of designing and implementing them, a sense of "that's the way it has always been," and the general sensitivity of employers and employees to changes in schedule properties, all reinforce the resistance to change.

C. Work Scheduling Project

The Work Schedule Design Handbook is the principal product of a project entitled "Improved Work Scheduling for Urban Service Delivery System Personnel" (grant number H-2576-RG) sponsored by the Office of Policy Development and Research at the Department of Housing and Urban Development. The project was undertaken by the City of Santa Clara, California, in cooperation with the California Innovation Group (CIG), its member cities, and The Institute for Public Program Analysis. CIG--now known as the Southwest Innovation Group (SIG)--is an urban technology transfer consortium funded jointly by its member cities, The National Science Foundation,

and, to a lesser degree, other federal agencies, to help local governments take advantage of new technologies. TIPPA is a not-for-profit research institute based in St. Louis, Missouri.

The purpose of the project was to develop the first comprehensive handbook of work schedule design methods, applicable to a wide range of municipal services, and to field test both the use of the Handbook and the application of the scheduling methods. Six CIG cities participated in the project: Santa Clara (lead city), San Jose, Fresno, Pasadena, Anaheim, and San Diego. Project activities included:

- a survey of selected extended-hours service agencies in the participating CIG cities,
- selection of target agencies in which the scheduling methods would be applied,
- meeting of CIG science advisors, target agency representatives, TIPPA staff, and other interested persons to review project activities and introduce participants to the scheduling methods,
- design of target agency work schedules,
- implementation of new work schedules in target agencies, and
- assessment of project outcomes.

A brief description of these activities is presented in the following paragraphs.

Survey of CIG Agencies

At the start of the project, personnel in selected service agencies in the participating cities were visited by TIPPA staff to determine their interest in the project and to assess the potential for applying innovative scheduling methods. These agencies had been nominated by CIG science advisors, who had previously been given a brief introduction to the types of

scheduling methods to be used. A total of 19 agencies were surveyed. Information collected from the agencies included:

- agency function and organizational structure,
- composition of the work force,
- demand for agency services,
- allocation of staff by shift and day of the week,
- properties of current work schedules,
- work scheduling constraints,
- schedule administration practices, and
- current methods of designing and evaluating agency work schedules.

Despite the complex nature of work scheduling and the potential benefits to be derived from improved scheduling techniques, none of the agencies surveyed had previously known of any resource material related to work schedule design. Management personnel were often unaware that schedule alternatives existed, and exchange of schedule-related information between agencies was rare. As a result, even agencies which were unable to implement new schedules during the scheduling project viewed the development of the Work Schedule Design Handbook as the significant accomplishment of the project.

Selection of Target Agencies

Initial selection of the project's target agencies was based upon results of the survey described above. Agencies were excluded for the following reasons: the project's scheduling methods were not appropriate for their work environments, new scheduling methods were not needed, or management personnel were not able to commit themselves to participation in the project. After careful screening, seven agencies were selected: two in Fresno and one in each of the

other participating CIG cities:*

- Anaheim Public Library,
- Fresno Transit Maintenance Department,
- Fresno Wastewater Treatment Plant,
- Pasadena Paramedic Ambulance Service,
- San Diego Aquatics Division,
- San Jose Vehicle Maintenance Department, and
- Santa Clara Public Library.**

Meeting of Project Participants

In June 1977, a two-day meeting was held in Anaheim, California. Attending the meeting were CIG staff and science advisors; TIPPA staff; the HUD project manager; representatives from each of the target agencies; and representatives from SRI International*** and the American Federation of State, County, and Municipal Employees (AFSCME). The agenda for the meeting included:

- review of project objectives and plans for work with each of the target agencies;
- introduction to the work schedule design methods and training materials, and a review of the potential benefits to be derived from the use of these methods;
- review of alternative work schedules designed by TIPPA for some of the target agencies; and
- discussion of initial outlines for the Work Schedule Design Handbook.

*Limited scheduling assistance was also provided to three other agencies during the project: Fresno Fleet Maintenance Department, Fresno Parks and Recreation Department, and the Santa Clara Electric Department.

**Individuals associated with each agency and the science advisor for each city are listed in Appendix B.

***SRI International was under contract to HUD to assess several HUD-sponsored productivity improvement projects.

Design of Target Agency Schedules

Following the Anaheim meeting, project efforts focussed upon application of the scheduling methods to the target agencies. For most of the agencies, alternative schedules were designed by TIPPA based on information supplied by agency personnel. In two instances, new work schedules were designed by agency personnel themselves. Table 1-1 summarizes the schedule design work and other services rendered by TIPPA to participating agencies during the project.

Implementation of New Work Schedules

After careful review of proposed alternative schedules, two participating agencies implemented new schedules based on the TIPPA design methods. Several other agencies were still considering implementation at the end of the project. A description of the field test results in the Fresno Transit Maintenance Department is presented below. More detailed case studies illustrating the varied and complex issues involved in the design of work schedules for the test agencies are presented in Appendix B.

Assessment of Project Outcomes

Assessment of project outcomes was accomplished by several means: continuous science advisor contact with target agencies, site visits by TIPPA and SRI International staff, and a project wrap-up meeting. The results of these efforts appear to confirm the value of the new scheduling resources. Specifically, the assessment activities indicated that

- work scheduling is indeed a problem for many extended-hours services, consumes considerable amounts of administrative time, and is supported by little in the way of written technical resources;
- many extended-hours services use the kinds of work schedules described in the Handbook;

Table 1-1

A SUMMARY OF TIPPA SCHEDULE DESIGN WORK AND
OTHER SERVICES RENDERED TO TARGET AGENCIES

<u>Agency</u>	<u>Current Schedules Analyzed</u>	<u>Sample Schedules Designed</u>	<u>Other Services Provided</u>
1. Anaheim Public Library	4	4	
2. Fresno Fleet Maintenance	4	8	
3. Fresno Parks and Recreation	1	1	
4. Fresno Transit Maintenance	2	4	-Provided instructional material which enabled supervisor to design own schedules
5. Fresno Wastewater Treatment Plant	2	11	-Suggested procedures for systematizing periodic schedule changes
6. Pasadena Paramedic Ambulance Service	1	8	-Calculated saturation probabilities for various call rates and numbers of units
7. San Diego Aquatics Division	3	10	-Provided instructional material which enabled agency to design own schedules
8. San Jose Vehicle Maintenance	3	9	
9. Santa Clara Electric Department	2	3	
10. Santa Clara Public Library	4	5	-Provided detailed analyses of workload data
Total	26	63	

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- agency supervisors, without advanced mathematical skills, can learn to use the methods presented in the Handbook; and
- use of the scheduling methods can reduce the administrative time spent on schedule design, enable agency personnel to more easily design work schedules with pre-specified attributes, and have a positive effect on the provision of services.

Additional information about project outcomes is presented in Appendix B.

D. Fresno Transit Maintenance - A Case Study of Work Schedule Design

This section presents an overview of the field test results in one target agency, and illustrates many of the issues that often arise in the design, review, and implementation of work schedules.

Background

The City of Fresno operates its own bus system; related maintenance work and road calls are provided 24 hours a day, seven days a week. Work performed in the maintenance shop includes daily servicing and washing, preventive maintenance, and mechanical and body repairs. At the time of the work scheduling project, shop personnel included: 10 mechanics, 8 service workers, 6 attendants, 7 specialists and other shop workers, 7 leadmen and foremen, and 3 management personnel.

The volume of workload in the maintenance shop varies by time of day and day of week. Each bus must be washed, inspected, and serviced before it is put on the road each morning. Most mechanical problems are reported when drivers start the buses in the morning, when new drivers take over in the afternoon, and when buses are taken out of service at night. As a result, workload is heaviest between 4:00 a.m. and 7:00 a.m., 2:00 p.m. and 5:00 p.m., and 8:00

p.m. and midnight. The daily workload volume depends upon the number of buses placed in service. Bus use is heaviest on Mondays and Thursdays and lightest on Sundays.

Scheduling Objectives Addressed

The entire transit system had been placed under new management approximately a year before the work scheduling project began, and all aspects of agency operation were being analyzed to identify needed improvements. A new manager of the maintenance shop had been hired three months before the project began, and he had already identified several problems related to work scheduling:

- the existing schedule did not provide on-duty staffing levels that were proportional to the cyclic variations in shop workload;
- periodic schedule revisions involved a time-consuming process of trial and error; and
- due to a lack of schedule design expertise and resource material, little could be done to adapt the schedule to temporary changes in workload.

The shop manager was interested in exploring alternative scheduling methods. Of particular interest was the possibility of designing work schedules with rotating employee shift assignments and rotating days off which would provide a more proportional distribution of staffing by shift and day of the week.

Discussions with the shop manager revealed several additional scheduling objectives and constraints. These included the following:

- a proper mix of employee skills must be available at different times of the day and on different days of the week;
- to utilize the shop's limited space and staff resources, the number of on-duty employees must be proportional to shop workload by shift and day of the week; and
- each employee must receive two consecutive days off each week, per the contractual agreement between

the City of Fresno and the employee bargaining unit (Local 2051, American Federation of State, County, and Municipal Employees).

Application of Innovative Scheduling Methods

During the initial interviews conducted by TIPPA staff in February 1977 with transit personnel and the Fresno science advisor, it was agreed that new work schedules should be designed first for shop mechanics and service workers and later for attendants.

Using workload data collected by shop personnel, several sample schedules for mechanics and service workers were designed by TIPPA staff and reviewed by the shop manager and selected employees. The schedules illustrated how proportional staffing by shift and day of the week could be achieved with either fixed or rotating days off and rotating shift assignments. Employee reactions to these schedules convinced the shop manager that it would not be feasible to use rotating days off and rotating shift assignments.

At the June 1977 project meeting in Anaheim, the shop manager was introduced to the TIPPA technique for designing schedules with fixed days off. Based on what he learned and training materials distributed at the meeting, he used agency workload data to allocate personnel by shift and day of the week and designed schedules for shop mechanics and service workers. At the same time, the union steward in the maintenance shop and senior employees were consulted to acquaint them with the reasons behind the changes being made.

The new schedules were implemented late in the summer of 1977 with little disruption and few complaints. Since that time, several

staffing changes have been made in the shop, necessitating further revision of some schedules. These revisions have been handled quickly and smoothly using the same schedule design techniques.

Project Outcomes

In August 1977, TIPPA staff conducted a follow-up visit to the Fresno Transit Department. At that time, the shop manager reported continued success in using the new scheduling techniques. He estimated that the amount of time required to design schedules had been cut in half--from two or three days per schedule to one day or less. Furthermore, he felt that he was producing better schedules since he now had extra staff on duty during heavy workload shifts, had essential positions staffed during other hours, and had eliminated split days off. In addition, he believed the simplified scheduling procedures would eventually allow him to delegate scheduling to staff at a lower supervisory level.

A later report from the Fresno science advisor confirmed that the transit agency was continuing to benefit from the new techniques. Although schedule design had become almost a monthly task due to vacations, employee turnover, increased workload, and the hiring of additional personnel, the manager was able to adjust easily using the new design procedures.

Conclusions

Factors contributing to the success of the schedule design effort in the Fresno Transit Maintenance Department included the following:

- There was a recognized need for revision of the agency's work schedules.
- The shop manager designed and implemented schedules on his own, simplifying the schedule design and review process.

- Other organizational changes occurring at the same time established a favorable climate for change.
- Labor and management cooperated in reviewing proposed schedules before implementation to ensure that all contractual requirements were satisfied.

E. How To Use the Schedule Design Handbook

Assessing the Usefulness of the Handbook for a Particular Application

Persons who are planning to use the Handbook should understand the kinds of schedules that can be designed using its methods, the basic assumptions and limitations of the schedules which it covers, and the kinds of schedules and scheduling problems that are not addressed.

Types of schedules covered in the Handbook. The Handbook describes manual methods for designing fixed bracket, duty cycle, and proportional rotating schedules, the most common types of work schedules employed by extended-hours services.

A fixed bracket schedule is one in which each employee receives the same days off each week. The name is derived from the fact that each employee works the same seven-day schedule "bracket" each week (i.e., upon completion of the seven-day sequence of work and off-duty assignments, the employee starts again with the first day of the same sequence). A different seven-day schedule bracket is assigned to each employee or group of employees. Fixed bracket schedules are used when coverage must be provided more than five days a week. These schedules can be used when daily staffing is uniform (i.e., when the same number of employees are on duty each day of the week) or when on-duty staffing varies by day of the week (e.g., to provide a "high" level of coverage on Monday through Friday and a "low" level of coverage on Saturday and Sunday).

Two fixed brackets schedules are shown in figures 1-1 and 1-2. The schedule in Figure 1-1 consists of seven brackets each containing exactly seven days. One employee is assigned to each bracket. Off-duty days in each bracket are identified with the letter R; on-duty days are left blank. The pattern of on- and off-duty days in each bracket describes the weekly work pattern for the employee assigned to that bracket. In Figure 1-1, for example, the employee assigned to bracket 1 works Wednesday through Sunday, and has Monday and Tuesday off each week. The employee assigned to bracket 5 works Sunday through Thursday, and has Friday and Saturday off each week. The six-bracket schedule in Figure 1-2 provides uniform staffing on Monday through Friday and a reduced staffing level on Saturday and Sunday.

In a duty cycle schedule, all employees follow the same pattern of rotating shift assignments and days off. Duty cycle schedules are used to provide levels that are uniform or nearly uniform by day of week. As an example, in a "four on, two off" duty cycle schedule, each employee works a six-day pattern, the duty cycle, consisting of four consecutive on-duty assignments followed by two consecutive off-duty days. Figure 1-3 illustrates how this pattern can be used to schedule six employees. Each employee is assigned to a different six-day bracket. After working the six-day pattern, each employee returns to the first day of the same bracket. Each bracket is based on the same six-day duty cycle. On each day, four employees are on duty and two employees are off duty. It should be noted that the use of a duty cycle which is not seven days in length will result in each employee's days off changing from week to week. This is illustrated in Figure 1-4.

	M	T	W	T	F	S	S
1	R	R					
2		R	R				
3			R	R			
4				R	R		
5					R	R	
6						R	R
7	R						R
No. of On-Duty Employees	5	5	5	5	5	5	5

Figure 1-1

SEVEN-BRACKET SCHEDULE WITH UNIFORM DAILY COVERAGE

	M	T	W	T	F	S	S
1		R	R				
2				R	R		
3	R						R
4						R	R
5						R	R
6						R	R
No. of On-Duty Employees	5	5	5	5	5	3	2

Figure 1-2

SIX-BRACKET SCHEDULE WITH NON-UNIFORM DAILY COVERAGE

<u>Bracket</u>	<u>Day</u>					
	1	2	3	4	5	6
1					R	R
2	R					R
3	R	R				
4		R	R			
5			R	R		
6				R	R	

Figure 1-3

SIX-DAY DUTY CYCLE SCHEDULE

<u>Week</u>	M	T	W	T	F	S	S
1					R	R	
2				R	R		
3			R	R			
4		R	R				
5	R	R					R
6	R					R	R

Figure 1-4

SIX-WEEK CALENDAR OF ASSIGNMENTS FOR
 ONE EMPLOYEE FOLLOWING THE SIX-DAY DUTY
 CYCLE; FOUR-ON, TWO-OFF

The primary feature of proportional rotating (PR) schedules is their ability to provide variable (or proportional) staffing by day of week without the use of permanently assigned days off. Each employee works a series of one-week schedule brackets in sequence and begins the sequence again after completing the final bracket. All employees follow the same sequence of brackets. When multi-shift schedules are designed, variable staffing levels by shift and day of the week can be achieved.

An example of a one-shift PR schedule is shown in Figure 1-5. This schedule consists of six brackets and is used in the following manner. One employee or group of employees is assigned to each bracket. After working the pattern of on- and off-duty days in that bracket (i.e., after one week), each employee or group rotates down to the next bracket in the schedule. (The employee

	M	T	W	T	F	S	S
1	R	R					
2		R	R	R			
3				R	R		
4					R	R	
5						R	R
6							R

Figure 1-5

ONE-SHIFT PR SCHEDULE

completing bracket 6 rotates back to bracket 1.) After six weeks, every employee will have spent exactly one week on each bracket in the schedule. Although the employees change brackets every week, the number of employees scheduled to be on duty on each day of the week does not change. For example, in the PR schedule in Figure 1-5, five employees are scheduled to be on duty on Mondays and Wednesdays and four employees are scheduled to be on duty on each of the other day of the week.

Assumptions and limitations of the schedules described in the Handbook. Assumptions and limitations associated with the Handbook's schedule design procedures include the following:

- Interchangeability of employees - It is assumed that all employees have the same skills and are interchangeable in the work schedule. To use the Handbook to design work schedules for agencies which must have a mixture of employee skills on duty, the work force is divided into sets of employees with comparable skills and separate schedules are designed for each set.
- Work force size - The Handbook is most readily used to construct schedules for agencies with between 5 and 30 employees or groups of employees. Work schedules for fewer than five employees can usually be found without the use of a systematic design procedure. When more than 30 employees are to be scheduled, it is usually advantageous to cluster them into groups of equal size and to design work schedules based on the number of groups. This simplifies the design process and usually produces a less complicated and easier-to-manage schedule.
- Individualized schedule preferences - The design methods in the Handbook are not useful for constructing schedules which are frequently adjusted (e.g., weekly) to accommodate the changing preferences of individual employees.

Schedule design methods not covered in the Handbook. This Handbook does not cover flexible hours schedules ("flexitime"), procedures for designing schedules on a weekly or bi-weekly basis, methods for periodically reassigning employees to new fixed schedule brackets, procedures for scheduling part-time employees,

or methods for determining how many employees are needed to handle a given workload level.

Flexible hours or flexitime schedules are fixed bracket schedules in which employees are allowed to set their own starting and quitting times, provided that they work a required number of hours each day and are present during required "core" hours. Further information on flexitime may be obtained from United States Civil Service Commission publications.*

Continuous schedule design procedures, in which employee work schedules are designed on a weekly or bi-weekly basis, are highly individualized to local agency settings. Such procedures are widely used in libraries, for example, where it is important to match on-duty staffing levels and individual employee skills with daily fluctuations in workload, and are usually dependent upon the schedule designer's knowledge of individual employee skills, agency workload patterns, and local personnel rules. As a result, procedures used by one agency are rarely transferrable to other work environments.

In order to have employees share equitably in days off and shift assignments, many agencies which use fixed bracket schedules periodically reassign employees to new brackets. The reassignment of days off and shifts usually occurs at fixed intervals, such as every three months. Such a procedure improves schedule equity while retaining the stability of fixed bracket schedules. The practice, however, can require considerable administrative work at the time of bracket reassignments to ensure that all employees are assigned the correct number of on- and off-duty days.

*Barbara L. Fiss, Flexitime - A Guide, Washington, D. C.: U. S. Government Printing Office, May 1974.

All of the schedule design methods presented in the Handbook assume that either the desired number of on-duty employees on each shift and day of the week or the total number of employees in the work force is known. The Handbook does not describe how agencies should measure their workload or how workload levels should be used to determine how many on-duty employees are required.

Using the Handbook to Design Schedules

The Design Handbook is organized to help the user with each major step of schedule design. These steps include: (1) analysis of the agency's current schedule(s) to determine what schedule-related constraints must be observed in the design of new schedules, (2) determination of the number of employees to be scheduled based on on-duty staffing requirements and their on-duty allocation by shift and day of the week, (3) selection of the appropriate schedule type and design method based on the required properties of the schedule, and (4) design of one or more alternative schedules.

Chapter II presents an overview of the schedule design process. Topics covered include the reasons schedules are changed, the frequency of schedule design, participants in the design process, and steps in designing, implementing, and evaluating new schedules.

Chapter III introduces the scheduling concepts and terminology used to describe the design procedures in the Handbook. (A glossary of scheduling terms is also presented in Appendix A.) This chapter is designed to help the reader analyze a work schedule to determine the average work week, length of the rotation period, staff allocation by shift and day of the week, the lengths of the on- and off-duty periods, the frequency of weekends off, and other properties related to shift reassignments.

Questions related to the number of employees and their allocation by shift and day of week are addressed in Chapter IV. A procedure for determining an agency's shift relief factor using employee attendance data is presented, and several examples are included to illustrate how relief factors can be used to determine how many employees are needed to support a specified on-duty staffing level. This chapter also describes procedures for allocating on-duty staff to match workload variations by shift and day of week. Allocation procedures are presented for one-shift, multishift, and overlapping shift work environments. Issues related to minimum staffing requirements are discussed further in appendixes C and D.

Chapter V presents a systematic procedure for determining which of the Handbook's schedule design methods, if any, can be used to accommodate a specified set of work rules and constraints: fixed bracket (Chapter VI), duty cycle (Chapter VII), or proportional rotating (Chapter VIII).

Issues related to the implementation and administration of new schedules are discussed in Appendix B. A listing of other resources dealing with schedule-related issues and design methods is presented in the Bibliography. Information and training on designing work schedules with programmable calculators, microcomputers, or large-scale computer systems is available from The Institute for Public Program Analysis.

CHAPTER II

OVERVIEW OF THE WORK SCHEDULE DESIGN PROCESS

A. Introduction

This chapter provides an introductory overview of the work schedule design process and the management environment within which work scheduling takes place. It covers the reasons for which schedules are changed, the frequency with which such changes are made, the range of participants in schedule design, and the steps involved in designing work schedules. At various points, references are made to more detailed discussions in other sections of this handbook.

The primary purpose of this overview chapter is to caution users of the handbook against the expectation that knowing how to design improved work schedules will help them solve every personnel problem related to work scheduling. Such is not the case. The technologies described in this handbook are only one management skill among many that are needed to effectively address the kinds of schedule-related issues discussed below.

B. Reasons for Changing Work Schedules

Most work schedules must be periodically revised or redesigned. The need for schedule redesign can arise as a result of any of the following:

- initiation of a new service,
- change in the size or deployment of the work force,
- change in the hours during which service is offered,
- change in the number of hours in the average work week,

- change in the employee leave-of-absence policies (e.g., increase in vacation leave),
- changes in employee use of sick leave and other forms of leave,
- changes in other aspects of collective bargaining agreements (e.g., seniority privileges),
- a perceived need to reassign employees to new shifts or days off to provide increased schedule equity, or
- changes in workload patterns, necessitating reallocation of on-duty employees by shift or day of the week.

C. Frequency of Schedule Changes

The length of time between the implementation of a new schedule and its subsequent cancellation is referred to as the schedule design interval. This interval is sometimes as short as one or two weeks, in which case schedule design is almost a continuous process. In other situations regular schedule revisions occur at longer intervals, such as every three months; and in still others changes are made irregularly and only when absolutely necessary.

Continuous Schedule Design

When schedule design is effectively continuous, supervisors generally have considerable authority to adjust schedules on a weekly, bi-weekly, or monthly basis, within established guidelines. These guidelines commonly include the number of hours to be worked by each employee, the maximum or minimum number of evening or weekend assignments to be given to each employee, and the number of on-duty employees needed from each skill level or personnel classification. For example, in some libraries, employees are required to work two evenings per week and every second or third Saturday.

This type of scheduling allows a great deal of flexibility in accommodating employee preferences regarding days off and evening assignments. When work schedules are continuously altered, however, scheduling becomes an on-going process requiring constant attention and sometimes consuming large amounts of supervisory time.

Fixed Interval Schedule Design

In this situation, the same schedule is followed for a specified period of time (e.g., 3 months), after which a new schedule is designed or employees are reassigned to different brackets within the same schedule. Supervisory authority to change employee schedules during the interval is normally limited to short-term reassignments to compensate for absences or temporary workload variations.

Fixed interval schedule redesign provides schedule stability and regularity within each design interval, since working hours and days off are usually fixed during each design period. Yet such a scheduling procedure can also provide long-term schedule equity if it involves periodic rotation of employee shift assignments and days off. While fixed interval schedule design requires less day-to-day supervisory attention than continuous scheduling, considerable work may still be needed to design new schedules at the end of each interval.

As-Needed Schedule Design

Often work schedules are revised only in response to an identified need and are used for long periods of time without modification. Supervisory authority to adjust schedules for

individual employees is usually limited to short-term reassignments to compensate for absences or temporary workload variations.

With this design procedure, schedule regularity and stability are provided over extended periods of time, but often the longer a schedule is used, the more difficult it becomes to initiate schedule changes. Thus, minor problems with the work schedule (e.g., gradual changes in workload) are often allowed to accumulate until the schedule becomes obviously inadequate in meeting management needs).

D. Schedule Design Participants

Schedule design may involve participation by a considerable number of people representing agency management, labor, technical support staff, and outside consultants. Management participants may include the agency director, personnel director, attorney, employee relations officer, and perhaps the local civil service commission. Labor participants may include representatives of the local employee bargaining unit or senior employees who act as informal spokesmen for the work force. Technical staff participating may include budget and data analysts and planners responsible for actually designing the schedules. Any of these groups may use outside consultants to provide assistance in the schedule design or collective bargaining processes. Other groups such as the National Council for Alternative Work Patterns or the Work in America Institute may have an indirect role in schedule design by disseminating information on work scheduling trends and issues.

Since work scheduling involves a variety of participants

with potentially conflicting objectives, the schedule design process often becomes one of bargaining and negotiation. Schedule attributes considered desirable by some participants may be unacceptable to others. When more than a few people are involved in a schedule design effort, some agencies have found it helpful to form a schedule design task force composed of persons who are most closely involved in the design and implementation of the new schedule.

E. Steps in Schedule Design

Schedule design involves a series of interrelated steps which include: analyzing the current schedule; identifying schedule design objectives and constraints; and designing, selling, implementing, and evaluating the new schedule. This process is illustrated in Figure 2-1.

Each step is influenced by work done in the preceding steps. Likewise, the successful completion of the tasks associated with each step is usually necessary for completion of tasks in subsequent steps. For example, final versions of schedules cannot be designed until major schedule objectives and constraints are clearly identified. Work performed at certain stages in the process often leads to a reassessment of work done in previous steps.

Each step in the design process is discussed briefly below, with references to more detailed discussions in other chapters of this handbook.

Analyzing the Current Schedule

Chapter III presents a detailed description of procedures

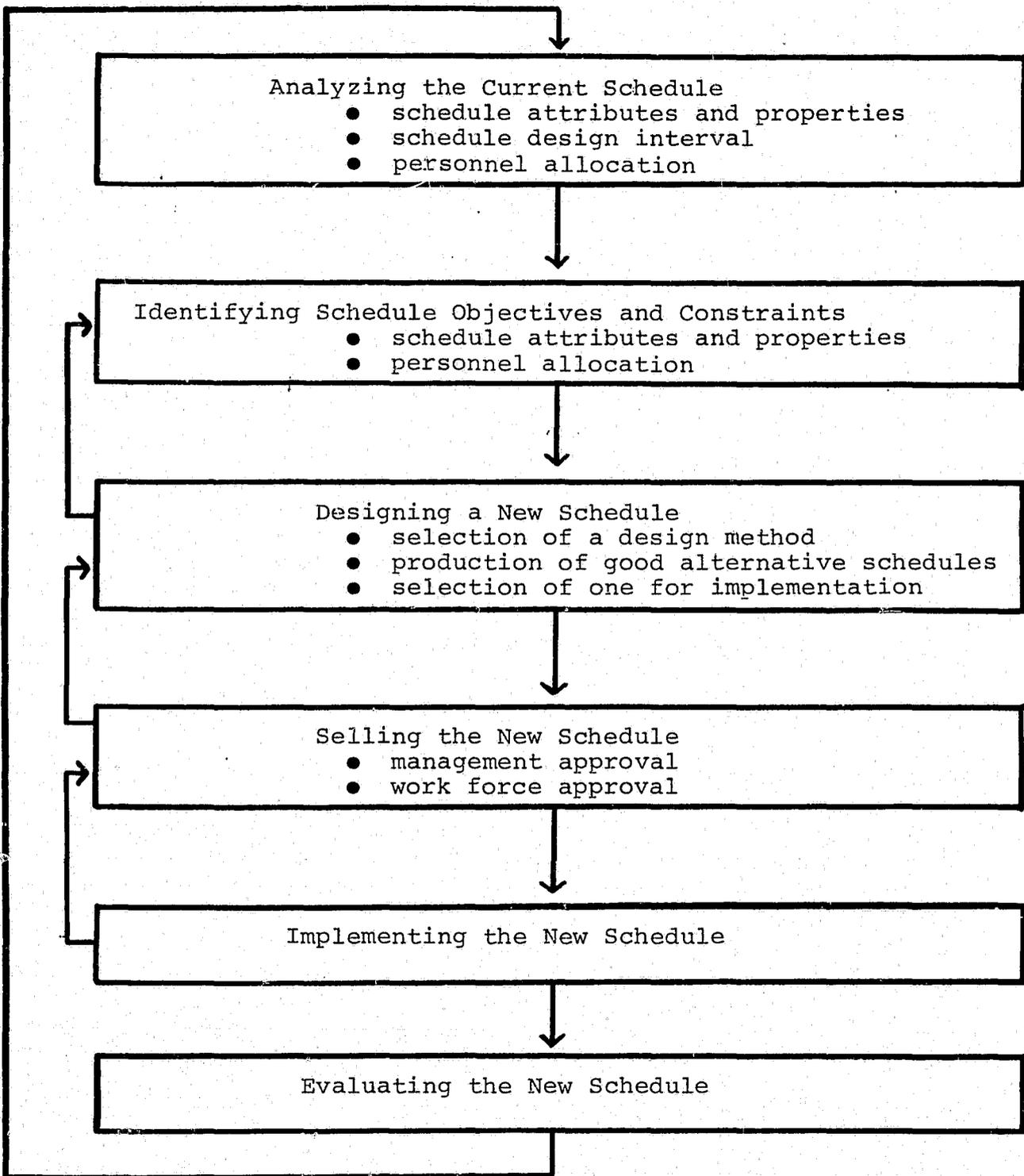


Figure 2-1

THE WORK SCHEDULE DESIGN PROCESS

for analyzing work schedules and identifying the following properties for each:

- shift properties, including number of shifts, shift starting times, shift length, shift overlaps, and shift rotation sequence (if any);
- length of the duty cycle and week cycle;
- properties of work periods and off-duty periods, including maximum and minimum lengths, frequency with which periods of various lengths occur, distribution of short and long periods within the week cycle, and number of weekends off;
- length of the average work week;
- number, size, and composition of groups of identically-scheduled employees, and degree of team integrity; and
- number of employees on duty by time of day and day of week.

Identifying Objectives and Constraints

Objectives are desirable schedule attributes, while constraints are required attributes. Both narrow the range of alternative schedules to be considered. They can arise from several sources:

- personal preferences of management and labor,
- legal and contractual restrictions on work schedules,
- equipment and facility constraints, and
- limitations on the size and composition of the work force.

Constraints and objectives relating to personnel allocation are discussed in Chapter IV, which focuses on procedures for matching on-duty staffing to variations in agency workload.

Legal restrictions on work schedules can be found in federal, state, and local laws. The federal Fair Labor Standards Act

(FLSA) sets standards for employees' wages and working hours. Most provisions of the FLSA currently apply only to private sector employers, but some states have passed laws containing similar or more restrictive provisions affecting schedules for public employees. Local ordinances and civil service regulations may also set standards for public employees' work schedules. Also, collective bargaining agreements frequently specify employees' working hours.

Agency equipment and facility limitations can affect work schedules in several ways. The availability of job-related equipment and agency facilities may limit the number of on-duty employees that can be effectively utilized. The need to share equipment among several units or facilities may also affect personnel allocation planning. Employee work schedules may also be affected by problems with job shop scheduling (i.e., the sequencing and timing of job-related tasks).

Work schedules are also affected by the size and composition of the work force. Most schedules involve dividing the work force into groups of identically-scheduled employees. The size and composition of these groups is an important schedule attribute. Chapter IV discusses procedures for calculating the number of employees needed to provide desired levels of on-duty staffing, and conversely, the levels of on-duty staffing that can be achieved with a given number of employees. The use of part-time employees can provide additional flexibility in achieving desired on-duty staffing levels, but may also create schedule management problems (see below and Appendix C).

The type of schedule selected and the make-up of the schedule groups depend upon whether the work force is composed of interchangeable employees or of employees of different skill levels and personnel classifications.

Designing a New Schedule

Once schedule design objectives and constraints have been identified, the design of new schedules can begin. The first decision facing the designer is the selection of an appropriate type of schedule and review of the corresponding design methods. Information on the selection of an appropriate type of schedule and design method is presented in Chapter V.

Schedule design problems often arise not because of the type of schedule or design method being used, but because of the relationship between work scheduling and other aspects of agency operations. Agency work schedules, workload patterns, and personnel policies are closely interrelated, and changes in one area may create problems in the others. For example:

- Existing personnel may no longer provide the desired level of coverage due to increases in workload, decreases in the average work week, or increases in employee absences; in such cases, additional employees may be needed or levels of coverage may need to be adjusted (see Chapter IV).
- Vacations may deplete the size of the on-duty contingent at certain times of the year, necessitating the use of special vacation scheduling procedures (see Appendix C).
- Use of part-time employees may present schedule design and management problems (see Appendix C).
- If employees are allowed time off for school or advanced training, procedures for covering these positions may be needed.

- If service is offered on holidays, policies regarding holiday leave may need to be revised when a new schedule is implemented.
- For some types of schedules, the number of on-duty days per pay period may vary, so that employees paid on the basis of actual hours worked may not receive the same compensation each pay period; as a result, schedule changes may necessitate pay policy changes (see Appendix C).

Selling a Schedule to Management and Labor

Before a new schedule can be implemented, it frequently must be approved by management or labor representatives or both. Less "selling" is usually needed if management and labor have been involved in the process leading up to the design of the schedule and if there has been preliminary agreement on schedule design objectives. However, such a mutual understanding approach may not always be possible--especially where work schedule changes are subject to formalized collective bargaining (or "meet and confer") procedures or where approval of schedule changes may be linked to other non-scheduling issues. Final agreements may also be subject to approval by an elected commission or city council. In some cases, the job of selling a new work schedule may be the responsibility of professional negotiators.

Implementing a New Schedule

Work schedule implementation problems can usually be eased somewhat if sufficient time and attention are devoted to preparatory tasks such as setting a changeover date, disseminating changeover information to employees, examining individual or group schedules for unacceptable changeover properties, and reviewing the impact of the new schedule upon personnel policies

and administrative procedures. Each of these tasks is discussed below.

Setting a changeover date. The selection of a changeover date is crucial to the smooth implementation of a new schedule. Considerations in setting it include the following:

- agency workload cycles;
- the duty cycle or week cycle of the existing schedule (it will generally be easier to change over to a new schedule at the end of a complete cycle of the old schedule);
- agency pay periods; and
- impact on other agency operations (e.g., it may or may not be advantageous to have the implementation of a new schedule coincide with the implementation of a new program or an administrative reorganization).

Dissemination of changeover information. Schedule calendars or duty rosters should be prepared and posted or given to individual employees well in advance of the changeover date. It may also be helpful to give supervisory personnel special training in the operation of the new schedule so that they can answer subordinates' questions and be prepared to accept responsibility for specific aspects of schedule implementation. Similarly, it may be helpful to summarize for employees the need for the new schedule, and the efforts being made to minimize operational disruptions and personal inconveniences resulting from the changeover. Methods of communicating this information include agency memoranda, employee newsletters, and employee meetings.

Examination of individual or group changeover properties. In changing from one work schedule to another, scheduling problems may result from joining the final work or off-duty periods under

the old schedule (i.e., the ones immediately preceding the changeover) with the first work or off-duty periods assigned as part of the new schedule (i.e., the ones immediately following the changeover). These problems may include:

- unacceptably long work periods,
- insufficient or excess numbers of work days in the pay period containing the changeover, and
- insufficient time off before beginning work on a different shift.

To rectify these problems it may be necessary to make some temporary changes in the schedules for some individuals or groups.

Review of schedule impact upon personnel policies and administrative procedures. Work scheduling is such an essential part of organizational management that it affects many other management practices such as employee leave policies (holidays, vacations, sick leave), pay procedures, work force composition and deployment, and scheduling of in-service training and other on-duty activities. A change in work schedules may necessitate changes in these related management practices. (See Appendix C.)

Evaluating a New Schedule

Evaluations of new schedules are usually limited to a monitoring of employee and management reactions and implementation problems in the first few weeks following the changeover. Problems may arise concerning some schedule attributes or changeover properties, difficulties with understanding new schedule calendars and duty rosters, or confusion with using new record-keeping procedures that may have been implemented along with the

new schedule. Persistent problems, however, may necessitate a reexamination of schedule objectives and attributes.

A more detailed evaluation of a new schedule may occasionally be desired. Such an evaluation may attempt to assess the schedule's impact upon productivity (e.g., work output, service delays, absenteeism), employee satisfaction, or ease of supervision. However, such effects are difficult to measure, and even more difficult to attribute directly to changes in the work schedule.

Attempts to evaluate the "quality" of a schedule may be of limited value because of the subjective nature of such evaluations. Also, a schedule may be faulted for many reasons unrelated to the schedule itself: the reasons for designing a new schedule may have been faulty, too much may have been expected of the schedule, or faulty assumptions may have been made in selecting schedule design objectives.

It is sometimes useful to focus evaluation efforts on the agency's schedule design capability, especially if new design methods have affected the agency's ability to design schedules to meet prescribed schedule design objectives and to identify assumptions underlying these objectives. Information gained from this type of an evaluation could provide valuable input for future schedule design efforts.

CHAPTER III

HOW TO ANALYZE A WORK SCHEDULE

A. Introduction

A work schedule is a specification of shift assignments and days off for individual employees or groups of employees. This chapter discusses methods of analyzing work schedules for a work force--the employees who form the organization, division, or unit being scheduled. All employees within a work force need not be on the same type of schedule. Consequently, in analyzing a work force's "schedule" it is often necessary to divide the force into subsets of employees with like schedules, and to analyze the schedule of each subset separately. As a result, analysis of a given work schedule may show that it designates on-duty shifts and off-duty days for the entire work force, a portion of the work force, or an individual employee.

In order to be able to analyze a schedule, one must first understand how schedules are commonly represented. Section B of this chapter presents the most commonly used formats. These are used throughout the handbook to illustrate schedules of various types. Section C introduces important properties of work schedules, and discusses how they can be determined for a given schedule. The final section summarizes the procedures used in analyzing a work schedule, and illustrates them with several examples.

B. Methods of Representing Work Schedules

The three most commonly used types of schedule representations are discussed in this section. These are:

- duty cycle representations, which show employees' shift assignments and days off without specifying the day of week or date associated with each assignment;
- bracket representations, which show an employees' shift assignments and days off for each day of the week; and
- calendar representations, which show employees' shift assignments and days off by date over an extended period of time, such as one year.

Formats used in each type of representation vary according to whether the schedule being shown is for a single employee, a single group of employees sharing the same shift assignments and days off, or several groups of employees. The remainder of this section describes and gives examples of these types of schedule representations.

As illustrated in the schedules shown in this section, various notations may be used to designate schedule assignments. For example, an on-duty assignment in a schedule which uses a single shift may be represented as W, X, *, or ON. Shift assignments in a two-shift schedule may be represented as D and N, A and B, or 1 and 2. Shift assignments in a three-shift schedule may be represented as D, A, and N; A, B, and C, etc. Other representations use shift starting times or shift lengths to designate assignments to the various shifts. Off-duty assignments may be represented as R (for "rest day"), O, or OFF.

Duty Cycle Representations

Most work schedules are based on repeating patterns of shift assignments and days off. These repeating patterns, termed duty cycles, provide a simple way of representing schedules--especially if the length of the pattern is not too long,

and the number of different duty cycles used by groups in the work force is small.

Duty cycle representations usually illustrate the schedules of groups of employees sharing the same pattern of shift assignments and days off. One common representation shows assignments for a single group and it is implicitly understood that all other groups use the same duty cycle as the first, with the starting day shifted a certain number of days earlier or later. Such a schedule is illustrated in Figure 3-1 for a duty cycle consisting of five day-shift assignments (denoted by D), two off-duty days (denoted by R), five afternoon-shift assignments (denoted by A), two off-duty days, five night-shift assignments (denoted by N), and two off-duty days. In this format, the duty assignment for the group is shown on each day of the

<u>Day of the Duty Cycle</u>																				
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>
D	D	D	D	D	R	R	A	A	A	A	R	R	N	N	N	N	N	N	R	R

Figure 3-1

DUTY CYCLE REPRESENTATION FOR A SINGLE GROUP

duty cycle. The schedule can be represented in a more compact form as

5D-2R-5A-2R-5N-2R

which specifies the number of consecutive days for which the duty assignment is unchanged and the sequence of shift assignments and off-duty days used.

Alternatively, the schedule may explicitly represent all groups simultaneously, as shown in figures 3-2 and 3-3. These figures are based on the same duty cycle shown above. In Figure 3-2, the duty assignment is specified for each group of identically-scheduled employees on each day of the duty cycle. Note that each group uses the same duty cycle (5D-2R-5A-2R-5N-2R), with the starting days for groups B and C shifted 7 and 14 days, respectively, to the right of the starting day for group A.

In Figure 3-3, the groups on duty each shift, and those off duty, are shown for each day of the duty cycle. For example, on the fifth day of the duty cycle, the day shift is staffed by group A, the afternoon shift by group C, and the night shift by group B; on the sixth and seventh days of the duty cycle, all groups are off duty.

Bracket Representations

Bracket representations of work schedules show duty assignments displayed in segments, termed brackets, which are usually one week in length. In such a representation, the day of week corresponding to each duty assignment is indicated, but specific dates are not. A single employee, or a group of several employees, may be assigned to each bracket. Also, employees may be permanently

Day of Duty Cycle

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>
Group A	D	D	D	D	D	R	R	A	A	A	A	A	R	R	N	N	N	N	N	R	R
Group B	N	N	N	N	N	R	R	D	D	D	D	D	R	R	A	A	A	A	A	R	R
Group C	A	A	A	A	A	R	R	N	N	N	N	N	R	R	D	D	D	D	D	R	R

Figure 3-2

DUTY CYCLE REPRESENTATION SHOWING DUTY ASSIGNMENTS FOR ALL GROUPS

Day of Duty Cycle

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>
Day Shift	A	A	A	A	A	-	-	B	B	B	B	B	-	-	C	C	C	C	C	-	-
Afternoon Shift	C	C	C	C	C	-	-	A	A	A	A	A	-	-	B	B	B	B	B	-	-
Night Shift	B	B	B	B	B	-	-	C	C	C	C	C	-	-	A	A	A	A	A	-	-
Off Duty	-	-	-	-	-	ABC	ABC	-	-	-	-	-	ABC	ABC	-	-	-	-	-	ABC	ABC

Figure 3-3

DUTY CYCLE REPRESENTATION SHOWING GROUPS ON DUTY ON EACH SHIFT
AND THOSE OFF DUTY ON EACH DAY OF THE DUTY CYCLE

assigned to brackets, or they may rotate weekly, or at some other fixed interval, from one bracket to the next. Figures 3-4 and 3-5 illustrate alternative bracket representations for a single-shift work schedule in which two employees are off duty on Thursday and Friday, three are off duty on Friday and Saturday, and one is off duty on Saturday and Sunday.

In Figure 3-4, the brackets defined by the three pairs of off-duty days are shown along with the numbers of employees assigned to each. Because only a single shift is involved, on-duty days are denoted by leaving blank the column for the corresponding day of week. If employees' bracket assignments remain fixed from week to week, the format illustrated in Figure 3-5 can be interpreted as showing the bracket permanently assigned to each employee; or if the bracket assignments are rotated periodically (e.g., weekly), as showing the brackets to which a single employee, or group of identically-scheduled employees, is assigned in succeeding weeks. Thus, an employee might begin by working the bracket shown in line 1 of Figure 3-5 for a week and then rotate to line 2 for a week, line 3 for a week, etc. After working line 6 for a week, the employee would rotate back to line 1. Note that rotating an employee through some number of brackets, n , is equivalent to permanently assigning that employee to a bracket that is n weeks in length (see Figure 3-6).

Calendar Representations

Calendar representations of work schedules generally show employees' daily assignments for a few months or a full year. Some show the duty assignment of individual groups of identically-

<u>Number of Employees</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
2				R	R		
3					R	R	
1						R	R

Figure 3-4

BRACKET REPRESENTATION SHOWING THE NUMBER OF EMPLOYEES
ASSIGNED TO EACH BRACKET

<u>Employee/ Week</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1				R	R		
2				R	R		
3					R	R	
4					R	R	
5					R	R	
6						R	R

Figure 3-5

BRACKET REPRESENTATION SHOWING THE BRACKET ASSIGNED
TO EACH EMPLOYEE OR THE BRACKET ASSIGNED TO A
SINGLE EMPLOYEE OR GROUP OF EMPLOYEES IN SUCCESSIVE WEEKS

Rotation Through Three One-Week Brackets:

<u>Week</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1				R	R		
2					R	R	
3						R	R

Permanent Assignment to a Three-Week Bracket:

<u>Employee</u>	<u>Day of Week</u>																						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>		
1				R	R							R	R							R	R		

Figure 3-6

EQUIVALENT BRACKET REPRESENTATIONS OF A WORK
SCHEDULE WITH A 21-DAY DUTY CYCLE

scheduled employees, while others show the groups which are assigned to each shift and those which are off duty, for each day of the period covered. Alternative formats are illustrated in figures 3-7 through 3-12.

Figure 3-7 illustrates a calendar representation which identifies the duty assignments for a specific employee, beginning in October 1976. The format used in Figure 3-8 is self-explanatory. In Figure 3-9 each row contains the dates, in columns headed "JAN," "FEB," etc., for which the duty assignments of the rightmost four columns for each group are applicable. For example, the topmost line of the table indicates that on February 2, March 30, May 25, July 20, September 14, and November 9, groups 1 and 4 are assigned to the day and night shifts, respectively, and groups 2 and 3 are off duty. Figure 3-10 contains a similar representation, in which each column contains the dates for which the duty assignments contained in the top four rows apply. (Note that the length of each row is equal to the length of the duty cycle.) In Figure 3-11 the group assigned to the day shift of a two-shift schedule appears in the upper right-hand corner of each date block, while the group assigned to the night shift appears in the lower right-hand corner of the block. Groups not listed on a particular date are off duty. For example, on January 17, group A works the day shift, group D works the night shift, and groups B and C are off duty. Figure 3-12 shows one other form of calendar representation. In this case, on-duty groups are indicated in the two leftmost columns of the schedule. Groups not listed are off duty.

Man Number 3 1976

OCTOBER							NOVEMBER							DECEMBER						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
			1	2	3	4							1		1	2	3	4	5	6
			A	R	R	A							D		M	M	M	M	M	R
5	6	7	8	9	10	11	2	3	4	5	6	7	8	7	8	9	10	11	12	13
A	A	A	A	A	A	R	D	D	D	D	D	D	R	R	R	R	A	A	A	A
12	13	14	15	16	17	18	9	10	11	12	13	14	15	14	15	16	17	18	19	20
R	R	R	D	D	D	D	R	M	M	M	M	M	R	A	A	A	R	R	A	A
19	20	21	22	23	24	25	16	17	18	19	20	21	22	21	22	23	24	25	26	27
D	D	R	R	D	D	D	R	R	R	M	M	M	M	A	A	A	A	R	R	A
26	27	28	29	30	31	23	24	25	26	27	28	29	28	29	30	31				
D	D	D	D	R	R	M	M	M	R	R	M	M	A	A	A	A				
							30													
							M													

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Figure 3-7

CALENDAR REPRESENTATION SHOWING DUTY ASSIGNMENTS FOR A SPECIFIC EMPLOYEE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
January																																
Group A	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O		
Group B	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	
Group C	O	O	O	O	W	O	W	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	O	O	W	O	W	
Group D	O	O	O	O	O	W	O	W	O	O	O	O	W	O	W	O	O	O	O	O	O	W	O	W	O	O	O	O	O	W	O	
February																																
Group A	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	W	O	W	O	O	O	O	O	O	W	O	W				
Group B	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	O	O	W	O			
Group C	O	O	O	O	O	W	O	W	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	O				
Group D	W	O	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O	O	O	W	O	W	O	O	O				

Note: Shift Length = 24 hours.

Figure 3-8

A CALENDAR REPRESENTATION SHOWING DUTY ASSIGNMENTS
FOR FOUR GROUPS FOR TWO MONTHS

1975	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	GROUP 1	GROUP 2	GROUP 3	GROUP 4
SUN	1	30		25		20		14		9			D			N
MON	2	31		26		21		15		10			D			N
TUE	3		1	27		22		16		11			N	D		
WED	4		2	28		23		17		12			N	D		
THU	5		3	29		24		18		13			N	D		
FRI	6		4	30		25		19		14			N	D		
SAT	7		5	31		26		20		15				N	D	
SUN	8		6		1	27		21		16				N	D	
MON	9		7		2	28		22		17			D			N
TUE	10		8		3	29		23		18			D			N
WED	11		9		4	30		24		19			N	D		
THU	12		10		5	31		25		20			N	D		
FRI	13		11		6		1	26		21				N	D	
SAT	14		12		7		2	27		22				N	D	
SUN	15		13		8		3	28		23				N	D	
MON	16		14		9		4	29		24				N	D	
TUE	17		15		10		5	30		25			D			N
WED	18		16		11		6		1	26			D			N
THU	19		17		12		7		2	27			N	D		
FRI	20		18		13		8		3	28			N	D		
SAT	21		19		14		9		4	29				N	D	
SUN	22		20		15		10		5	30				N	D	
MON	23		21		16		11		6		1			N	D	
TUE	24		22		17		12		7		2			N	D	
WED	25		23		18		13		8		3		D			N
THU	26		24		19		14		9		4		D			N
FRI	27		25		20		15		10		5		N	D		
SAT	28		26		21		16		11		6		N	D		
SUN	29		27		22		17		12		7			N	D	
MON	30		28		23		18		13		8			N	D	
TUE	31		29		24		19		14		9			N	D	
WED			30		25		20		15		10			N	D	
THU				1	26		21		16		11		D			N
FRI				2	27		22		17		12		D			N
SAT				3	28		23		18		13		N	D		
SUN				4	29		24		19		14		N	D		
MON				5	30		25		20		15			N	D	
TUE				6		1	26		21		16			N	D	
WED				7		2	27		22		17			N	D	
THU				8		3	28		23		18			N	D	
FRI				9		4	29		24		19		D			N
SAT				10		5	30		25		20		D			N
SUN				11		6	31		26		21		N	D		
MON				12		7		1	27		22		N	D		
TUE				13		8		2	28		23			N	D	
WED				14		9		3	29		24			N	D	
THU				15		10		4	30		25			N	D	
FRI				16		11		5	31		26			N	D	
SAT				17		12		6		1	27		D			N
SUN				18		13		7		2	28		D			N
MON				19		14		8		3	29		N	D		
TUE				20		15		9		4	30		N	D		
WED				21		16		10		5	31			N	D	
THU				22		17		11		6				N	D	
FRI				23		18		12		7				N	D	
SAT				24		19		13		8				N	D	

Note: Shift Length = 12 hours.

Figure 3-9

A ONE-YEAR CALENDAR REPRESENTATION FOR FOUR GROUPS

Group A	D	N	N	O	O	O	O	D
Group B	O	D	D	N	N	O	O	O
Group C	O	O	O	D	D	N	N	O
Group D	N	O	O	O	O	D	D	N
January	2	3	4	5	6	7	8	1
	10	11	12	13	14	15	16	9
	18	19	20	21	22	23	24	17
	26	27	28	29	30	31		25
February	3	4	5	6	7	8	9	1
	11	12	13	14	15	16	17	2
	19	20	21	22	23	24	25	10
	27	28						18
								26
March	7	8	9	10	11	12	13	1
	15	16	17	18	19	20	21	2
	23	24	25	26	27	28	29	6
	31							14
								22
April	8	9	10	11	12	13	14	1
	16	17	18	19	20	21	22	2
	24	25	26	27	28	29	30	6
								7

Note: Shift Length = 12 hours.

Figure 3-10

A CALENDAR REPRESENTATION IN WHICH THE LENGTH OF EACH LINE IS EQUAL TO THE LENGTH OF THE DUTY CYCLE

January

			1 A D	2 A D	3 B A	4 B A
5 C B	6 C B	7 D C	8 D C	9 A D	10 A D	11 B A
12 B A	13 C B	14 C B	15 D C	16 D C	17 A D	18 A D
19 B A	20 B A	21 C B	22 C B	23 D C	24 D C	25 A D
26 A D	27 B A	28 B A	29 C B	30 C B	31 D C	

February

						1 D C
2 A D	3 A D	4 B A	5 B A	6 C B	7 C B	8 D C
9 D C	10 A D	11 A D	12 B A	13 B A	14 C B	15 C B
16 D C	17 D C	18 A D	19 A D	20 B A	21 B A	22 C B
23 C B	24 D C	25 D C	26 A D	27 A D	28 B A	

March

						1 B A
2 C B	3 C B	4 D C	5 D C	6 A D	7 A D	8 B A
9 B A	10 C B	11 C B	12 D C	13 D C	14 A D	15 A D
16 B A	17 B A	18 C B	19 C B	20 D C	21 D C	22 A D
23 A D	24 B A	25 B A	26 C B	27 C B	28 D C	29 D C
30 A D	31 A D					

April

		1 B A	2 B A	3 C B	4 C B	5 D C
6 D C	7 A D	8 A D	9 B A	10 B A	11 C B	12 C B
13 D C	14 D C	15 A D	16 A D	17 B A	18 B A	19 C B
20 C B	21 D C	22 D C	23 A D	24 A D	25 B A	26 B A
27 C B	28 C B	29 D C	30 D C			

Figure 3-11

A CALENDAR REPRESENTATION BASED ON THE CONVENTIONAL CALENDAR FORMAT FOR EACH MONTH

DAY	NIGHT	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
D	C		24		21		16		11		6		1
D	C		25		22		17		12		7		2
A	D	1	26		23		18		13		8		3
A	D	2	27		24		19		14		9		4
B	A	3	28		25		20		15		10		5
B	A	4		1	26		21		16		11		6
C	B	5		2	27		22		17		12		7
C	B	6		3	28		23		18		13		8
D	C	7		4	29		24		19		14		9
D	C	8		5	30		25		20		15		10
A	D	9		6		1	26		21		16		11
A	D	10		7		2	27		22		17		12
B	A	11		8		3	28		23		18		13
B	A	12		9		4	29		24		19		14
C	B	13		10		5	30		25		20		15
C	B	14		11		6		1	26		21		16
D	C	15		12		7		2	27		22		17
D	C	16		13		8		3	28		23		18
A	D	17		14		9		4	29		24		19
A	D	18		15		10		5	30		25		20
B	A	19		16		11		6	31		26		21
B	A	20		17		12		7		1	27		22
C	B	21		18		13		8		2	28		23
C	B	22		19		14		9		3	29		24
D	C	23		20		15		10		4	30		25
D	C	24		21		16		11		5	31		26
A	D	25		22		17		12		6		1	27
A	D	26		23		18		13		7		2	28
B	A	27		24		19		14		8		3	29
B	A	28		25		20		15		9		4	30
C	B	29		26		21		16		10		5	31
C	B	30		27		22		17		11		6	
D	C	31		28		23		18		12		7	
D	C		1	29		24		19		13		8	
A	D		2	30		25		20		14		9	
A	D		3	31		26		21		15		10	
B	A		4		1	27		22		16		11	
B	A		5		2	28		23		17		12	
C	B		6		3	29		24		18		13	
C	B		7		4	30		25		19		14	
D	C		8		5	31		26		20		15	
D	C		9		6		1	27		21		16	
A	D		10		7		2	28		22		17	
A	D		11		8		3	29		23		18	
B	A		12		9		4	30		24		19	
B	A		13		10		5	31		25		20	
C	B		14		11		6		1	26		21	
C	B		15		12		7		2	27		22	
D	C		16		13		8		3	28		23	
D	C		17		14		9		4	29		24	
A	D		18		15		10		5	30		25	
A	D		19		16		11		6		1	26	
B	A		20		17		12		7		2	27	
B	A		21		18		13		8		3	28	
C	B		22		19		14		9		4	29	
C	B		23		20		15		10		5	30	

Figure 3-12

ANOTHER FORM OF CALENDAR REPRESENTATION

For example, the first line of the schedule indicates that on February 24, April 21, June 16, August 11, October 6, and December 1, group D is assigned to the day shift, group C is assigned to the night shift, and groups A and B are off duty.

A schedule representation such as that of Figure 3-7 pertains to a single employee only, so that separate calendars must be prepared for each employee. On the other hand, the remaining schedule representations shown indicate assignments for all groups. Although these tend to be more complex, they enable supervisors and administrators to determine from a single page which employees will be on duty on specific dates.

C. Identifying Properties of a Work Schedule

Important properties of work schedules are discussed in this section, as are general procedures for identifying and measuring these properties in a given schedule. Any additional procedures needed for analyzing the three basic types of schedules covered in this handbook are included in chapters VI through VIII, which deal with the design of these schedules.

Shifts Used

A shift is one of the sets of hours into which a day is divided for scheduling purposes.* Although the hours that comprise a shift are usually consecutive, they may be interrupted by a period of off-duty hours. Such a shift is termed a split shift. The important schedule properties related to shifts are (1) the shift length, (2) the number of shifts used per day, (3) shift starting times, and (4) whether employees' shift assignments are fixed or rotating.

*The term shift is sometimes used to refer to on-duty or work assignments (e.g., each employee works five shifts per week).

Shift length is the total number of hours included in each shift. Thus, a shift that begins at 9:00 a.m., ends at 5:00 p.m., and includes one hour off duty for lunch is eight hours in length. This is the most commonly used shift length, although 10-hour shifts are becoming more widely used. Schedules that require 24-hour shifts, and two-shift schedules employing 12-hour shifts, and combinations of nine- or 10-hour day shifts with 15- or 14-hour night shifts are used primarily in fire and paramedic/ambulance services.

Schedules in which all employees on duty during some hours of any 24-hour period arrive at approximately the same time and leave at approximately the same time are termed one-shift schedules. Schedules in which employees report at different times during the day are termed multishift schedules. The latter can be further classified as two-shift schedules, three-shift schedules, etc., according to the number of shifts used per day.*

When multiple shifts are used, shift starting times, as well as their lengths, must be known to determine whether the shifts are overlapping or non-overlapping. Shifts overlap when the starting time of one shift occurs between the starting and ending times of another shift. Overlapping shifts are sometimes used to extend the hours during which service is offered without extending the shift length. For example, li-

*Employee reporting times are sometimes staggered at a shift change to minimize disruptions in services. For example, police officers assigned to the day shift (e.g., 7:00 a.m. to 3:00 p.m.) may actually report for duty at various times between 6:00 a.m. and 8:00 a.m. Such minor variations in shift starting times for employees assigned to a given shift are not sufficient for the schedule to be considered as having multiple shifts.

braries that are open between 9:00 a.m. and 9:00 p.m. frequently schedule two overlapping shifts (e.g., 9:00 a.m. to 6:00 p.m., and noon to 9:00 p.m.) to provide the 12 hours of coverage required.

Overlapping shifts can also be used to provide additional on-duty employees at certain times of the day. Thus, the library schedule just described provides overlapping coverage between noon and 6:00 p.m. In general, the number of hours of overlapping coverage per day can be determined by summing the lengths of all shifts and subtracting the total number of hours per day for which service is provided. For example, the library schedule provides 12 hours of service per day with two nine-hour shifts. As a result, the number of hours of overlap is

$$9 + 9 - 12 = 6 \text{ hours.}$$

The number of on-duty employees during hours of overlap can be determined by summing the number on duty on each of the overlapping shifts. For example, if six employees are assigned to the 9:00 a.m. to 6:00 p.m. shift and four employees are assigned to the noon to 9:00 p.m. shift, the on-duty staffing during the hours of overlap is

$$6 + 4 = 10 \text{ employees.}$$

Another important property of multishift schedules is whether employees' shift assignments are fixed or rotating. Fixed or permanent shift assignments result when employees are assigned to a particular shift indefinitely. Such permanent assignments are

usually based on seniority, skill, or employee preference. Alternatively, shift assignments are said to be rotating if employees change shifts at regular intervals. Shift assignments are usually rotated in order to share preferred duty assignments equitably among employees, or to increase the proportion of employees familiar with service conditions at different times of the day.

When rotating shift assignments are used in a schedule utilizing three or more shifts, the shift rotation sequence becomes another important property. This sequence is the order in which employees are assigned to the various shifts. Thus, a schedule that requires each employee to rotate from the day (D) shift to the night (N) shift to the afternoon (A) shift before returning to the day shift is said to follow a D-N-A shift rotation sequence. The sequence is important because it can affect shift change properties discussed below.

Patterns of Duty Assignments

Duty cycles. As indicated earlier, the repeating pattern of shift assignments and days off in a schedule is termed a duty cycle. For example, a schedule in which employees work 9:00 a.m. to 5:00 p.m., Monday through Friday, and are off duty on Saturday and Sunday has the duty cycle DDDDDRR. The same duty cycle can also be represented as RDDDDDR, RRDDDDD, or in any other way obtainable by rotating the duty assignments in the original pattern by one or more positions to the left or right. Employees in a work force following a given duty cycle may be at different points in it on any day. That is, when one group of employees is working the schedule assignment specified for day 1

of the duty cycle, another group may be working the duty assignment specified for day 4. (Note, however, that the number of such groups cannot exceed the number of days in the duty cycle.) Similarly, when the first group works the assignment shown for day 2, the second group works the assignment shown for day 5, and so on. When some employees in the work force follow different duty cycles, the schedules for each duty cycle must be analyzed separately.

The important schedule properties related to the duty cycle are (1) the length of the duty cycle, (2) the lengths of periods of consecutive on-duty days or consecutive off-duty days, (3) the frequency of employees' weekends (Saturday and Sunday) off duty, (4) the length of off-duty periods between on-duty assignments on different shifts, and (5) schedule simplicity.

The duty cycle length is an important factor in determining a schedule's average work week, which is discussed in more detail below. The length, in days, can be determined by first identifying the repeating pattern of duty assignments in the schedule, and then counting the number of days in the pattern. In duty cycle and non-rotating bracket representations showing daily duty assignments (such as in figures 3-1, 3-2, 3-4, and 3-5), the repeating pattern constitutes any line in the schedule, although the pattern may differ from one line to the next. In calendar representations and schedule representations showing on-duty and off-duty groups (such as in figures 3-3, 3-7, 3-8, 3-9, 3-11, and 3-12), however, the duty cycle is not explicitly displayed, but can be determined as follows:

1. Consider the schedule of any group represented. For example, in Figure 3-8, consider only the row(s) or column(s) which are applicable to group A. In schedules of the type shown in figures 3-3 and 3-11, the schedule of group A can be determined by recording the group's duty assignment (e.g., O, W, D, N, etc.) on each day of the schedule.
2. Find the first day of the schedule on which group A's duty assignment changes (e.g., from D to N, from O to W, etc.)
3. Starting on that day, record the group's duty assignment on each succeeding day.
4. Each time a day is found on which the group's duty assignment is the same as on the starting day, check the duty assignments on succeeding days to determine if the pattern is the same as that following the starting day. If it is not, continue as before. If the pattern is repeated throughout the remainder of the schedule, that pattern is the basic duty cycle.

This procedure is illustrated in Figure 3-13. Note that the procedure may have to be repeated for the other groups represented in the schedule, to determine if all groups follow the same duty cycle.

Week cycle. Closely related to the duty cycle of a work schedule is the week cycle--the smallest whole number of weeks in which the duty cycle is repeated a whole number of times. Unless the length of a schedule's duty cycle is a multiple of seven days, which presents a special case discussed later, the length of the week cycle, in weeks, is equal to the number of days in the duty cycle, and the duty cycle will be repeated seven times during the week cycle. Such schedules are termed unlocked schedules and have the following useful property:

During the week cycle, each employee will be on duty and off duty each day of the week the same number of times as every other day of the week and the same number of times as every other employee using the same duty cycle.

CONTINUED

1 OF 5

On-Duty Group

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>	<u>22</u>	<u>23</u>	<u>24</u>	<u>25</u>	<u>26</u>	<u>27</u>	<u>28</u>	<u>29</u>	<u>30</u>	<u>31</u>	
January	C	A	B	A	B	C	B	C	A	C	A	B	A	B	C	B	C	A	C	A	B	A	B	C	B	C	A	C	A	B	A	
February	B	C	B	C	A	C	A	B	A	B	C	B	C	A	C	A	B	A	B	C	B	C	A	C	A	B	A	B	C	A	B	A
March	C	B	C	A	C	A	B	A	B	C	B	C	A	C	A	B	A	B	C	B	C	A	C	A	B	A	B	C	B	C	A	

Duty Assignments of Group A

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>	<u>22</u>	<u>23</u>	<u>24</u>	<u>25</u>	<u>26</u>	<u>27</u>	<u>28</u>	<u>29</u>	<u>30</u>	<u>31</u>	
January	O	W	O	W	O	O	O	O	W	O	W	O	W	O	O	O	O	W	O	W	O	W	O	O	O	O	O	W	O	W	O	W
February	O	O	O	O	W	O	W	O	W	O	O	O	O	W	O	W	O	W	O	O	O	O	O	W	O	W	O	W	O	O	O	W
March	O	O	O	W	O	W	O	W	O	O	O	O	W	O	W	O	W	O	O	O	O	O	W	O	W	O	W	O	O	O	O	W

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Determination of Repeating Pattern in Group A's Schedule

Starting date: January 2

(1) W O W O O

pattern x

pattern x does not repeat

(2) W O W O O O O W O W O W O O

pattern y

pattern y does not repeat

(3) W O W O O O O W O W O W O O O W O

pattern z

pattern z repeats throughout the remainder of the schedule

Figure 3-13

EXAMPLE OF PROCEDURE FOR DETERMINING THE
DUTY CYCLE USED IN A WORK SCHEDULE

For example, consider the six-day duty cycle **WWWRRR**. Figure 3-14 shows the six-week period of the week cycle (note that the duty cycle is repeated seven times). During the week cycle, each employee in the group represented is on duty on four Mondays, four Tuesdays, etc., and off duty on two Mondays, two Tuesdays, etc. The same is true for all other groups using the same duty cycle.

If the length of the duty cycle is a multiple of seven, the length of the week cycle is equal to the number of weeks in the duty cycle, and the duty cycle will repeat only once in the week cycle (i.e., the week cycle and the duty cycle are identical). Such schedules are termed locked schedules because each employee may not be on duty and off duty each day of the week the same number of times as every other day of the week

<u>Week</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1	W	W	W	W	R	R	W
2	W	W	W	R	R	W	W
3	W	W	R	R	W	W	W
4	W	R	R	W	W	W	W
5	R	R	W	W	W	W	R
6	R	W	W	W	W	R	R

Figure 3-14

WEEK CYCLE OF AN UNLOCKED SCHEDULE WITH DUTY CYCLE **WWWRRR**

and the same number of times as every other employee. For example, the employees using the seven-day duty cycle shown in Figure 3-15 will be on duty Monday through Thursday and off duty Friday through Sunday every week. Employees using a 14-day duty cycle will be on and off duty the same days every other week (see Figure 3-16), and so on.

Work and off-duty periods. By examining the duty cycle(s) used in a schedule, sequences of consecutive on-duty days--termed work periods--and sequences of consecutive off-duty days--termed off-duty periods--can be identified. The lengths of the work periods and off-duty periods in a schedule may be fixed or they may vary. Since these lengths may affect employees' performance or their satisfaction with the schedule, analysis of a work schedule should include determination of the following:

<u>Week</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1	W	W	W	W	R	R	R
2	W	W	W	W	R	R	R
3	W	W	W	W	R	R	R
.							
.							
.							

Figure 3-15

LOCKED SCHEDULE WITH THE SEVEN-DAY DUTY CYCLE WWWWRRR

<u>Week</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1	W	W	W	W	R	R	W
2	W	W	W	W	W	R	R
3	W	W	W	W	R	R	W
4	W	W	W	W	W	R	R
5	W	W	W	W	R	R	W
.							
.							
.							

Figure 3-16

LOCKED SCHEDULE WITH A 14-DAY DUTY CYCLE

- maximum and minimum length of work and off-duty periods experienced by each group of employees;
- frequency with which each group of employees experiences work and off-duty periods of various lengths;
- whether the maximum (minimum) length work and off-duty periods are grouped together or are distributed throughout the week cycle;
- whether long work periods (e.g., six or seven days) are followed by long off-duty periods (e.g., three or four days); and
- frequency within the week cycle with which combinations of the days of the week are included in off-duty periods (e.g., the number of times employees are off duty Friday through Sunday, Tuesday and Wednesday, etc.).

Off-duty periods that include both Saturday and Sunday are often of particular interest. The frequency of such weekend

off-duty periods can be determined by drawing out the schedule over the week cycle and simply counting the number of off-duty weekends. For unlocked schedules, the number of weekend off-duty periods can also be determined directly from the duty cycle by counting the number of off-duty days and the number of off-duty periods, and subtracting the latter from the former. The result is the number of off-duty weekends per week cycle. For example, a schedule with the 20-day duty cycle

WWWWRRRWWWWRRRWWWR

has six off-duty days and three off-duty periods per duty cycle, and provides

$$6 - 3 = 3 \text{ weekend off-duty periods}$$

per week cycle (20 weeks). This can be verified by drawing out the schedule's week cycle (see Figure 3-17). Note that drawing out a schedule over the week cycle can also be used to determine whether the weekend off-duty periods are distributed throughout the week cycle, or are clustered in one part of the week cycle, as in the above schedule.

Shift change properties. For multishift schedules, off-duty periods which occur between on-duty assignments on different shifts should also be examined, and the number of hours off duty at each shift change should be determined, to ensure that the number of off-duty hours is sufficient to allow adjustment to new working hours and adequate rest before returning to work. Off-duty periods of less than 16 hours at a shift change are

Day of Week

<u>WEEK</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1*	W	W	W	W	W	R	R
2*	W	W	W	W	W	R	R
3	R	W	W	W	W	R	W
4	W	W	W	W	R	R	W
5*	W	W	W	W	R	R	R
6	W	W	W	W	R	W	W
7	W	W	W	R	R	W	W
8	W	W	W	R	R	R	W
9	W	W	W	R	W	W	W
10	W	W	R	R	W	W	W
11	W	W	R	R	R	W	W
12	W	W	R	W	W	W	W
13	W	R	R	W	W	W	W
14	W	R	R	R	W	W	W
15	W	R	W	W	W	W	W
16	R	R	W	W	W	W	W
17	R	R	R	W	W	W	W
18	R	W	W	W	W	W	R
19	R	W	W	W	W	W	R
20	R	R	W	W	W	W	R

*Weeks containing a weekend off-duty period.

Figure 3-17

WEEK CYCLE OF THE SCHEDULE WITH THE 20-DAY DUTY CYCLE
 WWWWRRRWWWRRRWWWWR

termed short changeovers, which should be avoided. Note that the number of such off-duty hours depends not only on the number of days in the off-duty period at the shift change, but also on the shift lengths and the shift rotation sequence. Table 3-1 contains the number of off-duty hours for combinations of shift length and rotation sequence, including patterns of on-duty assignments which do not involve a shift change. Each off-duty day inserted at the changeover will add 24 hours to the number of hours shown.

Schedule simplicity. A final property of work schedules which is related to the pattern of duty assignments is schedule simplicity. This is a subjective criterion frequently used to compare alternative schedules. Simplicity refers to the ease with which (1) employees can determine their duty assignments, and (2) supervisors and schedule administrators can determine which employees will be on duty on particular future dates. For example, a schedule in which an employee is on duty on the same days and shifts every week would be considered simpler to use and administer than one in which on-duty days and shifts vary from week to week over an extended period. Of course, schedule complexity can be somewhat overcome by providing employees and supervisors with suitable calendar representations of the schedules.

Number of Groups

A group is one or more employees sharing identical on-duty shift assignments and off-duty days. As discussed in more detail in the remaining chapters of this handbook, the number of groups into which the work force is divided can have a signif-

Table 3-1

OFF-DUTY HOURS BETWEEN CONSECUTIVE ON-DUTY SHIFTS

<u>Pattern of Shift Assignments^a</u>	<u>8-Hour Shifts^b</u>	<u>10-Hour Shifts^c</u>	<u>10-Hour Shifts^d</u>	<u>10-Hour Shifts^e</u>	<u>10-Hour Shifts^f</u>	<u>12-Hour Shifts^b</u>	<u>24-Hour Shifts^b</u>
AA	16	14	14	14	14	12	0
AB	24	22	18	24	24	24	-
AC	32	30	28	28	10	-	-
BA	8	6	10	4	4	0	-
BB	16	14	14	14	14	12	-
BC	24	22	24	18	24	-	-
CA	0	-2 ^g	0	0	-6 ^g	-	-
CB	8	6	4	10	4	-	-
CC	16	14	14	14	14	-	-

^a"A" denotes the first shift that starts at midnight or after, "B" denotes the second shift, and "C" denotes the third shift.

^bNon-overlapping shifts.

^cTwo-hour overlap between each shift.

^dSix-hour overlap between shifts A and B, no overlap between shifts A and C or B and C.

^eSix-hour overlap between shifts B and C, no overlap between shifts A and B or A and C.

^fSix-hour overlap between shifts A and C, no overlap between shifts A and B or B and C.

^gTable entries less than zero indicate that the combination of shift length and rotation sequence requires at least one off-duty day.

ificant impact on some very important schedule properties (e.g., the average work week and the distribution of on-duty employees by day of week and shift). The number of employees assigned to each group also affects the distribution of on-duty employees by day of week and shift, as well as whether this distribution remains constant from week to week. Consequently, analysis of a work schedule should include determination of (1) the number of groups into which the work force is divided, (2) the number of employees assigned to each group, and (3) the composition of each group in terms of personnel classifications and skill levels of its members.

The number of groups can be easily determined for schedule representations such as those illustrated in figures 3-2, 3-4, and 3-8 since each line corresponds to a different group. Similarly, schedule representations of the type shown in figures 3-3 and 3-11 explicitly indicate the number of groups in the schedule. If representations are used which show the duty assignments of individual employees (such as in Figure 3-7), the assignments on corresponding days must be compared among employees to determine the number of different patterns represented. If a representation like that in Figure 3-1 is used, however, the number of groups cannot be determined from this information alone and must be determined in other ways (e.g., by questioning the schedule designer or administrator).

The number of employees assigned to each group may be the same for all groups or it may vary among the groups. Unless the schedule representation indicates the number of employees

assigned to each group, or the number of groups is the same as the total number of employees (in which case, one employee is assigned to each group), the allocation of employees to groups must also be obtained from other sources such as the schedule designer or administrator.

The employees assigned to any group may have equivalent skills and belong to the same personnel classifications, or they may represent a variety of skills and classifications. Assignment of employees with different skills to each group is frequently necessary to ensure that sufficient employees with needed skills are on duty at all times. This can be achieved either by initially assigning a proper mixture of employees to each group and designing a single schedule for the entire work force, or by designing separate schedules for each set of employees sharing the same skill. The former approach produces perfect team integrity--a management principle that is achieved if the same team of employees works together whenever any of the team's employees are on duty--while the latter approach will lead to some variation in the on-duty co-workers of any given employee.

A special type of work schedule which produces perfect team integrity is the platoon schedule. A platoon is a group of employees whose duty assignments are such that whenever the group is on duty, all other groups are off duty. A schedule is termed a platoon schedule if all groups are platoons. For example, if two groups cover a single shift by alternating four-day work periods and four-day off-duty periods so that when the first group is working the second is off, the schedule is refer-

red to as a two-platoon schedule.

On-Duty Staffing

On-duty staffing is usually specified in terms of the number of employees on duty by day of week and shift. As mentioned earlier, if shifts overlap, the on-duty staffing will also vary by time of day within the shifts. The staffing can be determined for any date and time of day by simply identifying which groups are scheduled to be on duty, and summing the number of employees assigned to these groups.

If the number of on-duty employees is the same whenever service is offered, staffing is said to be uniform. Otherwise, the staffing is said to be variable by time of day, day of week, or both. Staffing levels are said to be cyclic if they exhibit cyclic variations by time of day or day of week, and proportional if they match cyclic variations in the demand for service. Minor but unwanted cyclic variations in on-duty staffing, by day of week and shift sometimes result when the numbers of employees assigned to each schedule group are unequal. Proportional staffing by time of day is achieved by assigning different numbers of employees to each shift according to shift workloads, or by using overlapping shifts. Proportional staffing by day of week is achieved by assigning different numbers of employees to be on duty on each day according to daily workloads, or by scheduling Kelly days or payback days on particular days of the week.

Kelly Days and Payback Days

A Kelly day is an off-duty shift which is given instead

of a regularly scheduled work shift, for the purpose of reducing the average work week. Similarly, a payback day is a shift worked in addition to the regularly scheduled work shifts in order to raise the average work week. In order to have the desired effect of shortening the average work week, Kelly days must be treated as unpaid days and, therefore, not included in the computation of the hourly rate of pay.* This contrasts with compensatory days, vacation days, and holidays, which are days off duty with pay and do not affect the average work week. Similarly, payback days must be treated as paid days.

Kelly days may be either assigned under a pre-specified procedure, or scheduled at the discretion of individual employees (e.g., by seniority or rotating order of choice). Pre-specified procedures usually involve assigning each employee an "off number," with all employees who have the same "off number" taking a Kelly day on specified days (such as every fifteenth work day). Although complicated to set up, these procedures do enable managers to minimize staffing disruptions and avoid the problems associated with maintaining records when Kelly days are scheduled in a less structured manner. An alternate procedure, described in Chapter VII, involves inserting Kelly days or payback days into a schedule at selected points in the week cycle.

By using Kelly days and payback days, the average work week produced by a schedule can be modified without altering the

*If Kelly days are added to an employee's schedule and his annual salary remains unchanged, the employee's hourly rate of pay has, in effect, been raised, since the same salary is now given for fewer work hours.

basic duty cycle or number of employee groups required. In addition, Kelly days can be used to interrupt long periods of consecutive work days, and payback days can be used at management discretion to cover for absences. Kelly days and payback days, however, can disrupt team integrity by causing individual team members to be on or off duty when other team members are not.

Kelly days may be shown in schedule representations as a K or as a circled off-duty day (e.g., (R)). Similarly, payback days may be represented as a P or as a circled on-duty day (e.g., (D)). Often, however, Kelly days and payback days are not explicitly shown on schedule calendars. In such cases, the schedule designer or personnel manager must be consulted to determine whether Kelly days and payback days are used.

Average Work Week

The average work week is the average number of scheduled working hours per week, where paid time off for vacations, holidays, and sick leave are considered working hours. Regularly scheduled hours that are considered overtime, if any, are not considered working hours in the calculation of the average work week. If lunch periods and other breaks are considered working hours, they are included in calculating the average work week.

In order to calculate the average work week, it is necessary to know the number of working hours per shift, the number of shifts worked during the period over which work hours are to be averaged, and the number of days in the period used. The period over which work hours are averaged can be the length of the duty cycle, the week cycle, a pay period, or even a full

year. The general formula for calculating the average work week is:

$$\left(\begin{array}{l} \text{average} \\ \text{work week} \end{array} \right) = \frac{\left(\begin{array}{l} \text{working} \\ \text{hours} \\ \text{per shift} \end{array} \right) \times \left(\begin{array}{l} \text{on-duty} \\ \text{shifts per} \\ \text{period} \end{array} \right) \times 7}{\left(\begin{array}{l} \text{period length} \\ \text{in days} \end{array} \right)}. \quad (3-1)$$

For example, the typical office worker works eight hours per day, Monday through Friday. With 20 work days scheduled during each 28-day pay period,

$$\left(\begin{array}{l} \text{average} \\ \text{work week} \end{array} \right) = \frac{8 \times 20 \times 7}{28} = 40 \text{ hours.}$$

Similarly, for a mechanic working eight 10-hour shifts every two weeks,

$$\left(\begin{array}{l} \text{average} \\ \text{work week} \end{array} \right) = \frac{10 \times 8 \times 7}{14} = 40 \text{ hours.}$$

For most of the schedules covered in this handbook, the average work week can be calculated on the basis of the duty cycle length and the number of on-duty shifts per duty cycle, using the formula:

$$\left(\begin{array}{l} \text{average} \\ \text{work week} \end{array} \right) = \frac{\left(\begin{array}{l} \text{working} \\ \text{hours} \\ \text{per shift} \end{array} \right) \times \left(\begin{array}{l} \text{on-duty} \\ \text{shifts per} \\ \text{duty cycle} \end{array} \right) \times 7}{\left(\begin{array}{l} \text{duty cycle} \\ \text{length in days} \end{array} \right)}. \quad (3-2)$$

As an example, consider the schedule illustrated in Figure 3-17, and assume that on-duty shifts are eight hours in length. Using formula (3-2), the average work week is calculated as follows:

$$\left(\begin{array}{c} \text{average} \\ \text{work week} \end{array} \right) = \frac{8 \times 14 \times 7}{20} = 39.2 \text{ hours.}$$

If it has been determined, however, that the schedule being analyzed includes Kelly days or payback days not explicitly shown on the schedule calendar (see preceding section), formula (3-2) cannot be used. Instead, the number of Kelly days or payback days inserted in the schedule each week cycle must be determined and used in the following formula:*

$$\left(\begin{array}{c} \text{average} \\ \text{work} \\ \text{week} \end{array} \right) = \frac{\left(\begin{array}{c} \text{working} \\ \text{hours} \\ \text{per} \\ \text{shift} \end{array} \right) \times \left[7 \times \left(\begin{array}{c} \text{on-duty} \\ \text{shifts} \\ \text{per duty} \\ \text{cycle} \end{array} \right) + \left(\begin{array}{c} \text{payback} \\ \text{days} \\ \text{per week} \\ \text{cycle} \end{array} \right) - \left(\begin{array}{c} \text{Kelly} \\ \text{days} \\ \text{per week} \\ \text{cycle} \end{array} \right) \right]}{\left(\begin{array}{c} \text{week cycle} \\ \text{length} \\ \text{in weeks} \end{array} \right)} \quad (3-3)$$

For example, consider again the schedule in Figure 3-17, assuming a shift length of eight hours. If employees are required to work two payback days per week cycle, then using formula (3-3):

$$\left(\begin{array}{c} \text{average} \\ \text{work week} \end{array} \right) = \frac{8 \times (7 \times 14 + 2 - 0)}{20} = 40.0 \text{ hours.}$$

Similarly, if employees receive three Kelly days per week cycle:

$$\left(\begin{array}{c} \text{average} \\ \text{work week} \end{array} \right) = \frac{8 \times (7 \times 14 + 0 - 3)}{20} = 38.0 \text{ hours.}$$

D. Summary and Examples

To analyze a work schedule the following procedures are used:

1. Identify the different schedules used by employees in the work

*Note that this formula cannot be used if the schedule is locked.

force. If more than one schedule is used, the following steps should be performed for each.

2. Identify shifts used in the schedule.
 - How many shifts are used?
 - At what times does each shift start and end?
 - What is (are) the shift length(s)?
 - Do the shifts overlap?
 - Are employees permanently assigned to a shift, or do they periodically rotate shift assignments? If they rotate, what is the shift rotation sequence?
3. Identify the duty cycle(s) used in the schedule. If employees follow different duty cycles, each cycle used should be analyzed separately.
 - What are the lengths of the duty cycle and the week cycle?
 - Is the schedule locked? If so, the work and off-duty periods of each group of employees must be analyzed separately.
4. Identify the schedule's work periods and off-duty periods.
 - What are the maximum and minimum lengths of work periods and off-duty periods?
 - How frequently do employees have work and off-duty periods of various lengths?
 - Are long (short) work and off-duty periods grouped together or are they distributed throughout the week cycle?
 - Are long work periods followed by long off-duty periods?
 - Are short off-duty periods preceded by short work periods?
 - With what frequency are combinations of days of the week included in off-duty periods?
 - How many weekend off-duty periods are provided by the schedule?
 - How many off-duty hours are provided at each shift change?
5. Identify the groups of identically-scheduled employees

into which the work force using the schedule is divided.

- How many employees are assigned to each group?
 - What is the composition of each group in terms of personnel classifications and skill levels of group members?
 - To what extent does the schedule provide team integrity?
 - Do the groups of employees constitute platoons?
6. Determine on-duty staffing by time of day and day of week.
 7. Determine whether Kelly days or payback days are used and how often they are given.
 8. Determine the average work week.

To illustrate the procedure, suppose that a vehicle maintenance shop operates from 7:00 a.m. to 11:00 p.m., seven days per week, and employs two classifications of workers: mechanics and servicemen. The schedule for the shop's eight mechanics is shown in Figure 3-18, while that for its 10 servicemen is shown in Figure 3-19.

Analysis of the maintenance shop's schedule begins by observing that the mechanics and servicemen use different schedules. Therefore, the schedules must be analyzed separately.

Examination of Figure 3-18 reveals that the mechanics use a two-shift schedule. An eight-hour day shift begins at 7:00 a.m. and ends at 3:00 p.m., and an eight-hour night shift begins at 3:00 p.m. and ends at 11:00 p.m. Since the night shift does not begin until the day shift has ended, the shifts do not overlap. Employees 1 through 4 work only the day shift, while employees 5 through 8 work only the night shift (i.e., shift assignments are fixed).

Two duty cycles are used in the schedule: mechanics

<u>Employee</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1	D	D	D	D	R	R	D
2	D	D	D	D	D	R	R
3	R	D	D	D	D	D	R
4	D	R	R	D	D	D	D
5	N	N	N	N	N	R	R
6	N	N	N	N	N	R	R
7	R	N	N	N	N	N	R
8	N	R	R	N	N	N	N

"D" denotes the 7:00 a.m. to 3:00 p.m. day shift, "N" the 3:00 p.m. to 11:00 p.m. night shift, and "R" off duty.

Figure 3-18

WORK SCHEDULE USED BY EIGHT MECHANICS EMPLOYED BY A
VEHICLE MAINTENANCE SHOP

<u>Week</u>	<u>Day of Week</u>						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1	D	D	D	D	D	R	R
2	D	D	D	D	D	R	R
3	D	D	D	D	D	D	R
4	R	R	R	D	D	D	D
5	R	R	D	D	D	D	D
6	R	R	N	N	N	N	R
7	N	N	N	N	N	N	R
8	N	N	N	N	R	R	N
9	N	N	N	N	N	R	R
10	N	N	N	N	N	R	R

"D" denotes the 7:00 a.m. to 3:00 p.m. day shift, "N" the 3:00 p.m. to 11:00 p.m. night shift, and "R" off duty.

Employees rotate from one line of the schedule to the next each week. After working the schedule shown for week 10, employees rotate back to the schedule shown for week 1. On any week, each employee is working the schedule shown on a different line, and each line of the schedule is being worked by exactly one employee.

Figure 3-19

WORK SCHEDULE USED BY 10 SERVICEMEN EMPLOYED BY A
VEHICLE MAINTENANCE SHOP

assigned to the day shift follow the duty cycle DDDDDRR, and those assigned to the night shift follow the duty cycle NNNNNRR. The length of each cycle is seven days. Since this is a multiple of seven, the schedule is locked. Therefore, the week cycle is identical to the duty cycle, and its length is also seven days.

All work periods are five days in length and all off-duty periods are two days in length. This can be determined directly from the duty cycles. Since the schedule is locked, the off-duty days for each employee must be analyzed separately. This analysis shows that since only employees 2, 5, and 6 are off duty on both Saturday and Sunday they are the only ones who receive weekend off-duty periods.

The eight mechanics have been scheduled as seven groups, with two employees assigned to one group (i.e., employees 5 and 6) and a single employee assigned to each of the other six groups. Since several groups are usually on duty simultaneously, the groups are not platoons. If the mechanics must work together as teams, team integrity must also be considered. In this schedule, team integrity is low since, for example, employee 4 works with employees 1 and 2 on Monday, employees 2 and 3 on Friday, employee 3 on Saturday, and employee 1 on Sunday.

The number of on-duty mechanics on the day shift on any day of the week can be determined by summing the number of D's in the column of the schedule that corresponds to that day of the week. Similarly, summing the number of N's in a column gives the number of on-duty mechanics on the night shift on that day:

	Day of Week						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
Day Shift	3	3	3	4	3	2	2
Night Shift	3	3	3	4	4	2	1

Since each employee works five eight-hour shifts every seven days and no Kelly days or payback days are used, the average work week is simply

$$\frac{8 \times 5 \times 7}{7} = 40 \text{ hours,}$$

where formula (3-1) was used.

A similar analysis of the servicemen's schedule shown in Figure 3-19 will identify the following properties:

- The schedule provides for two non-overlapping shifts eight hours in length: a day shift that begins at 7:00 a.m. and a night shift that begins at 3:00 p.m.
- Employees rotate shifts every five weeks.
- Within the 10-week period represented in Figure 3-19, there is no repeating pattern of duty assignments. Therefore, the entire 10-week period is the duty cycle, which can also be represented as

5D-2R-5D-2R-6D-4R-4D-2R-5D-2R-4N-1R-6N-1R-4N-2R-6N-2R-5N-2R.

- The length of the duty cycle is 70 days, the length of the week cycle is 10 weeks, and the schedule is locked.
- Work periods are from four to six days in length. In a 10-week period, three work periods are four days in length, four are five days in length, and three are six days in length.
- Off-duty periods are from one to four days in length. In a 10-week period, two off-duty periods are one day in length, seven are two days in length, and one is four days in length.
- One of the six-day work periods is followed by a long off-duty period (four days). The other six-day work periods, however, are followed by one- and

two-day off-duty periods.

- One one-day off-duty period is preceded by a short work period (four days). The other one-day off-duty period is preceded by a six-day work period.
- In a 10-week period, each employee is off duty on the following sequences of days:

S-M-T-W (once)
 S-S (four times)
 M-T (twice)
 F-S (once)
 Sun (twice).

- In a 10-week period, each employee receives four weekend off-duty periods.
- When employees rotate from the day shift to the night shift, they are off duty from 3:00 p.m. on Sunday until 3:00 p.m. on Wednesday (i.e., for 72 hours). When they rotate from the night shift to the day shift, they are off duty from 11:00 p.m. on Friday until 7:00 a.m. on Monday (i.e., for 56 hours).
- Employees are scheduled as 10 groups with one employee assigned to each group. The groups are not platoons.
- Team integrity is low.
- On-duty staffing is determined on any day of the week by summing the number of D's or N's in the column that corresponds to that day. The result is:

	Day of Week						
	M	T	W	T	F	S	S
Day Shift	3	3	4	5	5	3	2
Night Shift	4	4	5	5	4	2	1

- Employees work 50 eight-hour shifts in a 70-day period. Therefore, the average work week is

$$\frac{8 \times 50 \times 7}{70} = 40 \text{ hours.}$$

CHAPTER IV

ALLOCATING STAFF TO SHIFTS AND DAYS OF THE WEEK

A. Introduction

The design of work schedules usually involves some or all of the following activities:

- determination of the number of employees required;
- determination of the number of on-duty staff-days to be scheduled each week;
- allocation of on-duty staff-days by shift and day of the week; and
- design of individual work schedules to preserve the desired staff allocation.

This chapter discusses the first three components listed above. The fourth component, the design of work schedules, is the topic of chapters V through VIII. This chapter is divided into two parts. The first presents the definition, derivation, and use of relief factors to determine the number of employees required to staff any number of positions. The second part describes how to determine the number of on-duty staff-days to be scheduled each week, and how to allocate them among the shifts and days of the week to match workload.

B. Shift Relief Factors

Introduction

Relief factors are used to identify the number of employees required to staff a given number of positions. Specifically, a shift relief factor is a single number which indicates the number of employees that are needed to staff one shift position.* Shift

*A shift position refers to a position or post that is staffed on one shift on every day the agency provides service.

relief factors almost always have values greater than one, and are measured in the units: employees per shift position. Shift relief factors are directly related to the number of agency work days per week; the more days per week an agency provides service, the higher its relief factor. Typical values for shift relief factors for agencies which operate 5, 6, and 7 days a week are shown in the chart below.

<u>No. of Agency Work Days/Week</u>	<u>Typical Shift Relief Factors (8-hour shifts)</u>
5	1.1 - 1.4
6	1.3 - 1.6
7	1.5 - 1.8

Using Shift Relief Factors

The shift relief factor for an agency can be used to determine the number of employees required to staff any number of shift positions by using the following formula:

$$\left(\begin{array}{c} \text{number of} \\ \text{employees} \\ \text{required} \end{array} \right) = \left(\begin{array}{c} \text{shift} \\ \text{relief} \\ \text{factor} \end{array} \right) \times \left(\begin{array}{c} \text{number of shift} \\ \text{positions to} \\ \text{be staffed} \end{array} \right)$$

Using the following notation:

NE - number of employees required,

SRF - shift relief factor,

NSP - number of shift positions to be staffed,

the formula above can be written

$$NE = SRF \times NSP. \quad (4-1)$$

To illustrate the use of formula (4-1), assume an agency has a shift relief factor of 1.60 (SRF = 1.60), and wants to hire enough

employees to staff 10 shift positions (NSP = 10). The answer, using formula (4-1), is

$$\begin{aligned} \text{NE} &= \text{SRF} \times \text{NSP} \\ &= 1.60 \times 10 \\ \text{NE} &= 16 \text{ employees.} \end{aligned}$$

Formula (4-1) can also be used to determine how many shift positions can be staffed with a given number of employees by rewriting it in the form

$$\begin{aligned} \left(\begin{array}{l} \text{number of shift} \\ \text{positions to} \\ \text{be staffed} \end{array} \right) &= \frac{\text{(number of employees)}}{\text{(shift relief factor)}} \\ \text{NSP} &= \frac{\text{NE}}{\text{SRF}}. \end{aligned} \tag{4-2}$$

To illustrate the use of formula (4-2), if an agency has a shift relief factor of 1.6 and 14 employees, the number of positions that can be staffed is given by

$$\begin{aligned} \text{NSP} &= \frac{\text{NE}}{\text{SRF}} \\ &= \frac{14}{1.60} \\ \text{NSP} &= 8.75 \text{ positions.} \end{aligned}$$

The 14 employees can be used to staff slightly less than 9 shift positions per week.

Determining the Number of Shift Positions To Be Staffed

When the number of employees scheduled to be on duty is the same on every agency work day, then that number represents the number of shift positions to be staffed. For example, if a library that is open six days a week schedules 10 employees to be on duty on each shift and day, then the library is staffing 10 shift positions on

each shift. As a second example, if a police department has 10 officers on duty on three shifts every day of the week, it is also staffing 10 shift positions on each shift.*

When the number of employees scheduled to be on duty is not the same on every agency work day, the average number of shift positions per work day should be used in formula (4-1). The following procedure can be used to obtain this value:

- (1) Determine the number of employees who will be on duty on each day of the week.
- (2) Add up the seven numbers identified in (1).
- (3) Count the number of days on which at least one employee is on duty.
- (4) Divide the sum obtained in step (2) by the count obtained in step (3). This quotient is the number of shift positions that should be used in formula (4-1).

This four-step procedure is quite simple to use. As an example, assume that an agency plans to schedule the following numbers of employees on each day of the week (step (1)):

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	Total <u>Staff-Days</u>
No. of On-Duty Employees	4	4	4	5	6	6	0	29

The sum of the seven numbers is 29 (step (2)), and there are six days (Monday through Saturday) with at least one employee on duty (step (3)). Therefore, the number of shift positions (step

*Although the police department and library are each staffing the same number of shift positions, the police department will require more employees than the library since it is providing service on seven days a week instead of six. The need for additional employees for the police department will be reflected in a higher relief factor.

4)) equals:

$$\begin{aligned} \left(\begin{array}{c} \text{number of} \\ \text{shift} \\ \text{positions} \end{array} \right) &= \left(\begin{array}{c} \text{total staff-days} \\ \text{to be} \\ \text{scheduled} \end{array} \right) \Bigg/ \left(\begin{array}{c} \text{number of days} \\ \text{with one or more} \\ \text{employees on duty} \end{array} \right) \\ &= 29/6 \end{aligned}$$

$$\left(\begin{array}{c} \text{number of} \\ \text{shift} \\ \text{positions} \end{array} \right) = 4.83.$$

Determining Shift Relief Factors from Agency Data

The following notation will be used to describe the procedure for determining shift relief factors from agency data:

ANSD - number of agency no-service days per year, includes both regular no-service days per week and agency holidays;

ERDO - number of employee regular days off per year (e.g., employees working an average of five days per week receive approximately 104 regular days off per year); and

EBDO - average number of employee benefit days off per year, includes vacation days, holidays, sick leave, and all other days off.

Shift relief factors are most easily calculated using agency data collected on an annual basis. The general formula is

$$\text{SRF} = \frac{\left(\begin{array}{c} \text{number of agency work} \\ \text{days/year} \end{array} \right)}{\left(\begin{array}{c} \text{average number of work} \\ \text{days/year/employee} \end{array} \right)} \quad (4-3)$$

In actual practice, formula (4-3) is more easily used if rewritten as

$$\text{SRF} = \frac{365 - \text{ANSD}}{365 - (\text{ERDO} + \text{EBDO})} \quad (4-4)$$

In formula (4-4), the number of agency work days per year is computed by subtracting the number of agency no-service days per year (ANSD)

from the total number of days in a calendar year (i.e., either 365 or 366 days). Agency no-service days consist of regularly scheduled days off per week and common holidays (i.e., days when all employees are off duty). Some emergency service agencies provide service seven days a week and have no common holidays. For these agencies, ANSD = 0, and the number of agency work days per year equals 365 or 366.

The average number of work days per year per employee is computed by subtracting the number of regular days off (ERDO) and the average number of benefit days off (EBDO) each employee receives per year from the total number of days in a year. In most agencies, almost all benefit days off occur for the following reasons:

- vacation days,
- holidays,
- sick leave,
- compensatory time off,
- funeral leave,
- military leave,
- education leave,
- special assignments, or
- temporary reassignments.

Once ANSD, ERDO and EBDO are known, formula (4-4) can be used to compute the shift relief factor. As an example, consider the following information for a municipal library:

1. agency work data

- closed one day a week
- closed for 10 municipal holidays a year

2. average employee work data (annual absences)

- 104 regular days off
- 12.5 vacation days
- 10 holidays
- 4.4 sick days
- 3.2 other absences

Using formula (4-4),

$$\begin{aligned} \text{SRF} &= \frac{365 - 62}{365 - (104 + 12.5 + 10 + 4.4 + 3.2)} \\ &= \frac{303}{230.9} \end{aligned}$$

$$\text{SRF} = 1.312 \text{ employees/position.}$$

The library is closed 62 days a year (one day each week and 10 holidays) leaving 303 agency work days for each position. Each employee is absent two days a week (104 days) plus an average of 30.1 days for vacations, holidays, illness, and all other reasons. As a result, each employee works an average of 230.9 days per year.

As a second example, consider the following employee work data for a large metropolitan police department (average annual absences):

● regular days-off	104.0
● vacation	13.0
● holidays	10.0
● illness	4.0
● all other absences	13.75

Total: 144.75 days

Since police agencies operate seven days a week with no common holidays (i.e., ANSD = 0), the shift relief factor for this example is calculated as follows:

$$\text{SRF} = \frac{365 - 0}{365 - (104 + 40.75)}$$

$$= \frac{365}{220.25}$$

$$\text{SRF} = 1.657 \text{ officers/position.}$$

The shift relief factor for the police agency is higher than that calculated for the library because the police have more work days per year, and the average police officer, in this example, is on duty fewer days per year than the average employee in the library.

As a final example, assume that the police department changes from five 8-hour shifts per week for each employee to four 10-hour shifts per week. Each employee would now receive three regular days off per week instead of two, and the total number of regular days off for the year would increase from 104 to 156 (i.e., $3 \times 52 = 156$). If the number of annual benefit days off remain the same, the total number of off-duty days per year for each employee would increase from 144.75 to 196.75. As a result, the shift relief factor would equal

$$\begin{aligned} \text{SRF} &= \frac{365 - \text{ANS D}}{365 - (\text{ERDO} + \text{EBDO})} \\ &= \frac{365 - 0}{365 - (156 + 40.75)} \\ &= \frac{365}{365 - 196.75} \\ &= \frac{365}{168.25} \end{aligned}$$

$$\text{SRF} = 2.169 \text{ officers/position.}$$

The increase in the shift relief factor for the 4/10 plan reflects the fact that the shift is now providing 70 hours of coverage per week (10 hours per day x 7 days) instead of 56 hours--an increase

of 25 percent.*

Multishift Operations - Daily Relief Factors

If an agency operates more than one shift per day, the procedures described above can be used to determine a relief factor for each shift. Whether shift assignments are fixed or rotating, relief factors determined for each shift are often different due to differences in the number of agency and employee work days. For example, an agency may operate a day shift six days a week, but only operate the night shift five days a week. Also, if given a choice, employees may tend to take more days off on one shift than another.

Agencies which use two or three shifts per day sometimes use a daily relief factor (DRF) to determine how many employees are needed to staff one daily position--a position staffed on all shifts each day. The daily relief factor for an agency is determined by adding the relief factors for each shift.** As an example, if a police agency which operates three shifts a day, seven days a week, has determined the following relief factors for each shift:

<u>Shift</u>	<u>Relief Factor</u>
day	= 1.789
afternoon	= 1.743
night	= 1.810,

*The reader may note that the increase in the relief factor (i.e., from 1.657 to 2.169) is greater than 25 percent. This occurs because the same number of employee benefit days off actually provide more hours off when 10-hour shifts are used. For example, 10 holidays now provide 100 off-duty hours per year instead of 80.

**The shifts can be overlapping. The same procedure is used to obtain the daily relief factor whether the shifts are non-overlapping (e.g., three 8-hour shifts) or overlapping (e.g., three 10-hour shifts with six hours of overlap per day).

the daily relief factor for the agency would equal 5.342 employees/position (i.e., the sum of 1.789, 1.743 and 1.810). Hence if the agency wants to have 10 employees on duty on each shift every day of the week, the total number of employees required is given by

$$\left(\begin{array}{c} \text{number of} \\ \text{employees} \end{array} \right) = \left(\begin{array}{c} \text{daily} \\ \text{relief factor} \end{array} \right) \times \left(\begin{array}{c} \text{number of} \\ \text{daily} \\ \text{positions} \end{array} \right) \quad (4-5)$$

$$NE = DRF \times NDP$$

$$= 5.342 \times 10$$

$$= 53.42$$

$$NE = 54 \text{ employees.}$$

If the number of employees scheduled to be on duty varies by shift and/or day of the week, the number of daily positions to be used in formula (4-5) is obtained by averaging the number of positions to be staffed on each shift. The procedure for obtaining the average number of daily positions consists of the following steps:

- (1) Determine the total number of staff-days per week for each shift.
- (2) Sum the totals obtained in step (1) to determine the total number of staff-days per week over all shifts.
- (3) Determine the number of service days per week for each shift.
- (4) Sum the numbers obtained in step (3) to determine the total number of shift service days per week.
- (5) Divide the total number of staff-days obtained in step (2) by the total number of service days obtained in step (4); the quotient equals the average number of daily positions to be staffed.

Step (5) can be summarized as

$$\left(\begin{array}{c} \text{average number of} \\ \text{daily positions} \end{array} \right) = \frac{\text{(total staff-days)}}{\text{(total number of service days)}}.$$

or

$$NDP = \frac{TSFD}{TSVD} \quad (4-6)$$

where

NDP - average number of daily positions,

TSFD - total number of staff-days per week for all shifts, and

TSVD - total number of service days per week for all shifts.

The method for determining the average number of daily positions is illustrated in three examples below.

Example 1.

Number of Employees On Duty	Day of Week							Total Staff-Days	
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>		
Shift 1	7	7	7	7	7	7	7	49	
Shift 2	10	10	10	10	10	10	10	70	
Shift 3	5	5	5	5	5	5	5	35	
	<u>Shift</u>		<u>Total Staff-Days</u>				<u>Total Service Days</u>		
	1		49				7		
	2		70				7		
	3		35				7		
	Total		154				21		

Using formula (4-6),

$$NDP = \frac{TSFD}{TSVD}$$

$$= \frac{154}{21}$$

NDP = 7.33 daily positions.

Example 2.

<u>Number of Employees On Duty</u>	<u>Day of Week</u>							<u>Total</u>
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	
Shift 1	7	7	7	7	7	7	7	49
Shift 2	8	8	8	9	12	12	6	63
Shift 3	5	5	5	5	5	0	0	25

<u>Shift</u>	<u>Total Staff-Days</u>	<u>Total Service Days</u>
1	49	7
2	63	7
3	25	5
Total	137	19

Using formula (4-6),

$$NDP = \frac{TSFD}{TSVD}$$

$$= \frac{137}{19}$$

NDP = 7.21 daily positions.

Example 3.

<u>Number of Employees On Duty</u>	<u>Day of Week</u>							<u>Total</u>
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	
Shift 1	5	6	7	7	10	10	4	49
Shift 2	7	8	8	9	12	12	0	56
Shift 3	4	4	5	5	6	0	0	24

<u>Shift</u>	<u>Total Staff-Days</u>	<u>Total Service Days</u>
1	49	7
2	56	6
3	<u>24</u>	<u>5</u>
Total	129	18

Using formula (4-6),

$$\begin{aligned}
 \text{NDP} &= \frac{\text{TSFD}}{\text{TSVD}} \\
 &= \frac{129}{18} \\
 &= 7.17 \text{ daily positions.}
 \end{aligned}$$

Understanding What the Shift Relief Factor Does

Shift relief factors provide a simple mechanism for determining the number of employees needed to staff a given number of positions. They are not, however, equally applicable to all work environments. They are most appropriate when the work to be done can be stockpiled or inventoried, and are less useful for work environments where service must be supplied on demand. To understand why this is true, it is useful to understand how relief factors work. Consider the following example: a municipal electric department has determined that it needs to have four employees on duty on the day shift seven days a week (i.e., four shift positions). Based on employee work data, a shift relief factor of 1.75 has been determined. Using formula (4-1) above,

$$\left(\begin{array}{c} \text{number of} \\ \text{employees} \end{array} \right) = \left(\begin{array}{c} \text{shift relief} \\ \text{factor} \end{array} \right) \times \left(\begin{array}{c} \text{number of} \\ \text{positions} \end{array} \right)$$

$$\begin{aligned}
 \text{NE} &= \text{SRF} \times \text{NSP} \\
 &= 1.75 \times 4 \\
 \text{NE} &= 7 \text{ employees.}
 \end{aligned}$$

Since each employee works 5 days a week, seven employees will provide a total of 35 staff-days per week. If distributed uniformly over all seven days of the week, these staff-days will provide five on-duty employees each day of the week--one more employee per day than is required. The additional employee scheduled on each day of the week will not, on the average, however, produce any overstaffing. To understand why this is true, a distinction must be made between the number of employees that are scheduled to be on duty and the number that actually report for work. The shift relief factor is the link between these two numbers. In the example above, five employees will be scheduled to report each day. On the average, however, only four will actually report for work due to absences because of vacations, holidays, illness, and other reasons. Restating this observation, shift relief factors are used to determine how many employees should be scheduled in order to insure that a specified average number of employees will actually report for work.

There are two important assumptions associated with the use of shift relief factors. These are:

- Since shift relief factors are determined using average employee work data, results based on relief factor calculations are only valid as averages used over an extended period of time.
- Calculations based on shift relief factors assume that absences are equally likely to occur on any day of the week or season of the year.

The significance of these assumptions is that staffing levels based

on relief factor calculations are only valid as indicators of average employee absences over an extended period of time, and cannot be used to predict day-to-day variations in the number of on-duty employees. In the example above, the relief factor calculations indicate that although five employees are scheduled for work, on the average, only four will actually report. The actual number of employees who will report each day will vary. On some days, all five will report; on other days, only four will report; and on still other days, only three or fewer will report. As a result, even though the number of employees who report for work each day will average four, the number who actually appear, on a day-to-day basis, will often be greater or less than this long-term average.

For most agencies, day-to-day variations in the number of employees who appear for work do not present serious administrative problems. Daily variations in on-duty staffing levels are the least disruptive for agencies which stockpile or backlog their workload (e.g., most office-type work, library reshelving and cataloging work, and preventative maintenance work). Although less desirable, daily variations in staffing levels are also tolerable for most agencies which provide service on demand (e.g., library checkout desks, license bureaus, and emergency services). Fewer on-duty employees for such services usually results in some degradation of service to agency clients (e.g., in the amount of time a client must wait for service). For the agencies described above, shift relief factors provide a useful mechanism for determining how many employees will be needed to provide an average number of on-duty employees.

For some agencies, however, it is considered unacceptable if

the number of on-duty employees falls below a specified minimum level. When an excessive number of regularly scheduled employees are absent, minimum staffing levels may be maintained by using part-time personnel or full-time employees on an overtime basis. Agencies which often use minimum staffing levels include ambulance services, fire suppression services, lifeguard activities, and security work. For such services, an agency usually incurs additional expense each time substitute employees must be used to meet minimum staffing levels. These costs occur regardless of the surplus staff that may appear for work on other days or whether the average number of employees equals the minimum staffing level.

As an example, consider an agency that must maintain at least four employees on duty seven days a week. Suppose that the actual number of employees that report for work on each day during one week is:

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
Min. Staffing	4	4	4	4	4	4	4	28
Actual On Duty	5	5	3	4	3	4	4	28
Deficit Tours			1		1			

On Wednesday and Friday, only three employees appear for work--one less than the minimum staffing level. On both days, one substitute employee must be found to bring the on-duty force up to minimum standards. What is important to note is that these deficits could not be covered by the extra employees that appeared on Monday and Tuesday. Also these deficits occurred despite the fact that the average number of on-duty employees equals the minimum staffing level (i.e., an average of four employees reported for work each day). Additional information on minimum staffing is presented in appendixes C and D.

C. Staff Allocation

Introduction

When the total number of employees is known, the number of staff-days to be scheduled each week can be allocated by shift and day of the week based on agency workload. Allocation procedures for both one-shift and multishift operations are presented in this section.

Determining the Number of Staff-Days To be Scheduled Each Week

The number of staff-days to be scheduled each week is the product of the number of employees and the average number of work days per employee per week. That is,

$$\left(\begin{array}{l} \text{number of} \\ \text{staff-days} \end{array} \right) = \left(\begin{array}{l} \text{number of} \\ \text{employees} \end{array} \right) \times \left(\begin{array}{l} \text{average number} \\ \text{of work days/} \\ \text{employee/week} \end{array} \right). \quad (4-7)$$

Ordinarily, the average number of work days per employee per week includes days off for vacations, holidays, sick leave, and other benefit days (i.e., the average number of work days equals seven minus the average number of regular days off per week).

As examples, if an agency has 12 employees, each of whom works five days a week, there are 60 staff-days to be scheduled each week. If an agency has eight employees and each works four 10-hour shifts a week, there are 32 staff-days to be scheduled.

The determination of the number of staff-days to be scheduled is somewhat more complicated in agencies which do not have common holidays. Under this system, each employee is guaranteed a fixed number of additional days off per year, and usually each employee must schedule his or her holidays on an individual basis. In some agencies, these additional days are treated as regular days off

and incorporated into the basic work schedule. For example, if an employee receives two days off per week and 10 holidays a year, some agencies design work schedules based on 114 off-duty days per year for each employee (i.e., $(52 \times 2) + 10 = 114$). Under this system, the average number of days each employee works per week must be adjusted slightly to account for holiday time off. The adjusted value is obtained using the following formula:

$$\left(\begin{array}{l} \text{adjusted avg.} \\ \text{no. of work} \\ \text{days/week} \end{array} \right) = \left(\begin{array}{l} \text{avg. no.} \\ \text{of work} \\ \text{days/week} \end{array} \right) - \left(\frac{\text{annual no.} \\ \text{of holidays}}{52} \right). \quad (4-8)$$

To illustrate the use of formula (4-8), assume that each employee works five days per week and receives 10 holidays a year. If these holidays are to be included in the employees' work schedule, an adjusted average number of work days per week for each employee must be determined. Using formula (4-8),

$$\begin{aligned} \text{adjusted no.} &= 5 - \frac{10}{52} \\ &= 5 - .1923 \\ \text{adjusted no.} &= 4.8077 \text{ work days/employee/week.} \end{aligned}$$

If this adjusted value is used in formula (4-7) instead of 5 work days/employee/week, the resulting number of staff-days to be allocated will be reduced by approximately .2 work days per employee. For seven employees, for example, the number of staff-days to be allocated would be reduced from 35 (7×5) to 33.65 (7×4.8077). Since the number of staff-days must be an integer for scheduling purposes, the 33.65 value must either be rounded down to 33 or up to 34. If 34 staff-days are used, the seven

employees will still accumulate additional time off at the rate of 0.35 staff-days per week (i.e., $34 - 33.65 = 0.35$ staff-days/week). Hence over a year's time, each employee would receive 2.60 holidays ($52 \times 0.35/7$ staff-days/employee/week). Time off for these remaining holidays is usually scheduled on an individual basis.

Determining Daily Agency Workload

For many service agencies, the most productive use of staff can be obtained by scheduling available staff-days in proportion to agency workload by shift and day of the week. Valid measures of workload depend on the type of service or coverage provided by an agency. Typical workload measures for several services are listed below.

<u>Service</u>	<u>Workload Measures</u>
Police patrol units	Calls for service
Highway patrol units	Traffic accidents
Library circulation desk	Number of books checked out
Refuse collectors	Volume of refuse
Toll collectors	Traffic volume

For some agencies, the principal service function is clearly defined, and valid and accurate workload measures are readily available (e.g., toll collectors). Some agencies, however, perform a variety of services (e.g., police) and there may be no general agreement on how the workload associated with these services should be measured. For such agencies, the definition and collection of valid workload data may represent a major effort of the schedule design process.

Once an acceptable workload measure has been determined, data must be collected to estimate the distribution of work by day of

the week. For one-shift operations and for agencies which use non-overlapping shifts, workload data can be collected for each shift. For example, if the daily volume of refuse collected is used as the workload measure for a six-day, one-shift refuse collection operation, a sample of agency records may indicate a daily workload distribution like that shown in Table 4-1. The data indicate that the greatest volume of refuse is collected on Mondays and Thursdays, and that the least volume is collected on Saturdays.

As a second example, if the number of job orders for a transit maintenance center that operates two non-overlapping shifts a day, seven days a week, are taken as the measure of workload, agency service records may indicate a daily distribution of workload like that shown in Table 4-2. The data indicate heavy volume on Mondays and Thursdays and a considerable dropoff in workload on the weekend. The fractions under each job count are based on the

Table 4-1

DAILY DISTRIBUTION OF REFUSE COLLECTION WORKLOAD

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
Refuse Collected (tons)	25	18	19	23	18	12	0	115
Fraction of Weekly Total	.217	.157	.165	.200	.157	.104	0	1.000

Table 4-2

DAILY DISTRIBUTION OF TRANSIT MAINTENANCE WORKLOAD
(Number of Job Orders)

<u>Shift</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
Day (6 a.m.-2 p.m.)	213 .168	148 .117	171 .135	283 .223	198 .156	104 .082	153 .120	1,270 .506
Night (2 p.m.-10 p.m.)	247 .199	153 .123	149 .120	304 .245	206 .166	141 .114	42 .034	1,242 .494
Total	460 .183	301 .120	320 .127	587 .234	404 .161	245 .098	195 .078	2,512 1.000

total count for each shift (e.g., the 171 jobs on Wednesdays on the day shift represent 13.5 percent of all day shift work).

How much data should be collected to estimate an agency's daily workload depends on the volume of work performed each week and the effects of seasonal variations. The following general guidelines for data collection should apply to all agencies:

- Workload data should be collected or sampled from a minimum of several weeks to smooth out the effects of particularly heavy or light workload weeks. The objective is to "stabilize" the daily fractions.
- If sampling is used, care should be taken to insure that a representative sample of work from all days of the week is obtained. Two sampling procedures frequently used are (1) randomly selecting several weeks from the last several months or year, and using workload counts for every day in each week selected, or (2) randomly selecting a fixed number of Mondays, Tuesdays, Wednesdays, etc., from the last several months or year (e.g., selecting 10 Mondays, 10 Tuesdays, etc.).

- If the distribution of agency workload by shift or day of the week varies by season of the year, workload data should be collected or sampled from agency records for an entire year.

If reliable estimates of agency workload cannot be obtained from existing records, it may be possible to initiate a short-term data collection effort. If data collection activities are not feasible, interviews with agency supervisors and foremen can sometimes be used to identify high, medium, and low workload days and shifts.

Allocating Staff-Days Over One Shift

This subsection presents a procedure for allocating a given number of staff-days over the days of the week for one shift. This procedure consists of two steps:

- (1) Determine the ideal number of staff-days for each day of the week.*
- (2) Adjust ideal numbers of staff-days to integer values.

The ideal number of staff-days for each day of the week is given by the product of the fraction of workload for each day and the total number of staff-days to be allocated; that is,

$$\left(\begin{array}{c} \text{ideal number} \\ \text{of staff-days} \end{array} \right) = \left(\begin{array}{c} \text{fraction of} \\ \text{workload} \end{array} \right) \times \left(\begin{array}{c} \text{total number} \\ \text{of staff-days} \end{array} \right) \quad (4-9)$$

To illustrate this step, consider an agency with the daily workload distribution shown in Table 4-3. If the agency has seven employees, each working five days a week, there are 35 staff-days to be allocated. Application of step (1) to this data is illustrated in Table 4-4.

*The term "ideal" is used throughout the remainder of this chapter to indicate values that are not constrained to be integers.

Table 4-3

DAILY WORKLOAD

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
Number of Service Calls	546	513	500	518	570	433	353	3,433
Fraction of Calls	.159	.149	.146	.151	.166	.126	.103	1.000

Table 4-4

DAILY ALLOCATION OF THE TOTAL NUMBER OF
STAFF-DAYS AVAILABLE EACH WEEK

<u>Staff-Days</u> <u>Allocated to</u>	<u>Fraction</u> <u>of Calls</u>	x	<u>Total No.</u> <u>Staff-Days</u>	=	<u>Ideal No.</u> <u>Staff-Days</u>	<u>Adjusted No.</u> <u>Staff-Days</u>
Monday	.159	x	35	=	5.6	6
Tuesday	.149	x	35	=	5.2	5
Wednesday	.146	x	35	=	5.1	5
Thursday	.151	x	35	=	5.3	5
Friday	.166	x	35	=	5.8	6
Saturday	.126	x	35	=	4.4	4
Sunday	<u>.103</u>	x	35	=	<u>3.6</u>	<u>4</u>
Total	1.000	x	35	=	35.0	35

The number of staff-days allocated to each day indicates the number of employees who should be on duty on each day of the week. Since this number must be an integer, each daily allocation value must be rounded up or down to the nearest integer value. In addition, the sum of the adjusted values must equal the total number of staff-days to be allocated. Adjusting each value in Table 4-4 yields the daily distribution of on-duty staff shown in the last column in the table.

A summary of the allocated staff-days for the seven employees is shown in Table 4-5. The number of off-duty employees for each day of the week is obtained by subtracting the number of employees who are on duty each day from the total number of employees available. The sum of the number of employees who are off duty over the entire week equals the average number of off-duty days each employee receives

Table 4-5

DAILY DISTRIBUTION OF ON- AND OFF-DUTY EMPLOYEES

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
On-Duty	6	5	5	5	6	4	4	35
Off-Duty	<u>1</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>1</u>	<u>3</u>	<u>3</u>	14
Total	7	7	7	7	7	7	7	

per week times the total number of employees (i.e., 14 off-duty days = (2 off-duty days/employee/week) x (7 employees)).

Allocating Staff for Multishift Schedules

The procedures for allocating a given number of staff-days over two or more shifts are based on the one-shift procedure described above. For most agencies, staff allocations over several shifts can be accomplished with the following steps:

- (1) Determine the ideal number of employees to be assigned to each shift based on the fraction of agency workload for each shift.
- (2) Adjust the ideal numbers of employees to integer values which sum to the total number of employees to be allocated.
- (3) Determine the number of staff-days to be allocated over each shift.
- (4) Allocate the staff-days for each shift based on the one-shift procedure described above.

To illustrate, assume that an agency with 20 employees has the workload distribution shown in Table 4-6. The procedure for determining the ideal and adjusted numbers of employees for each shift based on this workload data is illustrated in Table 4-7.

The ideal number of employees for each shift is obtained by multiplying the total number of employees by the fraction of workload on each shift. Rounding each ideal number to an integer value produces the adjusted number of employees shown in the last column. Once the number of employees is known for each shift, the one-shift allocation procedure described above can be used to determine the number of on-duty employees for each day of the week. This allocation procedure is valid for schedules with either fixed or rotating shift assignments.

Alternative multishift allocation procedure. An alternative

Table 4-6

WORKLOAD DISTRIBUTION BY SHIFT

<u>Shift</u>	<u>Fraction of Agency Workload</u>
Day	.321
Afternoon	.428
Night	<u>.251</u>
Total	1.000

Table 4-7

ALLOCATION OF EMPLOYEES BY SHIFT

<u>Employees Allocated To</u>	<u>Fraction of Workload</u>	x	<u>Number of Employees</u>	=	<u>Ideal Number of Employees</u>	<u>Adjusted Number of Employees</u>
Day	.321	x	20	=	6.42	6
Afternoon	.428	x	20	=	8.56	9
Night	<u>.251</u>	x	20	=	<u>5.02</u>	<u>5</u>
Total	1.000	x	20	=	20.00	20

allocation procedure can be used for multishift schedules if both of the following conditions are met:

- the schedule uses rotating shift assignments, and
- employees are not required to work a fixed number of days within each calendar week, seven days, or pay period.*

The basic steps of this alternative method are:

- (1) Determine the fraction of work the agency performs by shift and day of the week.
- (2) Determine the total number of staff-days to be distributed over all shifts.
- (3) Determine the ideal number of staff-days to be allocated to each shift and day of the week based on the workload fractions found in step 1.
- (4) Adjust the ideal staff-days to integer values which sum to the total number of staff-days to be allocated.
- (5) Determine the number of employees to be assigned to each shift.

To illustrate this procedure, assume that an agency that operates two shifts a day, seven days week, has the workload fractions for each shift and day of the week shown in Table 4-8 (step (1)). If the agency has 15 employees, each working 5 days a week, there are 75 staff-days to be allocated (step (2)). Table 4-9 presents the ideal number of staff-days for each shift and day of the week (step (3)). Each ideal number is obtained by multiplying 75 by the workload fractions shown in Table 4-8. Adjusting each ideal number to an integer value produces Table 4-10 (step (4)). The final step is to determine how many employees should be assigned to each shift. This is done by determining two numbers for each shift:

*This condition can also be stated as: employees are not required to receive a fixed number of days off within each calendar week, seven days, or pay period.

Table 4-8

WORKLOAD FRACTIONS FOR A TWO-SHIFT OPERATION

<u>Shift</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
Day	.076	.079	.083	.088	.092	.073	.055	.546
Night	.061	.063	.066	.073	.080	.065	.046	.454

Table 4-9

IDEAL NUMBER OF STAFF-DAYS

<u>Shift</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
Day	5.700	5.925	6.225	6.600	6.900	5.475	4.125	40.950
Night	4.575	4.725	4.950	5.475	6.000	4.875	3.450	34.050

Table 4-10

ADJUSTED NUMBER OF STAFF-DAYS

<u>Shift</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
Day	6	6	6	7	7	5	4	41
Night	5	5	5	5	6	5	3	34

the minimum number of employees required based on the number of staff-days allocated to each day of the week, and the adjusted number of employees based on the total workload fractions for each shift. The minimum number is determined by examining the number of on-duty employees in Table 4-10. The largest number of on-duty employees for each shift represents the minimum number of employees that must be assigned to the shift. For example, on the day shift, the largest number of on-duty employees is seven (on both Thursday and Friday). Hence, there must be at least seven employees assigned to the day shift. Similarly, examining the daily on-duty numbers indicates that at least six employees must be assigned to the night shift (six are required on Friday).

The adjusted numbers of employees for each shift are based on the total number of employees to be scheduled and the total workload

fractions for each shift. These numbers for the two-shift example above are shown in Table 4-11.

The number of employees to be assigned to each shift equals the greater of the two numbers computed for each shift (i.e., the greater of the minimum number required and the adjusted number based on the shift workload fractions). Hence, for the two-shift example, eight employees would be assigned to the day shift, and seven assigned to the night shift (see Table 4-12). The number of employees assigned to each shift must sum to the total number of employees available.

This alternate method of staff allocation for multishift operations provides a better match between on-duty staff-days and daily workload by ignoring the requirement that each employee must work a specified number of days per week on each shift. Instead, the required number of work days per week for each employee is averaged

Table 4-11

ADJUSTED NUMBERS OF EMPLOYEES FOR EACH SHIFT

<u>Shift</u>	<u>Workload Fraction</u>	<u>Number of Employees</u>	<u>Ideal Number of Employees</u>	<u>Adjusted Number of Employees</u>
Day	.546	15	8.19	8
Night	.454	15	6.81	7

Table 4-12

NUMBER OF EMPLOYEES ASSIGNED TO EACH SHIFT

<u>Shift</u>	<u>Minimum No. of Employees (column 1)</u>	<u>Adjusted No. of Employees (column 2)</u>	<u>Number of Employees Assigned (Greater of columns 1 and 2)</u>
Day	7	8	8
Night	6	7	7

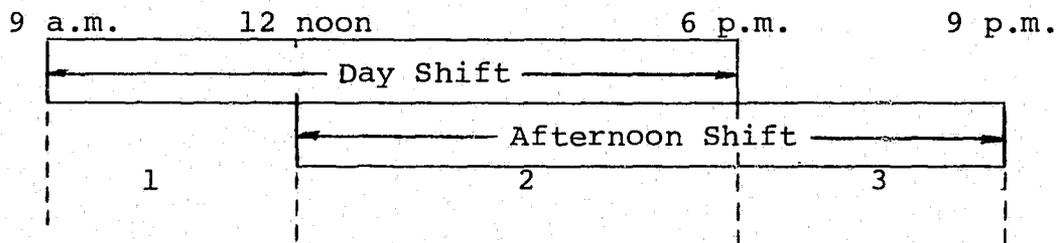
over all shifts (i.e., after rotating through all shifts, each employee will have worked the correct number of days). In the example just completed, the eight employees assigned to the day shift provide 41 staff-days per week (an average of 5.13 work days per week per employee) while the seven employees assigned to the night shift only provide 34 staff-days per week or an average of 4.86 work days per week per employee. Over both shifts, however, the 15 employees provide 75 staff-days per week, or five work days per week for each employee--the required amount. If this allocation is used for a schedule with rotating shift assignments, each employee will work the correct number of days per week during each rotation period of the schedule.

Allocating Personnel for Two Overlapping Shifts

This subsection presents a method for allocating staff by day

of week and shift for agencies which operate two overlapping shifts per service day. Description of the procedure is presented in two parts: data collection and preparation, and staff allocation.

Data collection and preparation. To allocate staff for two overlapping shifts, it is necessary to collect and prepare workload data for blocks of time with uniform staffing levels. Agencies using two overlapping shifts have three time blocks of uniform staffing each day. To illustrate, consider a library which operates two shifts a day, Monday through Saturday: a day shift that runs from 9 a.m. to 6 p.m., and an afternoon shift that runs from 12 noon to 9 p.m. The two shifts overlap each other from 12 noon to 6 p.m. daily (see the diagram below). The three time blocks of uniform staffing are (1) the day shift only from 9 a.m. to 12 noon, (2) both shifts from 12 noon to 6 p.m., and (3) the afternoon shift only from 6 p.m. to 9 p.m.



Staff allocations for two overlapping shifts are based on daily workload data collected for each time block. Sample workload fractions for the three time blocks of a two-shift operation are illustrated in Table 4-13. Once daily workload data for each time block are known, the workload fractions for time blocks 1 and 3 for each day of the week are modified using the following formulas:

Time block 1

$$w_1^i = \frac{w_1}{1 - \frac{w_2}{T}} \quad (4-10)$$

Table 4-13

WORKLOAD FRACTIONS FOR TWO OVERLAPPING SHIFTS

<u>Time Block</u>	<u>Hours</u>	<u>Day of Week</u>							<u>Total</u>
		<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	
1	9 a.m. - 12 noon	.035	.026	.029	.028	.031	.032	0	.181
2	12 noon - 6 p.m.	.091	.072	.073	.074	.079	.083	0	.472
3	6 p.m. - 9 p.m.	.066	.054	.055	.059	.065	.048	0	.347
	Total	.192	.152	.157	.161	.175	.163	0	1.000

and

Time block 3

$$W_3' = \frac{W_3}{1 - \frac{W_2}{T}} \quad (4-11)$$

where W_1' and W_3' represent the modified workload fractions for time blocks 1 and 3, W_1 , W_2 , and W_3 represent the original workload fractions for time blocks 1, 2, and 3, and T represents the total workload fraction for the day.

To illustrate the use of these formulas, the calculation of the modified workload fractions for time blocks 1 and 3 based on the data for Monday in Table 4-13 is given below.

Time block 1

$$\begin{aligned}w_1' &= \frac{W1}{1 - \frac{W2}{T}} \\ &= \frac{.035}{1 - \frac{.091}{.192}} \\ w_1' &= .067,\end{aligned}$$

Time block 3

$$\begin{aligned}w_3' &= \frac{W3}{1 - \frac{W2}{T}} \\ &= \frac{.066}{1 - \frac{.091}{.192}} \\ w_3' &= .125.\end{aligned}$$

The complete set of modified values for the workload fractions are shown in Table 4-14. Note that the sum of the modified workloads

Table 4-14

MODIFIED WORKLOAD FRACTIONS FOR TIME BLOCKS
1 AND 3 BASED ON THE WORKLOAD IN TABLE 4-13

<u>Block</u>	<u>Hours</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
1	9 a.m. - 12 noon	.067	.049	.054	.052	.057	.065	0	.344
3	6 p.m. - 9 p.m.	.125	.103	.103	.109	.118	.098	0	.656
	Total	.192	.152	.157	.161	.175	.163	0	1.000

for each day equals the daily workload total recorded in Table 4-13. This occurs because formulas (4-10) and (4-11) allocate all of the workload associated with time block 2 to time blocks 1 and 3.

The rationale for the data modification procedure described above is the fact that the number of employees allocated to each shift is determined entirely by the relative workloads in time blocks 1 and 3 only. This is most easily seen by observing that the number of on-duty employees in time block 2, the overlap period, always equals the sum of the number of employees scheduled to be on duty on the day and afternoon shifts regardless of the actual workload level in time block 2. Hence, the data modification procedure reallocates the workload in time block 2 to time blocks 1 and 3 in such a way that it preserves the relative workload levels for time blocks 1 and 3, and the relative workload levels by day of week.

Staff allocation. Once the modified workload for time blocks 1 and 3 are known, either of the multishift staff allocation procedures described above can be used by treating time blocks 1 and 3 as distinct shifts. As a review, the first multishift allocation procedure consists of the following steps:

- (1) Determine the ideal number of employees to be assigned to each shift based on the fraction of workload for each shift.
- (2) Adjust the ideal numbers of employees to integer values which sum to the total number of employees to be allocated.
- (3) Determine the number of staff-days to be allocated over each shift.
- (4) Allocate the staff-days for each shift based on the daily workload fractions for the shift.

As an example, assume that the modified workload fractions shown in Table 4-14 are to be used to allocate 18 employees for an agency that schedules each worker for five on-duty tours per week. The results of steps (1), (2), and (3) are summarized in Table 4-15. The daily allocation of staff-days for each shift is based on the modified workload fractions for each day of the week indicated in Table 4-14. To use the one-shift allocation procedure described above, the daily workload fractions for each shift must be adjusted so that the sum of the daily workload fractions for each shift equals 1.000. This is easily done by dividing each daily fraction in Table 4.14 by the current sum of the workload fractions for each shift (i.e., each fraction in time block 1 is divided by .344, and each fraction in time block 3 is divided by .656). The final allocation of the 18 employees by day of week and time block is shown in Table 4-16. The allocation of the 30 staff-days for the day shift are shown in time block 1, and the allocation of the 60 staff-days for the afternoon shift are shown in time block 3.

Table 4-15

ALLOCATION OF 18 EMPLOYEES BY SHIFT

<u>Employees Allocated To</u>	<u>Fraction of Workload</u>	x	<u>Number of Employees</u>	=	<u>Ideal Number of Employees</u>	<u>Adjusted Number of Employees</u>	<u>Number of Staff-Days to be Allocated</u>
Day	.344	x	18	=	6.192	6	30
Afternoon	<u>.656</u>	x	18	=	<u>11.808</u>	<u>12</u>	<u>60</u>
Total	1.000		18		18.000	18	90

Table 4-16

ALLOCATION OF 18 EMPLOYEES BY DAY OF WEEK
AND TIME BLOCK

<u>Time Block</u>	<u>Hours</u>	<u>Day of Week</u>							<u>Total</u>
		<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	
1(Day)	9 a.m.-12 noon	6	4	5	4	5	6	0	30
2 ^a	12 noon-6 p.m.	17	13	15	14	16	15	0	
3(Afternoon)	6 p.m.-9 p.m.	11	9	10	10	11	9	0	60

^aBoth shifts are on duty during time block 2.

The alternate multishift allocation procedure is based on the following steps:*

- (1) Determine the fraction of workload by shift and day of week.
- (2) Determine the total number of staff-days to be distributed over all shifts.
- (3) Determine the ideal number of staff-days to be allocated to each shift by day of week based on the workload fractions found in step (1).
- (4) Adjust the ideal number of staff-days to integer values which sum to the total number of staff-days to be allocated.
- (5) Determine the number of employees to be assigned to each shift.

Step (1) is accomplished by constructing the table of modified workload fractions for time blocks 1 and 3 (e.g., as shown in Table 4-14). To illustrate the remaining steps of the alternate procedure, assume that 18 employees must be allocated over two shifts

*See the discussion above for the limitations associated with use of the alternate allocation procedure.

using the workload fractions in Table 4-14. If each employee works five tours per week, there are 90 staff-days to be allocated over both shifts (step (2)). The ideal number of staff-days for each shift and day of the week are calculated using the modified workload fractions in Table 4-14 (step (3)). The results of adjusting each ideal number to an integer value are shown in Table 4-17 (step (4)). The only difference between the allocation shown in tables 4-16 and 4-17 is one staff-day that has been moved from the afternoon shift on Wednesday to the day shift on Thursday.

The number of employees to be assigned to each shift (step (5)) is determined by examining two numbers: the minimum number of employees required and the number of employees based on the total workload for the shift. Both numbers for each shift are shown in Table 4-18. The minimum requirements are driven by the number of employees assigned to each day of the week; hence, 6 employees are

Table 4-17

ALLOCATION OF 18 EMPLOYEES BY DAY OF WEEK
AND TIME BLOCK

<u>Time Block</u>	<u>Hours</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
1(Day)	9 a.m.-12 noon	6	4	5	5	5	6	0	31
2 ^a	12 noon-6 p.m.	17	13	14	15	16	15	0	90
3(Afternoon)	6 p.m.-9 p.m.	11	9	9	10	11	9	0	59

^aBoth shifts are on duty during time block 2.

Table 4-18

NUMBER OF EMPLOYEES ASSIGNED TO EACH SHIFT

<u>Shift</u>	<u>Minimum No. of Employees Required (1)</u>	<u>Adjusted No. of Employees (2)</u>	<u>Number of Employees Assigned (Greater of (1) and (2))</u>
Day	6	6	6
Afternoon	11	12	<u>12</u>
			18

needed on the day shift to cover Monday and Saturday and 11 employees are needed on the afternoon shift to cover Monday and Friday. The adjusted numbers of employees for each shift are based on the numbers of employees obtained by multiplying 18 times the workload fractions for time blocks 1 and 3.

CHAPTER V

SELECTING A SCHEDULE DESIGN METHOD

A. Introduction

The purpose of this chapter is to assist a schedule designer in selecting a design method from among those described in chapters VI through VIII by identifying which of them can produce a schedule meeting a specific set of constraints and objectives. In some cases, none of these methods will produce acceptable schedules. When this occurs, minor modification of the constraints or objectives frequently makes use of one of the methods feasible, but sometimes other types of schedules must be considered. On the other hand, in some cases more than one of this handbook's scheduling methods may produce acceptable schedules. When this happens, the design method may be selected arbitrarily, or useful but secondary constraints and objectives may be added until only one method remains.

The properties of schedules designed using each method are summarized in Section B. Section C identifies schedule properties and constraints which are incompatible with each method. A simple procedure for selecting a design method based on these properties is then presented.

B. Schedule Design Methods and Resulting Schedule Properties

Chapter VI discusses the design of fixed bracket (FB) schedules. Principal properties of these schedules include the following:

- each employee is always off duty on the same days each week (e.g., some employees may be off duty Saturday and Sunday, while others are off duty on Tuesday and Wednesday);

- work and off-duty periods are usually uniform in length;
- employees are permanently assigned to a shift;
- the number of on-duty employees may be uniform by day of week on each shift, or it may vary from day to day (e.g., in proportion to a cyclic day-of-week workload distribution);
- employees are on duty the same number of days and hours in every calendar week;
- schedule equity, in terms of days off and shift assignments, is not provided;
- complete team integrity and unity of command are not provided unless all team members and their supervisor are off duty on the same days of the week;
- holidays cannot be included as regularly-scheduled off-duty days; and
- schedules are relatively easy to design compared to the other types of schedules discussed.

Chapter VII discusses the design of two types of duty cycle schedules. Properties of basic duty cycle schedules include the following:

- all employees follow the same pattern of shift assignments and off-duty days (i.e., the duty cycle pattern), which continually repeats throughout the schedule design interval (unlike fixed bracket schedules, this pattern is not restricted to seven days in length);
- coverage is provided seven days a week on each staffed shift;
- the number of on-duty employees is nearly uniform by day of week on each shift;
- the number of on-duty employees may be uniform by shift, or it may vary from shift to shift;
- employees' off-duty days are not fixed (e.g., an employee's off-duty days normally change from week to week);
- employees' shift assignments are usually not fixed and may change within a single week or be fixed

for several weeks (however, fixed shift assignments may be achieved by designing separate duty cycle schedules for each shift);

- in general, employees are not on duty the same number of days and hours in every calendar week;
- schedule equity, in terms of the number of on-duty assignments on each shift and the lengths of each employee's work and off-duty periods, is provided;
- schedule equity, in terms of the number of week-ends and other days of the week that are included in each employee's off-duty periods, is also provided unless the duty cycle pattern is a whole number of weeks in length (i.e., when the schedule is locked);
- the length, in days, of the duty cycle pattern is equal to the number of groups of employees being scheduled; and
- complete team integrity and unity of command are not provided unless all team members and their supervisor are assigned to the same group.

Extended duty cycle schedules, the second type of duty cycle schedule covered in Chapter VII, have all of the above properties of basic duty cycle schedules except that the length, in days, of the duty cycle pattern is a multiple of the number of groups of employees being scheduled. In addition, extended duty cycle schedules have the following properties not necessarily provided by basic duty cycle schedules:

- "better" schedules can be designed when the number of employees being scheduled is small;
- work periods are uniform in length;
- shift changes are less frequent than in basic duty cycle schedules;
- extended off-duty periods are more easily provided than in basic duty cycle schedules;
- scheduling of one-day off-duty periods and consecutive on-duty days on different shifts can usually be avoided; and

- the period of time over which the number of on-duty assignments on each shift, the lengths of work and off-duty periods, and the number of weekends and other days of the week included in off-duty periods, balance among employees may be very long (e.g., a year or more).

Chapter VIII discusses the design of one-shift and multi-shift proportional rotating (PR) schedules. Principal properties of these schedules include the following:

- all employees follow the same duty cycle (the pattern of on- and off-duty assignments), which repeats continually throughout the schedule design interval;
- this duty cycle is a whole number of weeks in length;
- the number of groups of employees being scheduled is equal to the length of the duty cycle in weeks;
- the number of on-duty employees can be nearly uniform by day of week and shift, or it can vary from shift to shift, and by day of week on each shift;
- employees' shift assignments can be fixed (one-shift schedules) or rotate periodically (multishift schedules);
- in general, employees are not on duty the same number of days and hours in every calendar week;
- schedule equity, in terms of the lengths of each employee's work and off-duty periods and the number of weekends and other days of the week included in each employee's off-duty periods, is provided;
- multishift PR schedules are also equitable in terms of the proportion of each employee's time spent on duty on individual shifts;
- on-and off-duty periods of different lengths must usually be scheduled;
- for multishift schedules, employees are assigned to shifts for a whole number of weeks;
- holidays can be easily included as regularly-scheduled off-duty days;
- team integrity and unity of command are not provided unless all team members and their supervisor are assigned to the same group; and

- these schedules tend to be more difficult to design than fixed bracket or duty cycle schedules.

C. Identifying and Selecting an Acceptable Design Method

Any single schedule property will not normally restrict the scheduler to a single type of schedule and design method. For example, basic and extended duty cycle schedules, and one-shift and multishift proportional rotating schedules all can provide rotating days off for all employees. On the other hand, a single property can often be used to determine that a particular type of schedule (and design method) will be unacceptable. Thus, an agency requiring a schedule in which employees' off-duty days rotate from week to week can eliminate consideration of fixed bracket schedules. Following this type of reasoning, the schedule properties which are incompatible with each type of schedule are identified below.

Fixed bracket schedules cannot be used if any of the following schedule properties are required:

- regularly-scheduled rotation of the days of the week each employee is off duty;*
- regularly-scheduled rotation of the shift to which employees are assigned;
- schedule equity among employees, in terms of shift assignments and off-duty days of the week;
- variable-length off-duty periods (e.g., a regularly-scheduled extended weekend); or

*Some agencies using FB schedules periodically change all employees' bracket assignments to improve schedule equity. This practice, however, can require considerable administrative work at the time of bracket reassignment to ensure that all employees are assigned the correct number of on- and off-duty days and are allowed sufficient time off before starting work on a different shift.

- a pattern of shift assignments and off-duty days which is not seven days in length.

Similarly, neither basic nor extended duty cycle schedules can be used if any of the following schedule properties are required:

- the number of on-duty groups of employees varies by more than one among the days of the week on each shift;*
- a work shift is staffed less than seven days a week;
- days of the week each employee is off duty are fixed;
- groups of identically-scheduled employees vary significantly in size, or
- the number of on-duty days and hours per calendar week are fixed.

In addition, basic duty cycle schedules cannot be used if the number of groups of employees to be scheduled is less than the number of days in the duty cycle pattern, and extended duty cycle schedules cannot be used if any of the following properties are required:

- the duty cycle pattern is seven days in length;
- the number of groups of employees to be scheduled is equal to the number of days in the duty cycle; or
- work periods vary in length.

One-shift and multishift proportional rotating schedules cannot be used if any of the following properties are required:

- days of the week each employee is off duty are fixed;
- employees are assigned to a shift for other than a whole number of weeks;

*Greater variability in staffing levels can be achieved with duty cycle schedules, but this requires scheduling many Kelly days or payback days.

- the duty cycle is not a whole number of weeks in length;
- the duty cycle is less than two weeks in length; or
- the number of groups of employees to be scheduled is not equal to the length, in weeks, of the duty cycle pattern.

In addition, one-shift PR schedules cannot be used if regularly-scheduled shift rotation is required, and multishift PR schedules cannot be used if permanent shift assignments are to be used.

The incompatibility of certain schedule properties and types of schedules just described is summarized in Table 5-1. This table can be used to identify acceptable and unacceptable types of schedules as follows:

- Examine properties 1 through 9 listed in the left-hand column of the table, and determine which properties are required in the schedule being designed.
- For each of these properties which applies, identify the types of schedules which cannot be used by determining if an "X" appears in the table opposite the required property in the column corresponding to that type of schedule. For example, both basic and extended duty cycle schedules are unacceptable if property 1 (variable on-duty staffing by day of week) is required.
- Place an "X" in the bottom row of the table in each column corresponding to an unacceptable type of schedule.
- Determine which of properties 10 through 14 are affected by agency constraints and scheduling objectives. Also, determine how agency constraints affect each of these properties (e.g., should off-duty days of the week--property 10--be fixed or rotating).
- For each of properties 10 through 14 which apply, identify which of the types of schedules cannot be used by determining if the requirement for a property agrees with the description in the table opposite the property in the column corresponding

Table 5-1

IDENTIFICATION OF ACCEPTABLE AND UNACCEPTABLE TYPES OF SCHEDULES AND DESIGN METHODS

Schedule Property	Type of Schedule				
	Fixed Bracket (FB)	Duty Cycle		Proportional Rotating (PR)	
		Basic	Extended	One-Shift	Multishift
1. Variable on-duty staffing by day of week	-	X	X	-	-
2. Fixed number of on-duty hours per calendar week	-	X	X	X	X
3. Variable-length work periods	X	-	X	-	-
4. Variable-length off-duty periods	X	-	-	-	-
5. Days of week when a shift is not operated	-	X	X	-	-
6. Equitable distribution of off-duty days of week	X	-	-	-	-
7. Equitable distribution of shift assignments	X	-	-	X	-
8. Variable-sized schedule groups	-	X	X	-	-
9. Assignment to a shift for other than a whole number of weeks	X	-	-	X	X
10. Off-duty days of the week	Rotating	Fixed	Fixed	Fixed	Fixed
11. Shift assignments	Rotating	-	-	Rotating	Fixed
12. Length, in days, of repeating pattern of on- and off-duty days (i.e., the duty cycle)	Less than or greater than 7	-	7	Less than or equal to 7	Less than or equal to 14
13. Relation between number of schedule groups and length, in days, of the duty cycle	-	Unequal	Equal	-	-
14. Relation between number of schedule groups and length, in weeks, of the duty cycle	-	-	-	Unequal	Unequal
Unacceptable Types of Schedules ("X")					

to that type of schedule. For example, a fixed bracket schedule is unacceptable if employees' days of the week off duty (property 10) must rotate. On the other hand, the other four types of schedules cannot be used if days of the week off duty are fixed.

- Place an "X" in the bottom row of the table in each column corresponding to an unacceptable type of schedule.
- After all properties have been examined, the unacceptable types of schedules are those marked with an "X" in the bottom row of the table. Those not marked with an "X" in this row can be used to satisfy all of the previously identified constraints and objectives. Refer to the appropriate chapter for details on the design methods.

When all types of schedules are found to be unacceptable, one or more constraints will have to be relaxed if the design methods described in the handbook are to be used. On the other hand, if several types are acceptable, the schedule designer can use secondary constraints and objectives to decide which type is the most appropriate.

To illustrate these procedures, suppose that a schedule must be designed which provides (1) variable on-duty staffing by day of week, (2) permanent assignment of each employee to one of three shifts operated by an agency, and (3) a non-uniform distribution of employees among the three shifts. Reference to Table 5-1 shows that requirement (1) eliminates both types of duty cycle schedules since an "X" appears opposite property 1 in the columns corresponding to each of these types of schedules. Therefore, the scheduler places an "X" in these two columns in the bottom row of the table. Requirement (2) eliminates multishift PR schedules because "fixed" appears in the rightmost column opposite property 11, which agrees with the

agency's requirement regarding shift assignments. Therefore, an "X" is also placed in this column in the table's bottom row. Since none of the 14 properties listed in Table 5-1 relate to the distribution of employees among the shifts, requirement (3) is irrelevant to selection of the type of schedule to be used (i.e., in this respect any of the types would suffice).

An illustration of the way Table 5-1 would appear with the indicated X's entered in the bottom row is shown in Table 5-2. Circled table entries identify the combinations of rows and columns which were used to determine unacceptable types of schedules. The bottom row of the table shows that either a fixed bracket or one-shift proportional rotating schedule can be used. By comparing the properties of FB schedules to those of one-shift PR schedules (see Section B), the schedule designer can then choose between these two types of schedules. If, for example, schedule equity, in terms of days of the week off duty, is considered desirable, then the one-shift PR schedule would be selected. On the other hand, the FB schedule would be selected if permanent off-duty days each week were thought to be useful in simplifying understanding and administration of the schedule.

As a second example, suppose a schedule must meet the following constraints:

- employees must work five days (i.e., 40 hours) in every calendar week;
- the agency using the schedule does not operate on Sunday;
- employees' days of the week off duty change from week to week; and

Table 5-2

USE OF TABLE 5-1 TO IDENTIFY
ACCEPTABLE SCHEDULE TYPES PROVIDING VARIABLE ON-DUTY STAFFING BY
DAY OF WEEK, AND PERMANENT SHIFT ASSIGNMENTS

Schedule Property	Type of Schedule				
	Fixed Bracket (FB)	Duty Cycle		Proportional Rotating (PR)	
		Basic	Extended	One-Shift	Multishift
1. Variable on-duty staffing by day of week	-	⊗	⊗	-	-
2. Fixed number of on-duty hours per calendar week	-	X	X	X	X
3. Variable-length work periods	X	-	X	-	-
4. Variable-length off-duty periods	X	-	-	-	-
5. Days of week when a shift is not operated	-	X	X	-	-
6. Equitable distribution of off-duty days of week	X	-	-	-	-
7. Equitable distribution of shift assignments	X	-	-	X	-
8. Variable-sized schedule groups	-	X	X	-	-
9. Assignment to a shift for other than a whole number of weeks	X	-	-	X	X
10. Off-duty days of the week	Rotating	Fixed	Fixed	Fixed	Fixed
11. Shift assignments	Rotating	-	-	Rotating	Fixed
12. Length, in days, of repeating pattern of on- and off-duty days (i.e., the duty cycle)	Less than or greater than 7	-	7	Less than or equal to 7	Less than or equal to 14
13. Relation between number of schedule groups and length, in days, of the duty cycle	-	Unequal	Equal	-	-
14. Relation between number of schedule groups and length, in weeks, of the duty cycle	-	-	-	Unequal	Unequal
Unacceptable Types of Schedules ("X")		X	X		X

- employees must rotate periodically from one shift to another.

Table 5-3 shows how Table 5-1 would appear when completed for this schedule design problem--in this case, none of the types of schedules is acceptable. Suppose the designer decides that one or more of the above constraints can be relaxed. A fixed bracket schedule can be used if employees are given fixed shift assignments and fixed days of the week off duty for the duration of the schedule design interval. Similarly, a multishift proportional rotating schedule might be used if the requirement for five on-duty days per employee per calendar week is relaxed, and so on.

Table 5-3

USE OF TABLE 5-1 TO IDENTIFY A SET OF CONSTRAINTS FOR WHICH ALL TYPES OF SCHEDULES ARE UNACCEPTABLE

Schedule Property	Type of Schedule				
	Fixed Bracket (FB)	Duty Cycle		Proportional Rotating (PR)	
		Basic	Extended	One-Shift	Multishift
1. Variable on-duty staffing by day of week	-	X	X	-	-
2. Fixed number of on-duty hours per calendar week	-	(X)	(X)	(X)	(X)
3. Variable-length work periods	X	-	X	-	-
4. Variable-length off-duty periods	X	-	-	-	-
5. Days of week when a shift is not operated	-	(X)	(X)	-	-
6. Equitable distribution of off-duty days of week	X	-	-	-	-
7. Equitable distribution of shift assignments	X	-	-	X	-
8. Variable-sized schedule groups	-	X	X	-	-
9. Assignment to a shift for other than a whole number of weeks	X	-	-	X	X
10. Off-duty days of the week	Rotating	Fixed	Fixed	Fixed	Fixed
11. Shift assignments	Rotating	-	-	Rotating	Fixed
12. Length, in days, of repeating pattern of on- and off-duty days (i.e., the duty cycle)	Less than or greater than 7	-	7	Less than or equal to 7	Less than or equal to 14
13. Relation between number of schedule groups and length, in days, of the duty cycle	-	Unequal	Equal	-	-
14. Relation between number of schedule groups and length, in weeks, of the duty cycle	-	-	-	Unequal	Unequal
Unacceptable Types of Schedules ("X")	X	X	X	X	X

CHAPTER VI

DESIGN OF FIXED BRACKET SCHEDULES

A. Introduction

Fixed bracket (FB) schedules are used to schedule personnel for work environments in which coverage must be provided more than five days a week. These schedules can be used when daily staffing levels are uniform (i.e., when the same number of employees are on duty each day of the week) or when on-duty staffing varies by day of the week (e.g., to provide a "high" level of coverage on Monday through Friday and a "low" level of coverage on Saturday and Sunday).

Two FB schedules, illustrating each type of coverage are shown in figures 6-1 and 6-2. The schedule in Figure 6-1 consists of seven brackets each containing exactly seven days. One employee or group is assigned to each bracket.* Off-duty days are identified with the letter R; on-duty days are left blank. The pattern of on- and off-duty days in each bracket describes the weekly work pattern for the employee assigned to that bracket. In Figure 6-1, for example, the employee assigned to bracket 1 works Wednesday through Sunday, and has Monday and Tuesday off each week. The employee assigned to bracket 5 works Sunday through Thursday, and has Friday and Saturday off each week.

The number of employees on duty on each day of the week is indicated by the number of blanks in the seven bracket slots in the column for each day of the week. In Figure 6-1 for example, the five blanks in the Monday column (brackets 2 through 6)

*Throughout the remainder of this chapter, the terms group and employee are used interchangeably.

	M	T	W	T	F	S	S
1	R	R					
2		R	R				
3			R	R			
4				R	R		
5					R	R	
6						R	R
7	R						R
	5	5	5	5	5	5	5

Bracket

No. of On-Duty Employees

Figure 6-1

SEVEN-BRACKET SCHEDULE WITH UNIFORM DAILY COVERAGE

	M	T	W	T	F	S	S
1		R	R				
2				R	R		
3	R						R
4						R	R
5						R	R
6						R	R
	5	5	5	5	5	3	2

Bracket

No. of On-Duty Employees

Figure 6-2

SIX-BRACKET SCHEDULE WITH NON-UNIFORM DAILY COVERAGE

indicate that five employees will be on duty each Monday. Examination of the other days in Figure 6-1 reveals that although the employees or groups that are on duty change, there are always a total of five on duty each day. As a result, this fixed bracket schedule provides uniform coverage over all seven days of the week.

A second FB schedule is shown in Figure 6-2. This six-bracket schedule provides a uniform manning level on Monday through Friday and a reduced manning level on Saturday and Sunday.

B. Advantages and Disadvantages of Fixed Bracket Schedules

Fixed bracket schedules are used by many public and private agencies because of the following properties:

- Six- and seven-day coverage. FB schedules are often used by agencies which operate six or seven days a week. FB schedules can be used, for example, for scheduling police officers, medical personnel, bus drivers, baggage handlers, toll booth collectors, refuse collectors, and library workers.
- Proportional staffing levels. In addition to six- and seven-day coverage, FB schedules can be designed to provide staffing levels that are proportional to workload demand levels by day of the week. Many service agencies which operate six or seven days a week do not have a uniform daily workload. As an example, police departments often experience higher workload levels on Friday and Saturday. In contrast, Monday is, traditionally, the busiest day of the week for public libraries.
- Weekly bracket cycles. Since FB schedules use brackets that are seven days long, they are usually compatible with work rules and pay procedures based on weekly work cycles. In FB schedules, each person works the same number of days in each calendar week. (This may not be true in other types of work schedules.) As a result, these schedules are compatible with work rules which limit or control the number of hours worked in a calendar week. In addition, scheduling the same number of on-duty days for each employee each week insures that his weekly or bi-weekly paycheck will be based on a uniform number of hours.

- Fixed days off. In FB schedules each person receives the same days off each week (i.e., days off are fixed whereas in schedules with nonfixed or rotating days off, a person may receive different days off each week). This property is often viewed as desirable by employees who find it easier to schedule off-duty activities. This is particularly true for persons attending school or participating in organized recreational activities scheduled on a weekly basis.
- Simplicity of design. FB schedules can usually be designed with relatively little effort using manual techniques requiring only simple addition and subtraction.

The disadvantages of FB schedules include the following:

- Lack of schedule equity. Since the off-duty days that each person receives in a FB schedule are fixed, some employees may receive more desirable days off than others (e.g., some employees may have every Saturday and Sunday off while others have to work every weekend). Agencies using FB schedules often attempt to minimize this problem by allowing each person to select his own off-duty days (i.e., his schedule bracket) from the set of brackets in the FB schedule to be used. Requests for the same bracket are usually decided on the basis of seniority. Agencies may also periodically rotate all bracket assignments to insure that all employees spend some time in each schedule bracket. Such rotation systems, however, usually require one or more persons to be on duty for an extended work period at the time the brackets are reassigned.*
- Difficult to use in rotating multishift schedules. Agencies which use multiple shifts to provide staff coverage around the clock may have a policy of periodically rotating personnel through each shift. FB schedules designed for each shift rarely provide acceptable changeover properties when employees rotate from one shift to another (e.g., some persons may have to change shift assignments and work an extended number of days at the same time). Some of these disadvantages can be alleviated if equal numbers of employees are assigned to each shift and the same FB schedule is used on each shift.

*The design of proportional work schedules using rotating bracket assignments is discussed in Chapter VIII.

C. Designing FB Schedules

Two methods for constructing FB schedules are described in this chapter. The first method is a trial-and-error procedure which often yields excellent results with minimal effort, and is particularly useful for designing small FB schedules. The second method is an algebraic procedure, which, although more limited in scope, is also easy to use, and better suited for designing large schedules.

In this section, the descriptions of both design methods, and sample problems illustrating each method assume that the following apply:

- The total number of employees to be scheduled is known.
- Each employee works five tours per week.
- Each employee receives two consecutive days off each week.
- The daily distribution of on-duty and off-duty employees is known.

If one or more of these conditions are changed, the design methods must be modified as described in Section E.

Determining the Daily Distribution of On- and Off-Duty Employees

The design of FB schedules begins with the specification of a daily distribution of on-duty personnel using the procedures described in Chapter IV. The final result of applying these allocation procedures should be a table indicating the number of employees that are on and off duty on each day of the week. A separate distribution should be determined for each shift. An example of an allocation table for seven employees is shown in Table 6-1. This distribution is based on workload data for an agency that is very busy on Monday and Friday, and less

Table 6-1

DAILY DISTRIBUTION OF ON- AND OFF-DUTY EMPLOYEES

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
On-Duty	6	5	5	5	6	4	4	35
Off-Duty	<u>1</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>1</u>	<u>3</u>	<u>3</u>	14
Total	7	7	7	7	7	7	7	

busy on Saturday and Sunday.

Design Alternative 1: Cyclic Graph Method

The cyclic graph method uses a schematic, called a star diagram, to represent the daily distribution of off-duty employees. For example, the distribution of off-duty employees shown in Table 6-1 can be schematically represented as shown in Figure 6-3.

The star diagram consists of seven rays, one for each day of the week. The number of nodes on each ray indicates the number of employees who are off duty on each day of the week (e.g., the three nodes on the ray corresponding to Saturday indicate that three employees are off duty each Saturday).

The requirement that each employee in the schedule must receive two consecutive days off each week is equivalent to the requirement that each off-duty node in the star diagram must belong to a two-day off-duty period (i.e., that each node be paired either with a node immediately preceding it or immediately following it in the diagram). When each node in a star diagram has been paired with another node, the resulting figure is called a cyclic graph. Each pair of nodes in the graph is represented by a line connecting the nodes.

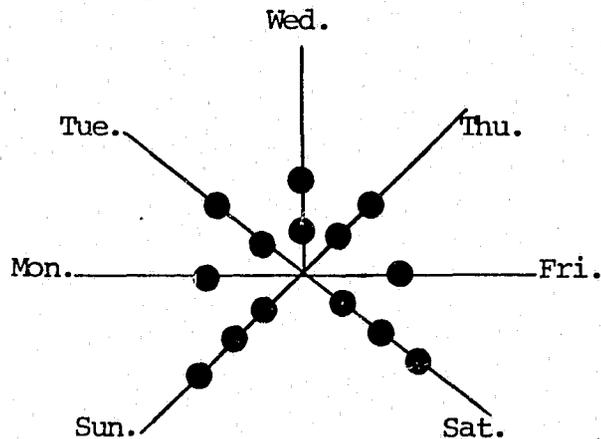


Figure 6-3

STAR DIAGRAM WITH 14 NODES

To illustrate, the cyclic graph in Figure 6-4 is based on the star diagram in Figure 6-3. The 14 nodes representing off-duty days are grouped into seven pairs, each representing a two-day off-duty period.

Each off-duty period in a cyclic graph defines a specific bracket for a FB schedule. As an example, the Monday-Tuesday off-duty period in Figure 6-4 defines the bracket:

M	T	W	T	F	S	S
R	R					

The collection of brackets defined by all of the off-duty periods in a cyclic graph specifies a complete FB schedule. To illustrate, the FB schedule shown in Figure 6-5 can be constructed from the

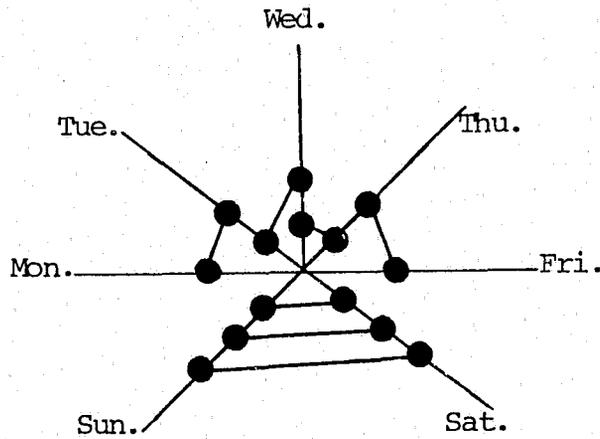


Figure 6-4

CYCLIC GRAPH CONSTRUCTED FROM THE STAR DIAGRAM IN FIGURE 6-3

	M	T	W	T	F	S	S
1	R	R					
2		R	R				
3			R	R			
4				R	R		
5						R	R
6						R	R
7						R	R
On-Duty Employees	6	5	5	5	6	4	4
Off-Duty Employees	1	2	2	2	1	3	3

Figure 6-5

FB SCHEDULE CONSTRUCTED FROM THE CYCLIC GRAPH IN FIGURE 6-4

seven brackets defined by the off-duty periods in Figure 6-4. This seven-bracket schedule produces the daily distribution of on-duty and off-duty personnel shown in Table 6-1.

To review, the cyclic graph method consists of the following steps:

- (1) Determine the daily distribution of on- and off-duty employees.
- (2) Construct a star diagram based on the distribution of off-duty employees.
- (3) Form a cyclic graph by pairing all of the nodes in the star diagram into two-day off-duty periods.
- (4) Construct the FB schedule from the brackets defined by each off-duty period in the cyclic graph.

Several observations should be noted about the cyclic graph method:

- The pairing of nodes into two-day off-duty periods is done by trial and error and the effort required for the process increases with the size of the problem (i.e., as the number of nodes on the star diagram increases).
- It is not possible to construct more than one cyclic graph from a star diagram (i.e., if a solution has been found, it is the only solution for that star diagram).
- It is not possible to construct a cyclic graph from every star diagram (see Section D).

The pairing of nodes into two-day off-duty periods to form a cyclic graph can be simplified by using the following procedure. Every star diagram consists of seven rays, and seven pairs of adjacent rays (i.e., Monday-Tuesday, Tuesday-Wednesday, etc.). The following two rules apply to each pair of adjacent rays and can be used to systematically determine each pair of nodes in the cyclic graph, if one exists. Both rules are based

on the number of unpaired nodes on each adjacent ray. To describe the rules, let N_A and N_B represent the number of unpaired nodes on adjacent rays A and B. (Ray B follows ray A.)

Rule 1: If the number of unpaired nodes is greater on ray B than the number of unpaired nodes on ray A, then at least $N_B - N_A$ two-day off-duty periods must begin on ray B.

Rule 2: If the number of unpaired nodes is greater on ray A than the number of unpaired nodes on ray B, then at least $N_A - N_B$ two-day off-duty periods must end on ray A.

Application of these rules is quite easy. To illustrate, consider the star diagram in Figure 6-3. The step-by-step use of these rules to form the cyclic graph in Figure 6-4 is listed in Table 6-2. In this example, each pair of adjacent rays is examined in sequence beginning with the Monday-Tuesday pair. By the time all seven pairs of rays have been examined,

Table 6-2

STEP-BY-STEP CONSTRUCTION OF THE CYCLIC GRAPH
IN FIGURE 4

<u>Step</u>	<u>Pair of Adjacent Rays Examined</u>	<u>No. of Unpaired Nodes, First Ray</u>	<u>No. of Unpaired Nodes, Second Ray</u>	<u>Applicable Rule</u>	<u>No. of Pairs of Nodes Formed</u>
1	Mon - Tue	1	2	1	1, Tue - Wed
2	Tue - Wed	1	1	none	none
3	Wed - Thu	1	2	1	1, Thu - Fri
4	Thu - Fri	1	0	2	1, Wed - Thu
5	Fri - Sat	0	3	1	3, Sat - Sun
6	Sat - Sun	0	0	none	none
7	Sun - Mon	0	1	1	1, Mon - Tue

the cyclic graph has been constructed. The following observations apply to the use of these rules:

- the pairs of adjacent rays can be examined in any order;
- neither rule applies when the adjacent rays have the same number of unpaired nodes (see steps 2 and 6 in Table 6-2); and
- if, at any time, the requirements of an applicable rule cannot be met by the remaining unpaired nodes, no cyclic graph can be constructed on the star diagram.

Design Alternative 2: Algebraic Method

The construction of FB schedules can also be described in algebraic terms using the following notation:

N = total number of employees to be scheduled:

W_i = number of employees scheduled to be on duty on day i , for $i=1, \dots, 7$ (1 = Monday, 2 = Tuesday, ..., 7 = Sunday);

r_i = number of employees scheduled to be off duty on day i , for $i=1, \dots, 7$; and

n_i = number of employees (brackets) with days i and $i+1$ off.

To illustrate, for the schedule shown in Figure 6-5, $N = 7$

and

	M	T	W	T	F	S	S
$i =$	1	2	3	4	5	6	7
$W_i =$	6	5	5	5	6	4	4
$r_i =$	1	2	2	2	1	3	3

The FB schedule can be described in terms of the n_i 's as follows:

n_i	Days Off	Schedule
$n_1 = 1$	1 and 2	one bracket with Mon-Tue off
$n_2 = 1$	2 and 3	one bracket with Tue-Wed off
$n_3 = 1$	3 and 4	one bracket with Wed-Thu off
$n_4 = 1$	4 and 5	one bracket with Thu-Fri off
$n_5 = 0$	5 and 6	no brackets with Fri-Sat off
$n_6 = 3$	6 and 7	three brackets with Sat-Sun off
$n_7 = 0$	7 and 1	no brackets with Sun-Mon off

Constructing an FB schedule with the algebraic method consists of finding a value for each of the seven n_i 's based on the conditions imposed by the values of the W_i 's, r_i 's, and N . These conditions include the following:

- (a) The sum of the number of employees on duty each day of the week must equal the total number of staff-days available each week; i.e.,

$$W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 = k \times N,$$

where k equals the number of days each employee works each week. In the example above,

$$6 + 5 + 5 + 5 + 6 + 4 + 4 = 5 \times 7 = 35.$$

- (b) The sum of the number of employees off duty each day of the week must equal the total number of off-duty days available per week; i.e.,

$$r_1 + r_2 + r_3 + r_4 + r_5 + r_6 + r_7 = (7 - k) \times N.$$

In the example above,

$$1 + 2 + 2 + 2 + 1 + 3 + 3 = (7 - 5) \times 7 = 14.$$

- (c) The sum of the number of employees on duty and the number of employees off duty each day must equal the total number of employees to be scheduled; i.e.,

$$W_i + r_i = N, \text{ for } i=1,2,\dots,7.$$

- (d) The total number of brackets in a schedule must equal the number of employees to be scheduled; i.e.,

$$n_1 + n_2 + n_3 + n_4 + n_5 + n_6 + n_7 = N.$$

CONTINUED

2 OF 5

The n_i 's are computed using the following formulas:*

(a) for n_1 , use

$$n_1 = \frac{1}{2}(r_1 + r_2 - r_3 + r_4 - r_5 + r_6 - r_7), \text{ and}$$

(b) for each subsequent n_i , use

$$n_i = r_i - n_{i-1};$$

i.e., use the following expressions for the remaining n_i 's:

$$n_2 = r_2 - n_1,$$

$$n_3 = r_3 - n_2,$$

$$n_4 = r_4 - n_3,$$

$$n_5 = r_5 - n_4,$$

$$n_6 = r_6 - n_5,$$

$$n_7 = r_7 - n_6.$$

To illustrate the use of these formulas, assume that an FB schedule must be designed for eight employees ($N=8$) with the daily distribution of on- and off-duty employees shown in Table 6-3. Note that the sum of on-duty and off-duty employees allocated to each day equals the total number of employees to be scheduled (i.e., $W_i + r_i = 8$ for $i=1,2,\dots,7$). In addition, the total number of on-duty shifts is $k \times n = 5 \times 8 = 40$, and the total number of off-duty shifts is $(7 - k) \times N = 2 \times 8 = 16$.

Using the formula for n_1 yields

$$n_1 = \frac{1}{2}(3 + 2 - 2 + 2 - 1 + 2 - 4) = \frac{1}{2}(2) = 1.$$

*These formulas are only applicable when each bracket consists of five consecutive on-duty days and two consecutive off-duty days.

Table 6-3

DAILY DISTRIBUTION OF ON- AND OFF-DUTY EMPLOYEES

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
$i =$	1	2	3	4	5	6	7	
$W_i =$	5	6	6	6	7	6	4	40
$r_i =$	3	2	2	2	1	2	4	16

Similarly, the remaining n_i 's become

$$\begin{aligned}
 n_2 &= 2 - 1 = 1, & n_5 &= 1 - 1 = 0, \\
 n_3 &= 2 - 1 = 1, & n_6 &= 2 - 0 = 2, \\
 n_4 &= 2 - 1 = 1, & n_7 &= 4 - 2 = 2.
 \end{aligned}$$

As required, the n_i 's sum to $N=8$. The FB schedule defined by these n_i 's is shown in Figure 6-6.

D. Guidelines for Recognizing Daily Staffing Distributions for Which FB Schedules Cannot be Constructed

Recognizing No-Schedule Distributions

A fixed bracket schedule cannot be constructed for every daily distribution of personnel. This section discusses several procedures for recognizing such distributions. These procedures can be used to avoid searching for non-existent schedules. Distributions for which no FB schedule can be designed can appear quite reasonable. As an example, consider the distribution shown in Table 6-4. This distribution of eight employees differs from the distribution shown in Table 6-3 by only one staff-day which has been moved from Tuesday to Saturday.

	M	T	W	T	F	S	S	
1	R	R						$n_1 = 1$
2		R	R					$n_2 = 1$
3			R	R				$n_3 = 1$
4				R	R			$n_4 = 1$
5						R	R	$n_6 = 2$
6						R	R	
7	R						R	$n_7 = 2$
8	R						R	
On-Duty Employees	5	6	6	6	7	6	4	
Off-Duty Employees	3	2	2	2	1	2	4	

Figure 6-6

FB SCHEDULE FOR EIGHT EMPLOYEES

Table 6-4

DAILY DISTRIBUTION OF ON- AND OFF-DUTY EMPLOYEES

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
$W_i =$	5	5	6	6	7	7	4	10
$r_i =$	3	3	2	2	1	1	4	16

Despite the similarity between the daily distributions, no FB schedule exists for the distribution in Table 6-4.

As expected, both of the design procedures described above fail when applied to a no-schedule distribution. If the cyclic graph method is used, no complete cyclic graph will be found for the star diagram (i.e., it will not be possible to pair each node into a two-day off-duty period). If the algebraic procedure is used, one or more of the n_i 's will be negative--a meaningless result.

Algebraic Guidelines for Determining Whether an FB Schedule Can be Found

There are a number of guidelines that can be used to determine whether an FB schedule can be found. The following list of rules are based on several of the assumptions previously discussed for the algebraic method and are included here for completeness:

Rule 1: The total number of on-duty tours in a daily distribution must equal the number of on-duty tours per employee per week times the number of employees to be scheduled; i.e.,

$$W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 = k \times N.$$

Rule 2: The total number of off-duty tours in a daily distribution must equal the number of off-duty tours per employee per week times the number of employees to be scheduled; i.e.,

$$r_1 + r_2 + r_3 + r_4 + r_5 + r_6 + r_7 = (7 - k) \times N.$$

Rule 3: The total number of employees scheduled to be on duty and off duty on each day must equal the total number of employees to be scheduled (i.e., $W_i + r_i = N$, for $i=1,2,\dots,7$). Since the number of employees scheduled to be on or off duty cannot be less than zero, the $W_i + r_i = N$ rule also implies that every W_i and r_i must be less than or equal to N (i.e., $W_i \leq N$ and $r_i \leq N$, for $i=1,2,\dots,7$).

Rule 4: The following inequalities must hold for every r_i in the daily distribution:*

(a) $r_i \leq r_{i-1} + r_{i+1}$, $i=1, \dots, 7$,

(b) $r_i + r_{i+2} \leq r_{i-1} + r_{i+1} + r_{i+3}$, $i=1, \dots, 7$,

(c) $r_i + r_{i+2} + r_{i+4} \leq N$, $i=1, \dots, 7$.

The application of these rules can be illustrated using the daily distribution shown in Table 6-4. This distribution of on- and off-duty tours for eight employees satisfies the first three rules listed above (i.e., the W_i 's sum to $5 \times 8 = 40$, the r_i 's sum to $2 \times 8 = 16$, and $W_i + r_i = N = 8$ with $W_i \leq 8$ and $r_i \leq 8$ for all i). Examination of the inequalities for Rule 4, however, produces the following results: although each r_i satisfies the first inequality $r_i \leq r_{i-1} + r_{i+1}$, the second inequality is not satisfied for $i=7$ (i.e., $r_2 + r_7$ is not less than or equal to $r_6 + r_1 + r_3$). Hence, no FB schedule can be constructed for this daily distribution.

Modifying a No-Schedule Distribution

Frequently, it is easier to apply the algebraic method, rather than first checking each of the above rules and inequalities since the absence of an FB schedule is readily indicated by one or more negative n_i 's. The results of applying the inequalities in Rule 4, however, can often be used to identify how a no-schedule distribution can be modified to create a new distribution for which a FB schedule can be constructed. (Such modifications, of course, require that a staffing distribution that is less proportional to the workload be used.) To illustrate, the application of Rule 4 to the daily distribution in

*The following rules apply in using these inequalities: $r_0 = r_7$, $r_8 = r_1$, $r_9 = r_2$, $r_{10} = r_3$, $r_{11} = r_4$, and $r_{12} = r_5$.

Table 6-4 indicates that no FB schedule exists for that distribution. Specifically, application of the second inequality in Rule 4 reveals that the following inequality is not satisfied: $r_7 + r_2 \leq r_6 + r_1 + r_3$ (i.e., the sum $r_7 + r_2$ is, in fact, greater than $r_6 + r_1 + r_3$). This result suggests that either the sum $r_7 + r_2$ should be reduced, or the sum $r_6 + r_1 + r_3$ should be increased. Note that modification to any r_i requires that a second r_i in the distribution also be changed to preserve the total number of off-duty days (i.e., the r_i 's must still sum to 16). Eleven distributions based on the r_i changes identified above are shown in Table 6-5. Each modified distribution is created by changing only one staff-day. In every case, however, this change is sufficient to satisfy all of the inequalities in Rule 4, thus ensuring that an FB schedule exists for every distribution shown.

E. Special FB Schedules

This section presents several variations to the type of FB schedule presented above in which two consecutive off-duty days were scheduled per bracket.

FB Schedules for 4/10 Plans

FB schedules can be easily designed for work environments in which each employee works 10 hours per shift, four tours per week, and receives three consecutive days off each week. Modifications to the design procedures are presented below.

Daily distribution. The number of staff-days to be allocated for N employees is reduced from 5N to 4N, and the number of off-duty tours increases from 2N to 3N. As a result, changing from a 5/8 to a 4/10 schedule for eight employees reduces the number

Table 6-5

ELEVEN MODIFIED DAILY DISTRIBUTIONS BASED ON THE
NO-SCHEDULE DISTRIBUTION IN TABLE 6-4

(FB Schedules Exist for Each Modified Distribution)

Original	M	T	W	T	F	S	S	Reduce		Increase		
								r ₂	r ₇	r ₁	r ₃	r ₆
	3	3	2	2	1	1	4					
1	4*	2	2	2	1	1	4	x		x		
2	3	2	3	2	1	1	4	x			x	
3	3	2	2	2	2	1	4	x				
4	3	2	2	2	1	2	4	x				x
<hr/>												
5	4	3	2	2	1	1	3		x	x		
6	3	3	3	2	1	1	3		x		x	
7	3	3	2	2	2	1	3		x			
8	3	3	2	2	1	2	3		x			x
<hr/>												
9	4	3	2	1	1	1	4			x		
10	3	3	3	1	1	1	4				x	
11	3	3	2	1	1	2	4					x

*Circled entries identify staffing levels which have been modified.

of weekly staff-days from 40 to 32, and increases the number of off-duty days from 16 to 24. The procedure for allocating the 4N staff-days to each day of week is unchanged.

Cyclic graph method. The formation of the star diagram remains the same. Completing the cyclic graph, however, is altered. Each node must be joined with two other nodes to form a three-day off-duty period. Each three-day period is used to identify one schedule bracket. The rules governing the minimum number of period starts and stops on each ray of the diagram are still applicable.

Algebraic method. The set of equations for constructing 4/10 FB schedules are slightly more complicated than those presented for 5/8 schedules in Section C. The definitions for N , W_i , and r_i are the same, but each n_i is now defined as the number of employees (brackets) who receive days i , $i+1$, and $i+2$ off each week. The algebraic procedure for determining each n_i for a 4/10 FB schedule is based on the following equations:

(a) for n_1 , use

$$n_1 = \frac{1}{3}(r_1 + r_2 + r_3 - 2r_4 + r_5 + r_6 - 2r_7),$$

(b) for n_2 , use

$$n_2 = \frac{1}{3}(r_2 + r_3 + r_4 - 2r_5 + r_6 + r_7 - 2r_1), \text{ and}$$

(c) for each subsequent n_i , use

$$n_i = r_i - n_{i-1} - n_{i-2},$$

which yields the following expressions for n_3 through n_7 :

$$n_3 = r_3 - n_1 - n_2,$$

$$n_6 = r_6 - n_4 - n_5,$$

$$n_4 = r_4 - n_2 - n_3,$$

$$n_7 = r_7 - n_5 - n_6.$$

$$n_5 = r_5 - n_3 - n_4,$$

Rules for no-schedule distributions. Rules 1, 2, and 3 in Section D also apply to 4/10 FB schedules. Rule 4, however, is changed to the following:

Rule 4: The following inequalities must hold for every r_i in the daily distribution:

- (a) $r_i \leq r_{i-1} + r_{i+1}$, $i=1, \dots, 7$, and
- (b) $r_i + r_{i+3} \leq N$.

If a no-schedule distribution is found, the r_i 's in the inequality that fails can usually be modified to obtain a distribution for which a 4/10 FB schedule can be constructed.

Sample 4/10 FB schedule. To illustrate the procedure for designing a 4/10 FB schedule, assume that a schedule is to be designed for seven employees based on the staffing distribution presented in Table 6-1. (A 5/8 FB schedule for seven employees based on this workload distribution is shown in Figure 6-5). The seven employees provide 28 on-duty days and 21 off-duty days per week. Allocating the 28 on-duty days to the days of week as described in Chapter IV produces the daily distribution of on- and off-duty staff-days shown in Table 6-6.

Table 6-6

DAILY DISTRIBUTION OF PERSONNEL FOR A 4/10
FB SCHEDULE BASED ON THE WORKLOAD
DISTRIBUTION IN TABLE 6-1

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
On-Duty	4	4	4	4	5	4	3	28
Off-Duty	3	3	3	3	2	3	4	21

The star diagram based on the 21 off-duty days in Table 6-6 is shown in Figure 6-7. Examining each pair of adjacent rays indicates that at least one three-day off-duty period must start on both Saturday and Sunday, and at least one period must end on Thursday and Sunday. Inserting these periods and connecting other nodes in the star diagram produces the cyclic graph shown in Figure 6-8. The 4/10 FB schedule constructed from this graph is shown in Figure 6-9.

The algebraic solution to the same design problem is:

$$n_1 = \frac{1}{3}(3 + 3 + 3 - 2(3) + 2 + 3 - 2(4)) = 0,$$

$$n_2 = \frac{1}{3}(3 + 3 + 3 - 2(2) + 3 + 4 - 2(3)) = 2,$$

$$n_3 = 3 - 0 - 2 = 1,$$

$$n_4 = 3 - 2 - 1 + 0,$$

$$n_5 = 2 - 1 - 0 = 1,$$

$$n_6 = 3 - 0 - 1 = 2,$$

$$n_7 = 4 - 1 - 2 = 1.$$

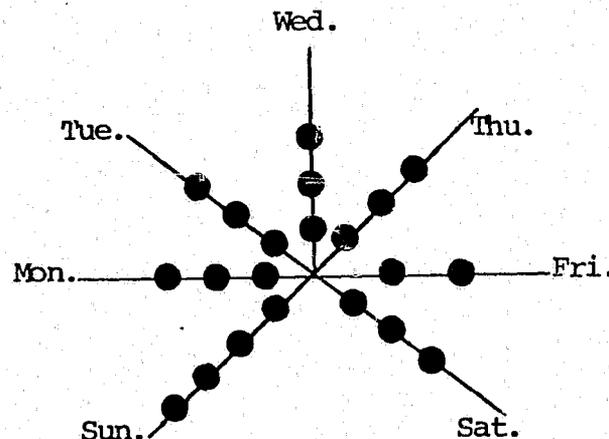


Figure 6-7

STAR DIAGRAM BASED ON THE DAILY
DISTRIBUTION IN TABLE 6-6

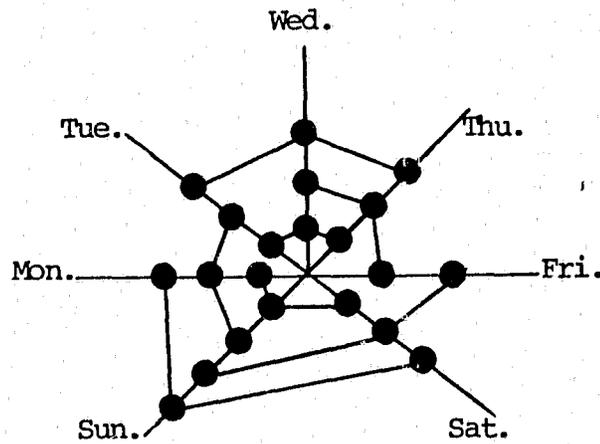


Figure 6-8

CYCLIC GRAPH CONSTRUCTED FROM THE STAR DIAGRAM IN FIGURE 6-7

	M	T	W	T	F	S	S
1		R	R	R			
2		R	R	R			
3			R	R	R		
4					R	R	R
5	R					R	R
6	R					R	R
7	R	R					R
On-Duty	4	4	4	4	5	4	3

Figure 6-9

A 4/10 FB SCHEDULE FOR THE DAILY DISTRIBUTION IN TABLE 6-6

These seven n_i 's define the same 4/10 FB schedule constructed from the cyclic graph in Figure 6-8.

Uniform Staffing

Schedules with uniform staffing provide for an equal number of employees to be on duty each day service is provided by an agency. FB schedules that satisfy this requirement are discussed below.

Two consecutive days off. The only FB schedule which provides uniform staffing seven days a week and also gives each employee two consecutive days off each week is shown in Figure 6-10. This schedule assumes that the number of employees to be scheduled can be divided into seven equal-sized groups. No FB schedules exist which provide uniform staffing six days a week and also give each employee two consecutive days off each week.

Three consecutive days off. The only 4/10 FB schedule which provides uniform staffing seven days a week and also gives each

	M	T	W	T	F	S	S
1	R	R					
2		R	R				
3			R	R			
4				R	R		
5					R	R	
6						R	R
7	R						R
On-Duty	5	5	5	5	5	5	5

Figure 6-10

ONLY FB SCHEDULE WHICH PROVIDES UNIFORM STAFFING SEVEN DAYS A WEEK AND TWO CONSECUTIVE DAYS OFF EACH WEEK

employee three consecutive days off each week is shown in Figure 6-11. No 4/10 FB schedules exist which provide uniform manning six days a week and also give each employee three consecutive days off each week.

Split days off. If the requirement that days off must be consecutive is dropped, FB schedules can be constructed which provide uniform staffing; three such schedules are shown in figures 6-12, 6-13, and 6-14. It should be noted, however, that these schedules may not be compatible with existing work rules in many agencies.

Special Design Constraints

Common day off. The number of FB schedules which can be designed with employees receiving a common day off (e.g., Sunday) is quite small. For the cyclic graph method, this requirement implies that each off-duty period in the cyclic graph must include

	M	T	W	T	F	S	S
1	R	R	R				
2		R	R	R			
3			R	R	R		
4				R	R	R	
5					R	R	R
6	R					R	R
7	R	R					R
On-Duty	4	4	4	4	4	4	4

Figure 6-11

ONLY FB SCHEDULE WHICH PROVIDES UNIFORM STAFFING SEVEN DAYS A WEEK AND THREE CONSECUTIVE DAYS OFF EACH WEEK

	M	T	W	T	F	S	S
1	R						R
2		R					R
3			R				R
4				R			R
5					R		R
6						R	R
On-Duty	5	5	5	5	5	5	0

Figure 6-12

5/8 FB SCHEDULE WHICH PROVIDES UNIFORM STAFFING SIX DAYS A WEEK WITH SPLIT DAYS OFF

	M	T	W	T	F	S	S
1	R	R					R
2		R	R				R
3			R	R			R
4				R	R		R
5					R	R	R
6	R					R	R
On-Duty	4	4	4	4	4	4	0

Figure 6-13

4/10 FB SCHEDULE WHICH PROVIDES UNIFORM STAFFING SIX DAYS A WEEK WITH SPLIT DAYS OFF

	M	T	W	T	F	S	S
1	R					R	R
2		R				R	R
3			R			R	R
4				R		R	R
5					R	R	R
On-Duty	4	4	4	4	4	0	0

Figure 6-14

FB SCHEDULE WHICH PROVIDES UNIFORM
STAFFING FIVE DAYS A WEEK WITH
SPLIT DAYS OFF

a node on the ray corresponding to the common day off. For the algebraic method, two observations can be made:

- two consecutive days off--if Sunday is the common day off, the daily distribution of personnel is

$$W_2 = W_3 = W_4 = W_5 = N, W_7 = 0, \text{ and } W_6 + W_1 = N;$$

that is, everyone is on duty Tuesday through Friday, no one is on duty on Sunday, and the sum of the numbers of employees on duty on Saturday and Monday equals the total number of employees to be scheduled. The solution to this FB schedule design problem is:

$$n_1 = n_2 = n_3 = n_4 = n_5 = 0, n_6 = N - W_6, n_7 = W_6.$$

- three consecutive day off--if Sunday is the common day off, the daily distribution of personnel is

$$W_3 = W_4 = N, W_7 = 0 \text{ and } W_1 + W_2 + W_5 + W_6 = 2N.$$

The algebraic solution for the FB schedule is:

$$n_1 = n_2 = n_3 = n_4 = 0,$$

$$n_5 = N - W_5,$$

$$n_6 = W_5 - W_6,$$

$$n_7 = W_6.$$

Restrictions on off-duty periods. It may occur that an agency has a policy that no person can have a particular two-day or three-day off-duty period. Such constraints, which are equivalent to specifying that particular n_i 's must equal zero, are usually easier to handle with the cyclic graph method of constructing FB schedules. A restriction against Friday-Saturday off-duty periods, for example, is graphically equivalent to a restriction against connecting any node on the Friday ray with any node on the Saturday ray.

Split days off. Allowing off-duty days to be split greatly expands the number of daily distributions for which FB schedules can be designed. Many staffing distributions for which no two or three consecutive days-off FB schedules can be constructed, can be provided by an FB schedule that contains one or two brackets with split days off. The cyclic graph method can be used to design such schedules in the following way. Using the star diagram based on the daily distribution of off-duty days, include as many nodes as possible in two-day off-duty periods if a 5/8 schedule is being designed, or three-day periods if a 4/10 schedule is being designed. The remaining nodes are then paired as split off-duty periods to complete the cyclic graph. Nodes on the same ray cannot be paired with each other.

As an example, the partially completed cyclic graph in Figure 6-15 provides the daily distribution of off-duty shifts shown in Table 6-4. It was shown in Section D that no FB schedule containing two consecutive day off for each bracket can be constructed for this distribution. All but two of the nodes in Figure 6-15 have been paired into two-day off-duty periods. The unpaired nodes are on Thursday and Sunday. If a bracket with these split off-duty days is allowed, the FB schedule in Figure 6-16 can be constructed.

Minimum staffing levels. To determine the minimum number of employees required to design a FB schedule with a fixed number of on-duty employees, seven days a week, the following formulas can be used:

- for FB schedules with five work tours per week, the minimum number of employees M_5 required to design a FB schedule with at least W on-duty employees each

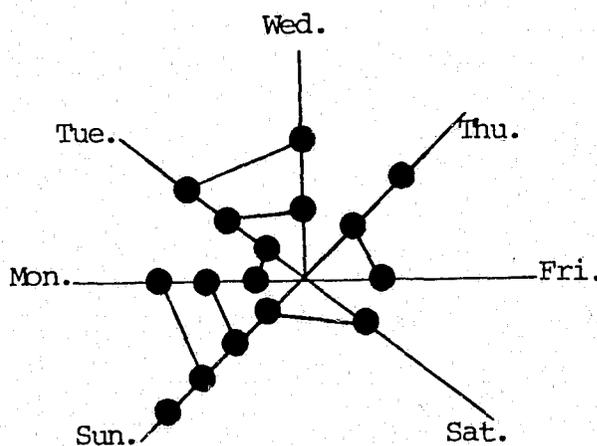


Figure 6-15

PARTIAL CYCLIC GRAPH PROVIDING THE
DAILY DISTRIBUTION IN TABLE 6-4

	M	T	W	T	F	S	S
1				R			R
2	R	R					
3		R	R				
4		R	R				
Bracket	5	5	6	6	7	7	4
5				R	R		
6						R	R
7	R						R
8	R						R
On-Duty	5	5	6	6	7	7	4

Figure 6-16

FB SCHEDULE PROVIDING THE DAILY DISTRIBUTION
IN TABLE 6-4 USING ONE SPLIT PERIOD

day of the week is given by:

$$M_5 = \left\langle \frac{7W}{5} \right\rangle . *$$

- for FB schedules with four work tours per week, the minimum number of employees M_4 required to design a FB schedule with at least W men on duty each day of the week is given by:

$$M_4 = \left\langle \frac{7W}{4} \right\rangle .$$

Values for M_4 and M_5 for daily on-duty coverages up to $W = 10$ are shown in Table 6-7. The columns marked slack indicate the number of "excess" staff-days per week that are available if M_4 or

*The symbol $\langle k \rangle$ is used to indicate that the number k should be rounded up to the next highest whole number if k is not a whole number (e.g., $\langle 4.7 \rangle = 5$, and $\langle 6 \rangle = 6$).

Table 6-7

MINIMUM NUMBER OF EMPLOYEES REQUIRED TO
PROVIDE AT LEAST W EMPLOYEES ON DUTY
EACH DAY OF THE WEEK

Number of Employees On Duty Each Day of the Week (W)	Five Tours Per Week		Four Tours Per Week	
	Min. No. of Employees M_5	No. of Staff-Days (Slack)	Min. No. of Employees M_4	No. of Staff-Days (Slack)
1	2	3	2	1
2	3	1	4	2
3	5	4	6	3
4	6	2	7	0
5	7	0	9	1
6	9	3	11	2
7	10	1	13	3
8	12	4	14	0
9	13	2	16	1
10	14	0	18	2

M_5 employees are used to provide a minimum daily coverage of W employees. As an example, if a FB schedule with five work shifts per week is designed for 13 employees (i.e., $M_5 = 13$), it is possible to provide at least nine employees on duty each day of the week. The slack value of two staff-days indicates that on two days in the week 10 employees will be on duty.

CHAPTER VII

DUTY CYCLE METHODS OF DESIGNING WORK SCHEDULES

A. Introduction

This chapter describes three methods of designing work schedules. Each method involves the design of a duty cycle-- a repeating pattern of shift assignments and days off that is used by all employees in the work force being scheduled. Employees are divided into groups whose duty assignments on any date correspond to different days in the cycle. The resulting schedules, termed duty cycle schedules, have the following properties:

- Staffing by day of week is basically uniform on each shift, although techniques are discussed below which introduce limited variability in daily on-duty staffing.
- Staffing by shift can be either uniform or variable.
- Since each employee follows exactly the same duty cycle as every other employee, the schedule is equitable in terms of the lengths of each employee's work and off-duty periods and the numbers of days each employee is on duty on each shift. Unless the schedule is locked, it is also equitable in terms of the number of weekends and other days of the week that are included in each employee's off-duty periods.
- The length of the duty cycle is a multiple of the number of employees, or of the number of groups into which the employees are divided.
- Team integrity is low unless all team members can be assigned to the same group.
- Unity of command is limited unless a supervisor can be assigned to each group.

Section B of this chapter reviews duty cycle representations of work schedules, and schedule properties that can be determined directly from the duty cycle. Section C discusses methods of

designing schedules in which the length of the duty cycle is equal to the number of groups of identically-scheduled employees. The methods can be used to design a schedule for a work force of a given size, or to design a schedule which achieves a given distribution of on-duty personnel by shift and day of week. Section D discusses a method of designing schedules whose duty cycle length exceeds the number of groups. This method can be used to provide more uniform work period lengths, periodic long off-duty periods, and less frequent shift rotation than the method described in Section C, especially if the number of groups is small. Section E discusses a method of designing platoon schedules.

B. Use of the Duty Cycle to Determine Schedule Properties

Several methods of representing a schedule's duty cycle are discussed in Chapter III. The simplest and most concise representation specifies the number of consecutive days for each duty assignment, and the sequence of duty assignments that are followed. For example, the notation

5D-2R-4N-1R-5A-3R

is interpreted to mean that employees work the day shift (D) for five consecutive days, and then are off duty (R) for the next two days. When they return, they work the night shift (N) for four consecutive days, are off duty the next day, work the afternoon shift (A) for five days, and are then off duty for three consecutive days. They then return to the day shift and repeat the same pattern again.

Most of the schedule properties discussed in Chapter III can be determined directly from this abbreviated representation of the duty cycle, as follows:

- The number of shifts can be determined by identifying the different symbols used to represent on-duty assignments. Since D, N, and A represent on-duty days in the above schedule, the number of shifts used is three. The order in which these symbols appear determines the shift rotation sequence (D-N-A in the example).
- The length of the duty cycle is determined by summing the numbers preceding the symbols which represent the duty assignments in the abbreviated representation. For example, the length of the duty cycle represented above is

$$5+2+4+1+5+3=20 \text{ days.}$$

- Unless the length of the duty cycle is a multiple of seven, the length of the week cycle in weeks is equal to the length of the duty cycle in days.* Therefore, the length of the week cycle of the above schedule is 20 weeks.
- The number of on-duty assignments per duty cycle on any shift is determined by summing the numbers which precede the symbol that represents that shift. In the example, each employee works five day-shift assignments, four night-shift assignments, and five afternoon-shift assignments.
- The number of on-duty assignments per week cycle on any shift is computed by multiplying the number of on-duty assignments per duty cycle by the number of times the duty cycle is repeated within the week cycle. (Within a week cycle, the duty cycle is repeated seven times for unlocked schedules and once for locked schedules.) Hence, in a 20-week period, each employee following the duty cycle described above will be on duty for 35 day shifts, 28 night shifts, and 35 afternoon shifts.
- The lengths of off-duty periods within a duty cycle are simply the numbers which precede the symbol

*If the length of the duty cycle is a multiple of seven, the length of the week cycle is computed by dividing the length of the duty cycle in days by seven.

representing off-duty days in the abbreviated representation (e.g., there is one one-day off-duty period, one two-day off-duty period, and one three-day off-duty period in the duty cycle above).

- Unless the schedule is locked, each possible combination of n consecutive days of the week will appear the same number of times as every other combination within n-day off-duty periods during the week cycle. For example, in a 20-week period, one one-day off-duty period will fall on Monday, one on Tuesday, one on Wednesday, etc. The three-day off-duty period will fall exactly once on each of the following sequences of days in a 20-week period:

Monday-Tuesday-Wednesday
Tuesday-Wednesday-Thursday
Wednesday-Thursday-Friday
Thursday-Friday-Saturday
Friday-Saturday-Sunday
Saturday-Sunday-Monday
Sunday-Monday-Tuesday

- The lengths of the work periods within a duty cycle can be identified by summing the numbers which precede the symbols representing on-duty assignments between adjacent off-duty periods. In the example above, there are two five-day work periods and one four-day work period per duty cycle.
- Unless the schedule is locked, the number of off-duty weekends per week cycle is computed by subtracting the number of off-duty periods within the duty cycle (three in the example above) from the number of off-duty days within the duty cycle (six in the example above). For the sample schedule, there are three off-duty weekends every 20 weeks.
- If the number of working hours per shift is known, the average work week can be computed as discussed in Chapter III. Since the sample schedule has 14 on-duty days in a 20-day duty cycle, if each shift contains eight working hours, the average work week is

$$\frac{8 \times 14 \times 7}{20} = 39.2 \text{ hours.}$$

The 20-week schedule corresponding to the abbreviated representation discussed above is shown in Figure 7-1.

Week	Day of Week						
	M	T	W	T	F	S	S
1	D	D	D	D	D	R	R
2	N	N	N	N	R	A	A
3	A	A	A	R	R	R	D
4	D	D	D	D	R	R	N
5	N	N	N	R	A	A	A
6	A	A	R	R	R	D	D
7	D	D	D	R	R	N	N
8	N	N	R	A	A	A	A
9	A	R	R	R	D	D	D
10	D	D	R	R	N	N	N
11	N	R	A	A	A	A	A
12	R	R	R	D	D	D	D
13	D	R	R	N	N	N	N
14	R	A	A	A	A	A	R
15	R	R	D	D	D	D	D
16	R	R	N	N	N	N	R
17	A	A	A	A	A	R	R
18	R	D	D	D	D	D	R
19	R	N	N	N	N	R	A
20	A	A	A	A	R	R	R

Figure 7-1

REPRESENTATION OF A WORK SCHEDULE WITH THE DUTY CYCLE
 DDDDDRRNNNNRAAAAARRR (5D-2R-4N-1R-5A-3R)

The number of groups of identically-scheduled employees, and the number of employees assigned to each group, are not explicitly stated in the abbreviated representation. If uniform staffing by day of week is required, however, the number of groups must equal the number of days in the duty cycle (exceptions to this rule are discussed in sections D and E of this chapter), the number of employees assigned to each group must be the same, and the groups' duty assignments on any given day must correspond to a different day of the duty cycle. Figure 7-2 shows the duty assignments of each of 20 groups for the above duty cycle. Each group works the pattern shown for 20 days, and then returns to day 1 and repeats the same pattern. Note that all groups follow the same duty cycle. The duty assignments for any group are the same as those for the preceding group, except that all assignments are shifted by one day to the right.

The number of groups on duty on any shift and day of the cycle can be determined in Figure 7-2 by counting the number of symbols representing the shift of interest in the appropriate column. If the number of groups equals the number of days in the duty cycle, this information can also be obtained directly from the abbreviated representation, as follows:

- The number of groups on duty each day on any shift is equal to the number of days per duty cycle that a group is on duty on that shift, and can be calculated in the same way (i.e., by summing the numbers which precede the symbol that represents the shift in the abbreviated representation). In the example above, there are five on-duty groups on the day shift, four on-duty groups on the night shift, and five on-duty groups on the afternoon shift every day.

Day of Duty Cycle

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	D	D	D	D	D	R	R	N	N	N	N	R	A	A	A	A	A	R	R	R
2	R	D	D	D	D	D	R	R	N	N	N	N	R	A	A	A	A	A	R	R
3	R	R	D	D	D	D	D	R	R	N	N	N	N	R	A	A	A	A	A	R
4	R	R	R	D	D	D	D	D	R	R	N	N	N	N	R	A	A	A	A	A
5	A	R	R	R	D	D	D	D	D	R	R	N	N	N	N	R	A	A	A	A
6	A	A	R	R	R	D	D	D	D	D	R	R	N	N	N	N	R	A	A	A
7	A	A	A	R	R	R	D	D	D	D	D	R	R	N	N	N	N	R	A	A
8	A	A	A	A	R	R	R	D	D	D	D	D	R	R	N	N	N	N	R	A
9	A	A	A	A	A	R	R	R	D	D	D	D	D	R	R	N	N	N	N	R
10	R	A	A	A	A	A	R	R	R	D	D	D	D	D	R	R	N	N	N	N
11	N	R	A	A	A	A	A	R	R	R	D	D	D	D	D	R	R	N	N	N
12	N	N	R	A	A	A	A	A	R	R	R	D	D	D	D	D	R	R	N	N
13	N	N	N	R	A	A	A	A	A	R	R	R	D	D	D	D	D	R	R	N
14	N	N	N	N	R	A	A	A	A	A	R	R	R	D	D	D	D	D	R	R
15	R	N	N	N	N	R	A	A	A	A	A	R	R	R	D	D	D	D	D	R
16	R	R	N	N	N	N	R	A	A	A	A	A	R	R	R	D	D	D	D	D
17	D	R	R	N	N	N	N	R	A	A	A	A	A	R	R	R	D	D	D	D
18	D	D	R	R	N	N	N	N	R	A	A	A	A	A	R	R	R	D	D	D
19	D	D	D	R	R	N	N	N	N	R	A	A	A	A	A	R	R	R	D	D
20	D	D	D	D	R	R	N	N	N	N	R	A	A	A	A	A	R	R	R	D

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Figure 7-2

DUTY ASSIGNMENTS FOR 20 GROUPS WHOSE WORK SCHEDULE HAS THE DUTY CYCLE
 DDDDRRNNNNRRAAAAARRR (5D-2R-4N-1R-5A-3R)

- The number of off-duty groups each day is equal to the number of days per duty cycle that a group is off duty. In the example above, there are six groups off duty every day.
- If more than one group is on duty on any shift, the schedule is not a platoon schedule.
- On-duty staffing on any shift can be computed by multiplying the number of on-duty groups by the number of employees in a group.

C. How to Design Duty Cycle Schedules

This section discusses methods of designing duty cycle schedules which provide on-duty staffing that is basically uniform by day of week, and which (1) provide uniform on-duty staffing by shift with a specified average work week; (2) can be used by a work force of a given size; or (3) achieve a specified distribution of on-duty personnel by shift.

Designing Duty Cycle Schedules with Uniform Staffing by Shift

Uniform staffing on each shift is frequently required by agencies (1) that must provide a minimum level of coverage at all times, (2) whose workload does not vary by shift or day of week, or (3) whose workload is not predictable. Uniform staffing is often used for fire suppression personnel, utility plant operators, security officers, and some equipment maintenance personnel.

An important quantity used in designing duty cycle schedules with uniform staffing is the job factor--the number of employees needed to schedule one on-duty position on each shift seven days a week. For example, if three eight-hour shifts are staffed, a total of

$$3 \times 8 \times 7 = 168 \text{ hours}$$

of schedule coverage is required per week. If each employee works an average of 42 hours per week, then

$$\frac{168}{42} = 4 \text{ employees}$$

would be needed to maintain a schedule for each on-duty position around the clock. Therefore, the job factor is four. The general formula used to compute it is

$$\text{job factor} = \frac{7 \times \left(\begin{array}{c} \text{number of} \\ \text{shifts staffed} \\ \text{per day} \end{array} \right) \times \left(\begin{array}{c} \text{shift} \\ \text{length} \\ \text{in hours} \end{array} \right)}{\left(\begin{array}{c} \text{average} \\ \text{work week} \\ \text{in hours} \end{array} \right)}$$

Table 7-1 contains the job factors for several combinations of shift length, number of shifts per day, and average work week. By multiplying the appropriate entry in Table 7-1 by the number of positions to be scheduled on each shift, the total number of employees required for the schedule can be determined.* For example, if five positions are to be maintained on each of three eight-hour shifts with a 40-hour average work week, then

$$(5) \times (4.20) = 21 \text{ employees}$$

are required.

Instead of expressing the job factor as a decimal fraction,

*Note that the calculation for the job factor does not take account of reductions in staffing levels resulting from vacations, holidays, sick leave, or any other form of leave except regularly scheduled off-duty days. Hence, job factors indicate the number of employees required to maintain a scheduled position, while relief factors indicate the number of employees needed to actually staff a position.

Table 7-1

RELATIONSHIP BETWEEN SHIFT LENGTH, NUMBER OF SHIFTS,
AVERAGE WORK WEEK, AND THE JOB FACTOR EXPRESSED AS
A DECIMAL FRACTION

Shift Length	Average Work Week	Number of Shifts Per Day			
		1	2	3	4
8	37.5	1.49	2.99	4.48	5.97
	38.0	1.47	2.95	4.42	5.89
	39.0	1.44	2.87	4.31	5.74
	40.0	1.40	2.80	4.20	5.60
	41.0	1.37	2.73	4.10	5.46
	42.0	1.33	2.67	4.00	5.33
	42.5	1.32	2.64	3.95	5.27
10	37.5	1.87	3.73	5.60	7.47
	38.0	1.84	3.68	5.53	7.37
	39.0	1.79	3.59	5.38	7.18
	40.0	1.75	3.50	5.25	7.00
	41.0	1.71	3.41	5.12	6.83
	42.0	1.67	3.33	5.00	6.67
	42.5	1.65	3.29	4.94	6.59

as in Table 7-1, it is also useful to express it as the ratio of two whole numbers (see Table 7-2). This form of stating the job factor is denoted below as $(JF)^R$, where "R" indicates that the job factor is expressed as a ratio. This form is particularly useful in designing duty cycle schedules with uniform staffing because of the following relationship:

$$(JF)^R = \frac{\left(\begin{array}{c} \text{duty cycle length} \\ \text{in days} \end{array} \right)}{\left(\begin{array}{c} \text{number of on-duty days} \\ \text{per duty cycle} \\ \text{on each shift} \end{array} \right)}$$

For example, if two 10-hour shifts are operated per day and the average work week is 42 hours, then the job factor can be expressed in ratio form as

$$(JF)^R = \frac{\left(\begin{array}{c} \text{duty cycle length} \\ \text{in days} \end{array} \right)}{\left(\begin{array}{c} \text{number of on-duty days} \\ \text{per duty cycle} \\ \text{on each shift} \end{array} \right)} = 10/3.$$

This result indicates that a 42-hour average work week with uniform staffing by shift and day of week can be achieved with a 10-day duty cycle with three on-duty days per cycle on each of the two shifts. For example, the following pattern could be used:

D D D R R N N N R R.

Any other arrangement of three D's, three N's and four R's would produce the same staffing and average work week. Selection from among the many arrangements possible is discussed below.

Table 7-2

RELATIONSHIP BETWEEN SHIFT LENGTH, NUMBER OF SHIFTS,
AVERAGE WORK WEEK, AND THE JOB FACTOR
EXPRESSED AS A RATIO OF WHOLE NUMBERS

Shift Length	Average Work Week	Number of Shifts Per Day			
		1	2	3	4
8	37.5	112/75	224/75	112/25	448/75
	38.0	28/19	56/19	84/19	112/19
	39.0	56/39	112/39	56/13	224/39
	40.0	7/5	14/5	21/5	28/5
	41.0	56/41	112/41	168/41	224/41
	42.0	4/3	8/3	4/1	16/3
	42.5	112/83	224/83	336/83	448/83
10	37.5	28/15	56/15	28/5	112/15
	38.0	35/19	70/19	105/19	140/19
	39.0	70/39	140/39	70/13	280/39
	40.0	7/4	7/2	21/4	7/1
	41.0	70/41	140/41	210/41	280/41
	42.0	5/3	10/3	5/1	20/3
	42.5	28/17	56/17	84/17	112/17

Alternatively, the job factor in this example could have been expressed in ratio form as 20/6, 30/9, etc., indicating that the duty cycle could have also been constructed with six day shifts and six night shifts in a 20-day duty cycle (e.g., 6D-3R-6N-5R), with nine day shifts and nine night shifts in a 30-day duty cycle, etc.

Once the length of the duty cycle and the number of on-duty days per duty cycle on each shift have been determined, alternative arrangements of the duty assignments within the cycle can be analyzed, using the procedures discussed in Section B of this chapter and in Chapter III. The pattern which provides the most acceptable properties can then be identified. Properties that should be considered include the following:

- lengths of work and off-duty periods;
- number of off-duty weekends per week cycle; and
- number of off-duty hours at each shift change.

As an example, Table 7-3 summarizes these properties for three alternative patterns of duty assignments.

When an acceptable pattern of duty assignments has been identified, the employees are divided into equal-sized groups, with the number of groups equal to the length of the duty cycle in days. For example, employees would be divided into 10 groups if the duty cycle 3D-2R-3N-2R as used. A table is then constructed with rows corresponding to the groups and columns corresponding to the days of the duty cycle. The first row is constructed by copying the duty cycle. The second row is formed by shifting all entries in the first row one position to the right. The entry in the rightmost column is shifted to

Table 7-3

PROPERTIES OF ALTERNATIVE ARRANGEMENTS OF THREE DAY SHIFTS,
THREE NIGHT SHIFTS, AND FOUR OFF-DUTY DAYS
WITHIN A 10-DAY DUTY CYCLE

<u>Properties</u>	<u>Alternative 1</u>	<u>Alternative 2</u>	<u>Alternative 3</u>
Arrangement of duty assignments*	3D-2R-3N-2R	3D-1R-3N-3R	2D-1R-1D-1R-1N-1R-2N-1R
Length of work periods	Two three-day work periods	Two three-day work periods	Two two-day and two one-day work periods
Length of off-duty periods	Two two-day off-duty periods	One one-day and one three-day off-duty period	Four one-day off-duty periods
Number of off-duty weekends per week cycle	2	2	0
Number of off-duty hours when changing from day to night shift	72	48	48
Number of off-duty hours when changing from night to day shift	52	76	28

*"D" denotes a 10-hour day shift beginning at 6:00 a.m. and ending at 4:00 p.m., "N" a 10-hour night shift beginning at 4:00 p.m. and ending at 2:00 a.m., and "R" off duty.

column 1. Subsequent rows are formed similarly by shifting the entries in the preceding row by one position to the right. Such a table is illustrated in Figure 7-3 for the example given above.

If the duty cycle schedule is not locked, an alternative representation can be obtained by specifying duty assignments for each day of the week cycle (i.e., by repeating the duty cycle seven times). When the schedule is first implemented, each group begins working the duty assignments shown for a different week in the week cycle. At the end of one week, each group rotates down one week in the schedule, with the group that had worked the duty assignments shown for the last week of the schedule rotating back to the first week. The same procedure is followed at the end of each successive week. Such a representation for the schedule discussed above is illustrated in Figure 7-4. Note that the representations shown in figures 7-3 and 7-4 are equivalent since the duty assignments of group 1 in Figure 7-3 are identical to those of the group in Figure 7-4 initially assigned to week 1, the duty assignments of group 2 in Figure 7-3 are identical to those of the group in Figure 7-4 initially assigned to week 8, and so on.

Designing Duty Cycle Schedules for a Work Force of Fixed Size

To achieve uniform staffing by day of week using the above method, the number of employees in the work force must be a multiple of the duty cycle length dictated by the job factor, so that the same number of employees can be assigned to each group. If this condition is not met, and additional employees cannot be hired, two alternative procedures can be used:

		Day of Duty Cycle									
<u>Group</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	
1	D	D	D	R	R	N	N	N	R	R	
2	R	D	D	D	R	R	N	N	N	R	
3	R	R	D	D	D	R	R	N	N	N	
4	N	R	R	D	D	D	R	R	N	N	
5	N	N	R	R	D	D	D	R	R	N	
6	N	N	N	R	R	D	D	D	R	R	
7	R	N	N	N	R	R	D	D	D	R	
8	R	R	N	N	N	R	R	D	D	D	
9	D	R	R	N	N	N	R	R	D	D	
10	D	D	R	R	N	N	N	R	R	D	

Figure 7-3 .

DUTY ASSIGNMENTS OF 10 GROUPS FOLLOWING
THE 10-DAY DUTY CYCLE 3D-2R-3N-2R

Week	Day of Week						
	M	T	W	T	F	S	S
1	D	D	D	R	R	N	N
2	N	R	R	D	D	D	R
3	R	N	N	N	R	R	D
4	D	D	R	R	N	N	N
5	R	R	D	D	D	R	R
6	N	N	N	R	R	D	D
7	D	R	R	N	N	N	R
8	R	D	D	D	R	R	N
9	N	N	R	R	D	D	D
10	R	R	N	N	N	R	R

Figure 7-4

EQUIVALENT REPRESENTATION, BY DAY OF WEEK, OF DUTY ASSIGNMENTS
OF 10 GROUPS FOLLOWING THE 10-DAY DUTY CYCLE 3D-2R-3N-2R

- the work force can be divided into the same number of groups with some groups having one more employee than the other groups; or
- the work force can be divided into a different number of equal-sized groups.

The former procedure introduces cyclic variations into the daily staffing levels. For example, if groups 1 and 2 shown in Figure 7-3 have two employees, while the remaining groups have only one, there will be four employees on duty on the day shift and three employees on duty on the night shift on day 1 (which may fall on a Monday, for example). On day 8 (also a Monday), however, there will be three employees on duty on the day shift and five employees on duty on the night shift. On the following Monday there will be three employees on duty on both shifts.

The latter procedure produces uniform staffing, but an average work week that is higher or lower than required. This necessitates adding more on- or off-duty days to the schedule, which in turn also introduces some variation in daily on-duty staffing levels. This method, however, allows the schedule designer to control the shifts and days of the week when fewer employees are on duty. Since such control is preferable to cyclic variations, this method is discussed in more detail below.

To apply the method, the total number of on-duty staff-days per week that the work force can provide must be computed using the formula:

$$\left(\begin{array}{l} \text{available} \\ \text{staff-days} \\ \text{per week} \end{array} \right) = \frac{\left(\begin{array}{l} \text{number of} \\ \text{employees} \end{array} \right) \times \left(\begin{array}{l} \text{average} \\ \text{work week} \end{array} \right)}{\left(\begin{array}{l} \text{shift} \\ \text{length} \end{array} \right)} \quad (7-1)$$

The formula for the average number of employees on duty on each shift is:

$$\left(\begin{array}{c} \text{average on-duty} \\ \text{employees} \\ \text{per shift} \end{array} \right) = \frac{\left(\begin{array}{c} \text{available} \\ \text{staff-days} \\ \text{per week} \end{array} \right)}{\left(\begin{array}{c} \text{shifts} \\ \text{operated} \\ \text{per week} \end{array} \right)}. \quad (7-2)$$

If the result is a whole number, uniform staffing on each shift can be obtained using the procedure described above. If the result is not a whole number--i.e., it is a whole number n plus a fraction--then there will be n employees on duty on some shifts and days of the week, and $n+1$ employees on duty on all other shifts and days of the week. The number of shifts per week staffed by n employees is given by the formula:

$$\left(\begin{array}{c} \text{shifts per week} \\ \text{staffed by } n \\ \text{employees} \end{array} \right) = \left(\begin{array}{c} \text{shifts} \\ \text{operated} \\ \text{per week} \end{array} \right) \times (n + 1) - \left(\begin{array}{c} \text{available} \\ \text{staff-days} \\ \text{per week} \end{array} \right). \quad (7-3)$$

The number of shifts per week staffed by $n + 1$ employees is given by the formula:

$$\left(\begin{array}{c} \text{shifts per week} \\ \text{staffed by } n+1 \\ \text{employees} \end{array} \right) = \left(\begin{array}{c} \text{shifts} \\ \text{operated} \\ \text{per week} \end{array} \right) - \left(\begin{array}{c} \text{shifts per week} \\ \text{staffed by } n \\ \text{employees} \end{array} \right). \quad (7-4)$$

For example, suppose an agency with 15 employees maintains two eight-hour shifts per day and has a 40-hour average work week. The number of available staff-days per week can be computed using formula (7-1):

$$\frac{(15) \times (40)}{(8)} = 75 \text{ available staff-days per week.}$$

Since two shifts are maintained per day, seven days per week, there are 14 shifts operated per week. The average number of employees on duty on each of these 14 shifts is computed using formula (7-2):

$$\frac{75}{14} = 5.357 \text{ employees on duty per shift.}$$

Since this is not a whole number, on-duty staffing will not be uniform on each of the 14 shifts. Instead, some shifts will have five on-duty employees and other shifts will have six on-duty employees (i.e., $n=5$ and $n+1=6$). The number of shifts with five on-duty employees is given by formula (7-3):

$$(14) \times (6) - 75 = 9 \text{ shifts per week staffed by five employees.}$$

Formula (7-4) is used to compute the number of shifts with six on-duty employees:

$$14 - 9 = 5 \text{ shifts per week staffed by six employees.}$$

Once the numbers of shifts per week that can be staffed by n and $n+1$ employees have been determined, the shifts and days of the week that will have n on-duty employees, and those that will have $n+1$ employees, are designated by the schedule designer. The allocation of on-duty employees to shifts and days of the week is usually based on workload. For example, if the workload on the night shift is heavier than the workload on the day shift, and the workload on Tuesday through Saturday nights is heavier than the workload on Sunday and Monday nights, the nine shifts to be staffed by five employees and the five shifts to be staffed by

six employees might be distributed as follows:

	Day of Week						
	<u>S</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>
Day Shift	5	5	5	5	5	5	5
Night Shift	5	5	6	6	6	6	6
Off Duty	5	5	4	4	4	4	4

After the available on-duty staff-days have been distributed among the shifts and days of the week, a duty cycle schedule can be designed by dividing the work force into equal-sized groups.* The number of groups determines the length of the duty cycle:

$$\left(\begin{array}{l} \text{length of} \\ \text{duty cycle} \\ \text{in days} \end{array} \right) = \left(\begin{array}{l} \text{number of} \\ \text{groups of} \\ \text{employees} \end{array} \right) \quad (7-5)$$

The number of days in the duty cycle that each group should be assigned to a shift i is determined by the relation:

$$\left(\begin{array}{l} \text{number of days per} \\ \text{duty cycle each group} \\ \text{is assigned} \\ \text{to shift } i \end{array} \right) = \left(\begin{array}{l} \text{number of groups} \\ \text{on duty on shift} \\ \text{ } i, \text{ seven days per} \\ \text{week} \end{array} \right) \quad (7-6)$$

The number of days in the duty cycle that each group should be off duty is:

$$\left(\begin{array}{l} \text{number of days per} \\ \text{duty cycle each group} \\ \text{is off duty} \end{array} \right) = \left(\begin{array}{l} \text{number of groups} \\ \text{off duty each day,} \\ \text{seven days per week} \end{array} \right) \quad , \text{ or}$$

*Frequently, each employee will be placed in a different group (i.e., each group will contain a single employee), especially if the number of employees in the work force is small and team integrity is not important.

$$\left(\begin{array}{l} \text{number of days per} \\ \text{duty cycle each group} \\ \text{is off duty} \end{array} \right) = \left(\begin{array}{l} \text{length of} \\ \text{duty cycle} \\ \text{in days} \end{array} \right) - \left(\begin{array}{l} \text{number of days per} \\ \text{duty cycle each group} \\ \text{is on duty} \\ \text{on all shifts} \end{array} \right).$$

For example, if the 15 employees in the above example are scheduled as 15 groups (i.e., one employee in each group), the schedule designed should have a 15-day duty cycle (formula (7-5)). Since five employees (groups) are to be on duty on the day shift each day, the duty cycle will contain five on-duty assignments on the day shift (formula (7-6)). Since five employees (groups) are to be on duty on the night shift on two days a week, and six are to be on duty on the other days of the week, the duty cycle designed will contain either five or six on-duty assignments on the night shift.* If the duty cycle contains five night-shift assignments, it will contain five off-duty assignments, and if it contains six night-shift assignments, it will contain four off-duty assignments.

Once the numbers of off-duty assignments and on-duty assignments on each shift to be included in the duty cycle have been determined, alternative patterns of the duty cycle can be analyzed to determine which is "best" in terms of the lengths of work and off-duty periods, the number of off-duty weekends per week cycle, and off-duty hours at each shift change. For example, the

*The choice is arbitrary since the resulting schedules will be identical.

pattern selected may be

5D-2R-5N-3R,

with five night shift assignments per duty cycle, or

5D-2R-6N-2R,

with six night shift assignments per duty cycle.

Using payback days to adjust the average work week. The schedule with the duty cycle 5D-2R-5N-3R has an average work week of:

$$\frac{(8) \times (10) \times (7)}{(15)} = 37.333 \text{ hours.}$$

Since a 40-hour average work week is required, an average of 2.667 additional on-duty hours must be added. This is accomplished by requiring each employee to work days during the week cycle that would normally be off-duty days if the duty assignments specified in the duty cycle were followed without modification. These additional on-duty days are termed payback days. The number of payback days required per week cycle to raise the average work week by h hours is given by:

$$\left(\begin{array}{l} \text{number of} \\ \text{payback days} \\ \text{required per} \\ \text{week cycle} \end{array} \right) = \frac{\left(\begin{array}{l} \text{h hours} \\ \text{per week} \end{array} \right) \times \left(\begin{array}{l} \text{length of duty} \\ \text{cycle in days} \end{array} \right)}{\left(\begin{array}{l} \text{shift length} \\ \text{in hours} \end{array} \right)} \quad (7-7)$$

For example, using formula (7-7), the number of payback days required per week cycle (15 weeks) to raise the average work week from 37.333 to 40 hours is:

$$\frac{(2.667) \times (15)}{8} = 5 \text{ payback days.}$$

Any off-duty day in the week cycle can be designated as a payback day, and employees can be required to work these days on any shift or combination of shifts. By scheduling the payback days on the shifts and days of the week when additional staffing is required, the previously determined personnel allocation can be achieved. For example, by scheduling one of the five payback days required in the example above on the night shift on Tuesday through Saturday, five employees will be on duty on the day shift, seven days per week, five will be on duty on the night shift on Sunday and Monday, and six will be on duty on the night shift, Tuesday through Saturday. The resulting schedule is illustrated in Figure 7-5.

Using Kelly days to adjust the average work week. If the duty cycle 5D-2R-6N-2R is used to design the schedule, the average work week is:

$$\frac{(8) \times (11) \times (7)}{(15)} = 41.067 \text{ hours.}$$

To reduce the average work week from 41.067 hours to 40 hours, employees must be given additional off-duty days, termed Kelly days, during the week cycle. The number of Kelly days required per week cycle to lower the average work week by h hours is given by:

$$\left(\frac{\text{number of Kelly days required}}{\text{per week cycle}} \right) = \frac{\left(\frac{h \text{ hours}}{\text{per week}} \right) \times \left(\frac{\text{length of duty cycle in days}}{\text{shift length in hours}} \right)}{.} \quad (7-8)$$

For example, using formula (7-8), to lower the average work week from 41.067 to 40 hours,

Week	Day of Week						
	S	M	T	W	T	F	S
1	D	D	D	D	D	R	R
2	N	N	N	N	N	(N)	R
3	R	D	D	D	D	D	R
4	R	N	N	N	N	N	(N)
5	R	R	D	D	D	D	D
6	R	R	N	N	N	N	N
7	R	R	R	D	D	D	D
8	D	R	R	N	N	N	N
9	N	R	R	R	D	D	D
10	D	D	R	R	N	N	N
11	N	N	(N)	R	R	D	D
12	D	D	D	R	R	N	N
13	N	N	N	(N)	R	R	D
14	D	D	D	D	R	R	N
15	N	N	N	N	(N)	R	R

*Circled entries in the schedule denote pay-back days.

Figure 7-5

DUTY CYCLE SCHEDULE DESIGNED FOR
15 EMPLOYEES USING PAYBACK DAYS*

$$\frac{(1.067) \times (15)}{8} = 2 \text{ Kelly days}$$

must be added every 15 weeks.

Any on-duty day on any shift can be designated as a Kelly day. By scheduling the Kelly days on the shifts and days of the week when fewer on-duty employees are needed, the previously determined personnel distribution is achieved. In the example above, one Kelly day would be scheduled on the Sunday and Monday night shifts. The resulting schedule is illustrated in Figure 7-6, and is identical to the schedule in Figure 7-5.

Designing Duty Cycle Schedules with Specified Numbers of On-Duty Employees on Each Shift and Day of Week

To design a duty cycle schedule with a specified average work week and specified numbers of employees on duty on each shift and day of the week, the total number of on-duty staff-days required per week must be determined by summing the numbers of on-duty employees required on each shift and day of week. The number of employees required can then be computed using the following formula:

$$\left(\begin{array}{c} \text{number of} \\ \text{employees} \\ \text{required} \end{array} \right) = \frac{\left(\begin{array}{c} \text{staff-days} \\ \text{required} \\ \text{per week} \end{array} \right) \times \left(\begin{array}{c} \text{shift} \\ \text{length} \\ \text{in hours} \end{array} \right)}{\left(\begin{array}{c} \text{average} \\ \text{work week} \end{array} \right)} \quad (7-9)$$

If the result is a whole number, a duty cycle schedule can be designed with the desired personnel distribution, using the method described above. If the result is not a whole number, but is a whole number n plus a fraction, a schedule can be designed for a work force of either n employees or n+1 employees.

Week	Day of Week						
	S	M	T	W	T	F	S
1	D	D	D	D	D	R	R
2	N	N	N	N	N	N	R
3	R	D	D	D	D	D	R
4	R	N	N	N	N	N	N
5	R	R	D	D	D	D	D
6	R	R	N	N	N	N	N
7	R	R	R	D	D	D	D
8	D	R	R	N	N	N	N
9	N	R	R	R	D	D	D
10	D	D	R	R	N	N	N
11	N	N	N	R	R	D	D
12	D	D	D	R	R	N	N
13	N	N	N	N	R	R	D
14	D	D	D	D	R	R	N
15	N	N	N	N	N	R	R

*Circled entries in the schedule denote Kelly days.

Figure 7-6

DUTY CYCLE SCHEDULE DESIGNED FOR
15 EMPLOYEES USING KELLY DAYS*

For example, if the number of employees required equals 4.25, a schedule can be designed for 4.0 employees (i.e., n employees) or 5.0 employees (i.e., n+1 employees).

If a schedule for n employees is used, some shifts and days of the week will have one fewer on-duty employee than required. The number of these shifts is given by the formula:

$$\left(\begin{array}{l} \text{number of shifts} \\ \text{with fewer on-duty} \\ \text{employees than} \\ \text{required} \end{array} \right) = \left(\begin{array}{l} \text{staff-days} \\ \text{required} \\ \text{per week} \end{array} \right) - \frac{(n) \times \left(\begin{array}{l} \text{average} \\ \text{work week} \end{array} \right)}{\left(\begin{array}{l} \text{shift length} \\ \text{in hours} \end{array} \right)}. \quad (7-10)$$

The remaining shifts of the week will have the required number of on-duty employees.

If a schedule for n+1 employees is used, some shifts and days of the week will have one more on-duty employee than required. The number of shifts with excess staffing is given by the formula:

$$\left(\begin{array}{l} \text{number of shifts} \\ \text{with more on-duty} \\ \text{employees than} \\ \text{required} \end{array} \right) = \frac{(n + 1) \times \left(\begin{array}{l} \text{average} \\ \text{work week} \end{array} \right)}{\left(\begin{array}{l} \text{shift length} \\ \text{in hours} \end{array} \right)} - \left(\begin{array}{l} \text{staff-days} \\ \text{required} \\ \text{per week} \end{array} \right). \quad (7-11)$$

The remaining shifts of the week will have the required number of on-duty employees.

For example, suppose an agency maintains two 10-hour shifts per day, has a 40-hour average work week, and requires the following distribution of on-duty personnel by shift and day of week:

	Day of Week							Total
	S	M	T	W	T	F	S	
Day Shift	3	4	4	4	4	4	3	26
Night Shift	1	2	3	3	3	3	2	17
Total	4	6	7	7	7	7	5	43

Since a total of 43 staff-days is required per week, using formula (7-9), the number of employees required is:

$$\frac{(43) \times (10)}{(40)} = 10.75 \text{ employees.}$$

Since this is not a whole number, the required personnel distribution cannot be achieved exactly. If a schedule for 10 employees is used, there will be:

$$43 - \frac{(10) \times (40)}{(10)} = 3 \text{ shifts per week}$$

with one fewer on-duty employee than required (formula (7-10)).

If a schedule for 11 employees is used, there will be:

$$\frac{(11) \times (40)}{(10)} - 43 = 1 \text{ shift per week}$$

with one more on-duty employee than required (formula (7-11)).

The schedule for 11 employees is designed as follows:

- Since there are 11 employees, an 11-day duty cycle with uniform staffing by day of week on each shift will be formulated. Since most day shifts require four on-duty employees and most night shifts require three on-duty employees, the duty cycle will be designed to provide these numbers of on-duty employees each day. One such duty cycle is:

4D-2R-3N-2R.

- Use of this duty cycle produces an average work week of:

$$\frac{(10) \times (7) \times (7)}{(11)} = 44.55 \text{ hours.}$$

- Since an average work week of 40 hours is required, Kelly days must be added to reduce the average work week by:

$$44.55 - 40 = 4.55 \text{ hours.}$$

- The number of Kelly days required per week cycle (11 weeks) is:

$$\frac{(4.55) \times (11)}{(10)} = 5 \text{ Kelly days (formula (7-8)).}$$

- By scheduling these Kelly days on the shifts and days of the week when fewer on-duty employees are required, a personnel distribution is obtained similar to the one required. For example, if one Kelly day is scheduled on the day shift on a Sunday and Saturday, two on the Sunday night shift, and one on the Saturday night shift, the following distribution of on-duty personnel results:

	<u>Day of Week</u>						
	<u>S</u>	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>
Day Shift	3	4	4	4	4	4	3
Night Shift	1	3	3	3	3	3	2

Note that there is one more employee on duty than required on the night shift on Monday.

The resulting schedule is shown in Figure 7-7.

D. Extended Duty Cycle Schedules

The methods of designing duty cycle schedules discussed in Section C require that the length of the duty cycle in days be

Week	Day of Week						
	S	M	T	W	T	F	S
1	D	D	D	D	R	R	N
2	N	N	R	R	D	D	D
3	(R)	R	R	N	N	N	R
4	R	D	D	D	D	R	R
5	(R)	N	N	R	R	D	D
6	D	D	R	R	N	N	(R)
7	R	R	D	D	D	D	R
8	R	N	N	N	R	R	(R)
9	D	D	D	R	R	N	N
10	(R)	R	R	D	D	D	D
11	R	R	N	N	N	R	R

*Circled entries in the schedule denote Kelly days.

Figure 7-7

DUTY CYCLE SCHEDULE DESIGNED TO ACHIEVE A SPECIFIED DISTRIBUTION OF ON-DUTY EMPLOYEES BY SHIFT AND DAY OF WEEK*

equal to the number of groups of employees being scheduled. The method described in this section produces schedules for which the duty cycle length is a multiple of the number of groups. This feature enables the schedule designer to eliminate several undesirable properties common to duty cycle schedules with short duty cycles.

To illustrate these undesirable properties, suppose an agency must schedule 10 groups of employees, each working 42 hours per week, in such a way that four groups are on duty during the day shift, and two groups are on duty during the night shift, seven days per week. Both shifts are 10 hours long. Using the methods discussed in Section C, the following duty cycle could be formulated:

4D-2R-2N-2R.

A schedule with this duty cycle would have the following undesirable properties:

- There are two shift changes in every 10-day period.
- Work periods are not uniform in length (i.e., the day shift is four days long and the night shift is two days long).
- Work periods on the night shift are very short.
- There are no off-duty periods longer than two days.

Other 10-day duty cycles that could be formulated would have similar undesirable properties. For example, a schedule with the duty cycle

4D-2N-4R

has extended off-duty periods (i.e., all off-duty periods are

four days in length), but there are still two shift changes in every 10-day period, long work periods (i.e., six days in length), and no off-duty days when employees change from the day shift to the night shift.

Extended duty cycle schedules, on the other hand, have the following desirable properties:

- The same average work week and distribution of on-duty employees by shift and day of week can be achieved as with duty cycle schedules in which the duty cycle length is the same as the number of groups being scheduled.
- Work periods are usually uniform in length, except for those that are shortened or lengthened by Kelly days or payback days.
- Shift changes are required less frequently than in duty cycle schedules with the duty cycle length equal to the number of groups.
- It may be possible to schedule extended off-duty periods without scheduling one-day off-duty periods or requiring employees to work consecutive days on different shifts.

To design an extended duty schedule for some number of groups, m , the procedures described in Section C are used to determine the following:

- the number of on-duty assignments on the day shift, d , on the night shift, n , etc., that would be scheduled in an m -day duty cycle if a duty cycle schedule were being designed with the duty cycle length equal to the number of groups;
- the number of off-duty days, r , that would be scheduled in an m -day duty cycle; and
- the number of Kelly days, k , or payback days, p , that would be scheduled in an m -week cycle to achieve the average work week required.

To design an extended duty cycle schedule for the agency with 10 employees described above, the procedures described in Section C would also be used to determine that four day-shift assignments

($d=4$), two night-shift assignments ($n=2$), and four off-duty days ($r=4$) should be used in a 10-day duty cycle (i.e., $m=10$), and that no Kelly days ($k=0$) or payback days ($p=0$) are required to achieve a 42-hour average work week.

At this point, the most desirable length, w , for the work periods is selected by the schedule designer, and a duty cycle is formulated with the following properties:*

- the length of the duty cycle is $(w) \times (m)$ days;
- the number of on-duty assignments per duty cycle on the day shift is $(w) \times (d)$, and the number on the night shift is $(w) \times (n)$;
- the number of off-duty days per duty cycle is $(w) \times (r)$;
- the number of Kelly days per week cycle is $(w) \times (k)$; and
- the number of payback days per week cycle is $(w) \times (p)$.

The only restriction in formulating the duty cycle is that the numbers of consecutive on-duty assignments on any shift, without an off-duty day or on-duty assignment on another shift, must be multiples of w .

As an example, suppose that the 10-employee agency described above wants work periods which are four days in length ($w=4$). This requirement would suggest an extended duty cycle schedule with a length

$$(4) \times (10) = 40 \text{ days.}$$

The number of day-shift assignments per 40-day duty cycle would be

*Note that some work periods will be $w-1$ days in length if Kelly days are scheduled, or $w+1$ days in length if payback days are scheduled.

(4) x (4) = 16 day-shift assignments;

the number of night-shift assignments per 40-day duty cycle would be

(4) x (2) = 8 night-shift assignments;

and the number of off-duty days per duty cycle would be

(4) x (4) = 16 off-duty days.

No Kelly days or payback days are required. One such extended duty cycle is:

4D-2R-4D-2R-4D-2R-4D-4R-4N-2R-4N-4R

The schedule based on this extended duty cycle is shown in Figure 7-8.

The schedules designed in Section C are initiated by assigning each group to a different week of the week cycle. Since the number of groups is equal to the number of weeks in the week cycle, one group is assigned to each week of the schedule. In an extended duty cycle schedule, however, the number of weeks in the week cycle exceeds the number of groups; and consequently, one group cannot be assigned to each week in the schedule. Instead, the groups are assigned to weeks in the schedule which are w weeks apart. For example, the 10 groups using the schedule shown in Figure 7-8 might be initially assigned to work the duty assignments for weeks 1, 5, 9, 13, 17, 21, 25, 29, 33, and 37 (i.e., group assignments would be separated by four weeks in the schedule).

Week	Day of Week						
	M	T	W	T	F	S	S
1	D	D	D	D	R	R	D
2	D	D	D	R	R	D	D
3	D	D	R	R	D	D	D
4	D	R	R	R	R	N	N
5	N	N	R	R	N	N	N
6	N	R	R	R	R	D	D
7	D	D	R	R	D	D	D
8	D	R	R	D	D	D	D
9	R	R	D	D	D	D	R
10	R	R	R	N	N	N	N
11	R	R	N	N	N	N	R
12	R	R	R	D	D	D	D
13	R	R	D	D	D	D	R
14	R	D	D	D	D	R	R
15	D	D	D	D	R	R	R
16	R	N	N	N	N	R	R
17	N	N	N	N	R	R	R
18	R	D	D	D	D	R	R
19	D	D	D	D	R	R	D
20	D	D	D	R	R	D	D
21	D	D	R	R	R	R	N
22	N	N	N	R	R	N	N
23	N	N	R	R	R	R	D
24	D	D	D	R	R	D	D
25	D	D	R	R	D	D	D
26	D	R	R	D	D	D	D
27	R	R	R	R	N	N	N
28	N	R	R	N	N	N	N
29	R	R	R	R	D	D	D
30	D	R	R	D	D	D	D
31	R	R	D	D	D	D	R
32	R	D	D	D	D	R	R
33	R	R	N	N	N	N	R
34	R	N	N	N	N	R	R
35	R	R	D	D	D	D	R
36	R	D	D	D	D	R	R
37	D	D	D	D	R	R	D
38	D	D	D	R	R	R	R
39	N	N	N	N	R	R	N
40	N	N	N	R	R	R	R

Figure 7-8

EXTENDED DUTY CYCLE SCHEDULE FOR 10 GROUPS

In successive weeks, the groups simply rotate through the schedule (e.g., the 10 groups would follow the duty assignments for weeks 2, 6, 10, 14, 18, 22, 26, 30, 34, and 38 during the second week of the schedule). In a 40-week period, the schedules of all employees are equivalent in terms of off-duty days, off-duty weekends, on-duty assignments on each shift, etc. In addition, the following schedule properties are produced:

- the average work week is 42 hours;
- four groups are on duty on the day shift on each day;
- two groups are on duty on the night shift on each day;
- all work periods are four days in length;
- in a 40-week period, 14 off-duty periods are four days in length;
- all other off-duty periods are two days in length;
- in a 40-week period, there are 14 shift changes, compared to 56 shift changes that would be required if an extended duty cycle was not used; and
- there are four off-duty days at every shift change.

Use of Kelly days and payback days to adjust the average work week. To illustrate the use of Kelly days* in extended duty cycle schedules, suppose that a 40-hour, instead of a 42-hour, work week is required by the above agency. This change necessitates scheduling:

$$\frac{(42 - 40) \times (10)}{(10)} = 2 \text{ Kelly days per week cycle} \quad (\text{formula (7-8)})$$

if a 10-day duty cycle is used. Therefore, in an extended 40-day

*The same procedure can be used when payback days are needed.

duty cycle, the number of Kelly days required is

$$(4) \times (2) = 8 \text{ Kelly days per 40-week period.}$$

Scheduling these Kelly days will result in fewer on-duty groups than required on some shifts and days of the week. Any on-duty day on any shift can be designated as a Kelly day. However, if two Kelly days are scheduled on the same shift and day of the week in two schedule brackets that are separated by a multiple of w weeks, where w is the work period length specified in formulating the extended duty cycle schedule, some weeks will have two groups off duty on that shift and day. For example, the schedule shown in Figure 7-9 will never have two groups off duty for Kelly days at the same time*, since no two Kelly days scheduled on Saturday are in schedule weeks separated by a multiple of $w=4$ weeks. Similarly, no two Kelly days scheduled on Sunday are in schedule weeks separated by a multiple of four weeks. On the other hand, if the Kelly days are scheduled as shown in Figure 7-10, two groups will be off duty for Kelly days on the night shift on both Saturday and Sunday every fourth week because the Kelly days scheduled for these shifts and days in weeks 4 and 28 are separated by 24 weeks--a multiple of $w=4$. As a result, there will be no groups on duty. If this is unacceptable, an alternative placement of some Kelly days in the schedule is necessary.

E. Platoon Schedules

Schedules with only one group on duty on all shifts and

*In fact, exactly one group will be off duty for Kelly days on the night shift on Saturday and Sunday every week.

Week	Day of Week						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1	D	D	D	D	R	R	D
2	D	D	D	R	R	D	D
3	D	D	R	R	D	D	D
4	D	R	R	R	R	Ⓡ	N
5	N	N	R	R	N	N	N
6	N	R	R	R	R	D	D
7	D	D	R	R	D	D	D
8	D	R	R	D	D	D	D
9	R	R	D	D	D	D	R
10	R	R	R	N	N	N	Ⓡ
11	R	R	N	N	N	Ⓡ	R
12	R	R	R	D	D	D	D
13	R	R	D	D	D	D	R
14	R	D	D	D	D	R	R
15	D	D	D	D	R	R	R
16	R	N	N	N	N	R	R
17	N	N	N	N	R	R	R
18	R	D	D	D	D	R	R
19	D	D	D	D	R	R	D
20	D	D	D	R	R	D	D
21	D	D	R	R	R	R	Ⓡ
22	N	N	N	R	R	Ⓡ	N
23	N	N	R	R	R	R	D
24	D	D	D	R	R	D	D
25	D	D	R	R	D	D	D
26	D	R	R	D	D	D	D
27	R	R	R	R	N	N	N
28	N	R	R	N	N	N	Ⓡ
29	R	R	R	R	D	D	D
30	D	R	R	D	D	D	D
31	R	R	D	D	D	D	R
32	R	D	D	D	D	R	R
33	R	R	N	N	N	Ⓡ	R
34	R	N	N	N	N	R	R
35	R	R	D	D	D	D	R
36	R	D	D	D	D	R	R
37	D	D	D	D	R	R	D
38	D	D	D	R	R	R	R
39	N	N	N	N	R	R	Ⓡ
40	N	N	N	R	R	R	R

*Circled entries in the schedule denote Kelly days.

Figure 7-9

EXTENDED DUTY CYCLE SCHEDULE FOR 10 GROUPS USING KELLY DAYS*

Week	Day of Week						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
1	D	D	D	D	R	R	D
2	D	D	D	R	R	D	D
3	D	D	R	R	D	D	D
4	D	R	R	R	R	(R)	(R)
5	N	N	R	R	N	N	N
6	N	R	R	R	R	D	D
7	D	D	R	R	D	D	D
8	D	R	R	D	D	D	D
9	R	R	D	D	D	D	R
10	R	R	R	N	N	N	(R)
11	R	R	N	N	N	N	R
12	R	R	R	D	D	D	D
13	R	R	D	D	D	D	R
14	R	D	D	D	D	R	R
15	D	D	D	D	R	R	R
16	R	N	N	N	N	R	R
17	N	N	N	N	R	R	R
18	R	D	D	D	D	R	R
19	D	D	D	D	R	R	D
20	D	D	D	R	R	D	D
21	D	D	R	R	R	R	N
22	N	N	N	R	R	(R)	N
23	N	N	R	R	R	R	D
24	D	D	D	R	R	D	D
25	D	D	R	R	D	D	D
26	D	R	R	D	D	D	D
27	R	R	R	R	N	N	N
28	N	R	R	N	N	(R)	(R)
29	R	R	R	R	D	D	D
30	D	R	R	D	D	D	D
31	R	R	D	D	D	D	R
32	R	D	D	D	D	R	R
33	R	R	N	N	N	(R)	R
34	R	N	N	N	N	R	R
35	R	R	D	D	D	D	R
36	R	D	D	D	D	R	R
37	D	D	D	D	R	R	D
38	D	D	D	R	R	R	R
39	N	N	N	N	R	R	(R)
40	N	N	N	R	R	R	R

*Circled entries in the schedule denote Kelly days.

Figure 7-10

ALTERNATIVE PLACEMENT OF KELLY DAYS*
IN AN EXTENDED DUTY CYCLE SCHEDULE FOR 10 GROUPS

days of the week are termed platoon schedules. They have the following useful properties:

- An employee's co-workers are the same whenever he is on duty, except when absences occur due to Kelly days, sick leave, etc.; when an employee must work a payback day with another platoon; or when employees from other platoons are working payback days with his platoon. As a result, team integrity is high.
- The number of groups scheduled is small (usually five or less). As a result, it may be possible to assign a supervisor to each group. This produces unity of command since an employee will report to the same supervisor, except when he must work a payback day with another platoon or his supervisor is absent.
- The length of the duty cycle can be a multiple of the number of groups. Extending the duty cycle produces the schedule properties discussed in the previous section.

To design platoon schedules, the number of groups (platoons) into which the work force must be divided is determined by computing the job factor with the formula:

$$\text{job factor} = \frac{7 \times \left(\frac{\text{number of shifts}}{\text{staffed per day}} \right) \times \left(\frac{\text{shift length}}{\text{average work week}} \right)}{\left(\frac{\text{average work week}}{\text{work week}} \right)}$$

If a whole number results, a platoon schedule having the required average work week can be designed without using either Kelly days or payback days. If the result, however, is between two whole numbers, n and $n+1$, platoon schedules can be designed with either n groups or $n+1$ groups. If n groups are scheduled, Kelly days must be added to produce the correct average work week. If $n+1$ groups are scheduled, payback days must be added.

For example, if three eight-hour shifts are to be staffed daily by a work force that works 42 hours per week, the job

factor is:

$$\frac{(7) \times (3) \times (8)}{(42)} = 4.$$

Therefore, a platoon schedule could be designed for four groups without using Kelly days or payback days. If a 40-hour average work week is required, the job factor is:

$$\frac{(7) \times (3) \times (8)}{(40)} = 4.2.$$

In this case, a platoon schedule could be designed for four groups with Kelly days added to lower the average work week from 42 to 40 hours, or a schedule could be designed for five groups with payback days added to raise the average work week from 33.6 to 40 hours.

Once the number of groups, m , has been determined, a schedule with an m -day duty cycle and one on-duty group on all shifts can be designed by using the method discussed in Section C, or an extended duty cycle schedule can be designed by using the method described in Section D. Alternatively, the following procedure can be used to design an m -platoon schedule:

- The length of the duty cycle is set to a multiple of m .
- The duty cycle is divided into m components of equal length.
- Duty assignments are specified for the first day of each component in such a way that exactly one of the days contains an on-duty assignment on each shift.
- Duty assignments for the second and subsequent days are specified in the same way.
- When on-duty assignments have been specified for the last days in the components, all days for which an

on-duty assignment has not been specified are off-duty days.

- The schedule for the first platoon is given by the duty cycle constructed in this way. The schedule for the second platoon is formed by rotating the schedule for the first platoon to the right a number of days equal to the length of the components.
- The schedule for the third platoon is formed by rotating the schedule for the second platoon to the right an equal number of days, etc.

A four-platoon schedule constructed in this way is shown in Figure 7-11. Note that for each platoon, both the first days of the four components into which the duty cycle has been divided (i.e., days 1, 6, 11, and 16), and the second through fifth days of the four components each contain one day shift, one afternoon shift, one night shift, and one off-duty assignment; and that on each day of the duty cycle there is exactly one platoon on duty on each shift.

Use of Kelly days and payback days to adjust the average work week. When a platoon schedule is designed which has a higher or lower average work week than required, Kelly days or payback days must be scheduled. The procedures discussed in Section C and D can be used to assign Kelly days and payback days on a group basis--all group members are off duty for a Kelly day, or on duty for a payback day, at the same time. If these procedures are used to designate Kelly days in a platoon schedule, however, there will be no employees on duty on a shift and day when a Kelly day is scheduled since everyone in the only platoon assigned to work that shift will be off duty. On payback days, two entire platoons would report to work at the same time. Consequently, in platoon schedules, Kelly days and payback

Day of Duty Cycle

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Platoon 1	D	D	D	D	D	R	N	N	N	N	N	R	R	A	A	A	A	A	R	R
Platoon 2	A	A	A	R	R	D	D	D	D	D	R	N	N	N	N	N	R	R	A	A
Platoon 3	N	R	R	A	A	A	A	A	R	R	D	D	D	D	D	R	N	N	N	N
Platoon 4	R	N	N	N	N	N	R	R	A	A	A	A	A	R	R	D	D	D	D	D

Figure 7-11

THREE-SHIFT, FOUR-PLATOON SCHEDULE WITH A 20-DAY DUTY CYCLE

days must be assigned on an individual basis.

Two procedures are used to do this. The first procedure is strictly administrative and does not involve the schedule designer. Using this method, Kelly days or payback days are scheduled at the discretion of the employee and his supervisor. For example, Kelly days may be scheduled to extend the employee's annual vacation or to give periodic days off duty to conduct personal business. Payback days may be used by administrators to cover absences of other employees due to vacation, sick leave, etc. The main problem with this method is that detailed records are often required to ensure that all employees receive the correct number of Kelly days or payback days, and that these days are scheduled in such a way that all agency restrictions are satisfied (e.g., that the days are scheduled within prespecified time periods, or that no more than a specified number of employees are off duty for Kelly days at the same time).

The second procedure involves specifying the Kelly days or payback days for each group member in the schedule. Each member is assigned a different off-number. If there are n employees in each platoon, and each employee is entitled to k Kelly days* per week cycle, then $(n) \times (k)$ Kelly days are identified in the schedule, and off-numbers are associated with each Kelly day in such a way that there are k Kelly days with each off-number. On the days and shifts when a Kelly day is indicated in the schedule, only the platoon member with the off-number associated with the Kelly day is off duty.

For example, suppose that a four-platoon schedule is to

*The same procedure is used to schedule payback days.

be designed with a 40-hour average work week. The schedule shown in Figure 7-11 can be used if:

$$\frac{(42 - 40) \times (20)}{8} = 5 \text{ Kelly days}$$

are scheduled during the 20-week week cycle for each platoon member. If three employees are assigned to each platoon, a total of 15 on-duty assignments in the schedule will be designated as Kelly days. Five Kelly days will correspond to off-number 1, five to off-number 2, and five to off-number 3. One possible schedule is shown in Figure 7-12. All of the Kelly days are scheduled on the night shift so that regularly scheduled off-duty periods are extended by one or two days. The Kelly days are distributed among the days of the week in such a way that in every five-week period, there will be one employee off duty on the night shift on three of five Sundays, and two of five Mondays, Tuesdays, Wednesdays, Thursdays, Fridays, and Saturdays. The platoon member with off-number 1 is off duty for a Kelly day on Saturday of week 4, Sunday of week 10, Monday of week 11, Wednesday of week 13, and Tuesday of week 16. The platoon member with off-number 2 is off duty on Sunday of week 1, Wednesday of week 5, Thursday of week 10, Saturday of week 16, Monday of week 19, and so on. The other platoon members are on duty on these days.

Week	Day of Week						
	M	T	W	T	F	S	S
1	D	D	D	D	D	R	(N) ²
2	N	N	N	(N) ³	R	R	A
3	A	A	A	A	R	R	D
4	D	D	D	D	R	(N) ¹	N
5	N	N	(N) ²	R	R	A	A
6	A	A	A	R	R	D	D
7	D	D	D	R	(N) ³	N	N
8	N	(N) ³	R	R	A	A	A
9	A	A	R	R	D	D	D
10	D	D	R	(N) ²	N	N	(N) ¹
11	(N) ¹	R	R	A	A	A	A
12	A	R	R	D	D	D	D
13	D	R	(N) ¹	N	N	N	(N) ³
14	R	R	A	A	A	A	A
15	R	R	D	D	D	D	D
16	R	(N) ¹	N	N	N	(N) ²	R
17	R	A	A	A	A	A	R
18	R	D	D	D	D	D	R
19	(N) ²	N	N	N	(N) ³	R	R
20	A	A	A	A	A	R	R

*Circled entries in the schedule denote Kelly days. Superscripts on these entries denote off numbers associated with the Kelly days.

Figure 7-12

THREE-SHIFT, FOUR-PLATOON SCHEDULE WITH A
20-DAY DUTY CYCLE AND KELLY DAYS*

CHAPTER VIII

DESIGN OF PROPORTIONAL ROTATING WORK SCHEDULES

A. Introduction

This chapter describes methods for designing a special type of rotating work schedule which can provide variable on-duty staffing by shift and day of week. Because on-duty staffing is frequently allocated in proportion to daily workload, these schedules are also called proportional rotating, or simply, PR schedules.

An example of a one-shift PR schedule is shown in Figure 8-1. This schedule consists of six brackets and is used in the following manner. One employee or group of employees is assigned to each bracket. After working the pattern of on- and off-duty days prescribed in that bracket (i.e., after one week), each employee or group rotates down to the next bracket in the schedule. The employee completing bracket six rotates back to bracket one. After six weeks, every employee will have spent exactly one week on each bracket in the schedule. It is important to note that although the employees change brackets every week, the number of employees scheduled to be on duty on each day of the week does not change. For example, in the PR schedule in Figure 8-1, five employees are scheduled to be on duty every Monday and Wednesday, and four employees are scheduled to be on duty on each of the other days of the week.

A multishift PR schedule is illustrated in Figure 8-2. This schedule covers three shifts and consists of 19 brackets.

	M	T	W	T	F	S	S
1	R	R					
2		R	R	R			
3				R	R		
4					R	R	
5						R	R
6							R

Bracket

Figure 8-1

ONE-SHIFT PR SCHEDULE

It is used in the same manner as a one-shift PR schedule; one employee is assigned to each bracket and at the end of each week every employee rotates down to the next bracket (or from bracket 19 to bracket 1). After 19 weeks, each employee has worked in each bracket once and has spent six weeks on the night shift, seven weeks on the afternoon shift, and six weeks on the day shift. Although each employee rotates every week, the number of employees scheduled to be on duty on each day of the week on each shift does not change.

Other properties of proportional rotating work schedules include the following:

- The length of the duty cycle (also termed the schedule rotation period) of a PR schedule is a multiple

Shift		M	T	W	T	F	S	S
Night	1	R	R	R	R			
	2					R	R	R
	3	R						
	4		R	R				
	5				R	R		
	6						R	R
Afternoon	7							R
	8	R	R					
	9			R	R			
	10					R	R	R
	11	R						
	12		R	R	R			
	13					R	R	R
Day	14	R						
	15		R	R	R			
	16						R	R
	17							
	18		R	R	R			
	19					R	R	R

Figure 8-2

NINETEEN-WEEK MULTISHIFT PR SCHEDULE

of the number of employees, or of the number of groups into which the employees are divided.

- The length of the duty cycle always equals a whole number of weeks (i.e., the schedule is locked). With a duty cycle length of several weeks, however, employees usually receive a variety of days off instead of the same days off each week.
- Since employees rotate through all of the schedule brackets, proportional rotating schedules are equitable in terms of the frequency with which employees are on and off duty on each day of the week.
- On- and off-duty periods are usually variable in length.
- Employees can be permanently assigned to one shift, or can periodically rotate from one shift to another.
- When employees rotate shifts, they are assigned to the same shift for a whole number of weeks.
- The same number of employees can be assigned to each shift, or a different number can be assigned to different shifts.
- Holidays can be included in a rotating work schedule as regularly-scheduled off-duty days for agencies which do not close on designated days of the year.

Section B of this chapter briefly discusses the types of schedule constraints and properties that can influence the design of proportional rotating work schedules. Section C summarizes the procedure for allocating personnel among the shifts and days of the week. Section D describes a method for designing one-shift proportional rotating schedules, and Section E presents methods for designing multishift proportional rotating schedules.

B. Identifying Agency Constraints and Schedule Properties

The first step in designing proportional rotating work

schedules is to identify schedule constraints that exist because of legal, contractual, or preference restrictions. Properties of PR schedules that can be explicitly controlled in the design process include the following:

- distribution of on-duty personnel among the shifts and days of the week--typical constraints include minimum staffing requirements, and upper limits on the number of on-duty employees;
- length of work and off-duty periods;
- length of off-duty periods when employees rotate shifts--agencies may require longer off-duty periods between on-duty assignments on different shifts to give employees adequate time to adjust to new working hours; and
- shift rotation sequence and first day of the work week (i.e., the day on which employees rotate shifts and schedule brackets).

For example, an agency may require that at least one employee be on duty on each day of the week, that off-duty periods be from two to four days long, that work periods be from four to seven days long, and that the work week begin on Monday.

C. Allocating Personnel Among the Shifts and Days of the Week

The next step in designing PR schedules is to distribute the employees in the work force among the shifts. Once the number of employees to be assigned to each shift has been determined, the number of staff-days available per week on each shift can be computed using the average number of days each employee works per week and the number of holidays per year for each employee to be included as regularly-scheduled days off duty. The number of staff-days available on each shift is then distributed among the days of the week--usually in proportion to daily workload.

Procedures for allocating employees among the shifts, calculating the number of available staff-days per week, and distributing these among the days of the week are discussed in Chapter IV.

After a distribution of on-duty employees by day of week has been specified, the number of employees scheduled to be off duty on each day of the week can be easily determined with the formula:

$$\left(\begin{array}{c} \text{number of employees} \\ \text{scheduled to be} \\ \text{off duty} \end{array} \right) = \left(\begin{array}{c} \text{number of employees} \\ \text{assigned to shift} \end{array} \right) - \left(\begin{array}{c} \text{number of employees} \\ \text{scheduled to be} \\ \text{on duty} \end{array} \right).$$

The resulting distribution of off-duty employees on each day of the week can be represented using a star diagram. Each ray of the diagram represents a specific day of the week, and each node placed on a ray represents an off-duty day to be scheduled once on that day of the week during the schedule rotation period.

As an example, suppose that an agency has decided to assign four employees to the night shift, and to distribute an average of 19 available staff-days in such a way that there are three employees on duty on Monday, Wednesday, Thursday, Friday, and Saturday, and two employees on duty on Tuesday and Sunday; i.e.,

	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>	<u>Total</u>
On-Duty Employees	3	2	3	3	3	3	2	19
Off-Duty Employees	1	2	1	1	1	1	2	9
Total	4	4	4	4	4	4	4	28

A star diagram representing this daily distribution of off-duty employees is shown in Figure 8-3.

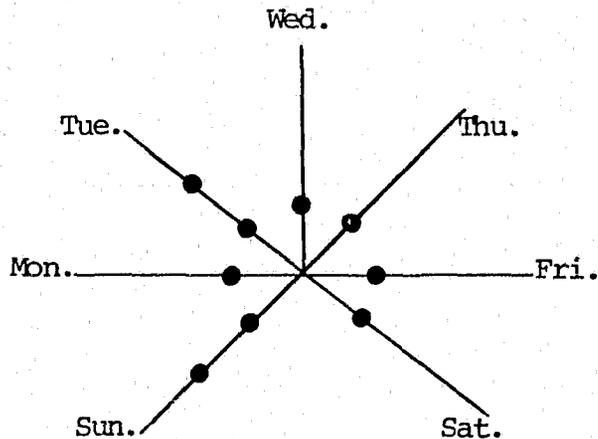


Figure 8-3

STAR DIAGRAM REPRESENTING A DAILY DISTRIBUTION OF
OFF-DUTY EMPLOYEES

D. Designing One-Shift Proportional
Rotating Schedules

This section discusses methods for designing one-shift proportional rotating schedules. Such schedules are used primarily by agencies which (1) assign employees permanently to a shift for an entire schedule design interval, (2) want to vary the number of on-duty employees by day of week (e.g., in proportion to agency workload), or (3) do not want employees to have the same days off duty each week (i.e., agencies that cannot use a fixed bracket schedule).

Steps in the schedule design process include the following:

- Step 1: Identify the number and lengths of each off-duty period;
- Step 2: Assign each off-duty period to a specific set of consecutive days of the week;

- Step 3: Identify acceptable sequences of the off-duty periods (i.e., ways of scheduling the off-duty periods so that the work periods between successive off-duty periods have acceptable lengths);
- Step 4: Select one sequence of work and off-duty periods from the collection of acceptable sequences identified in the previous step; and
- Step 5: Construct the pattern of on- and off-duty assignments used during the rotation period.

Each of these steps is described below.

Identifying the Number and Lengths of Off-Duty Periods to be Scheduled

Assume that a total of nine off-duty days are to be scheduled during a four-week rotation period. One alternative would be to schedule all nine off-duty days as a single off-duty period. If this was done, the four-week schedule would consist of nine consecutive off-duty days followed by 19 consecutive on-duty days.

At the other extreme, each off-duty day could be scheduled as a one-day off-duty period. This would require that the 19 on-duty days be divided into nine work periods.

Obviously, neither alternative would be acceptable. In terms of the constraints identified in Section B, neither satisfies the requirement that off-duty periods be between two and four days in length. As illustrated in Figure 8-4, however, there are many other alternative groupings of nine off-duty days. Each alternative is called a partitioning of the off-duty days into off-duty periods. Acceptable partitionings (i.e., those for which no off-duty period is longer than four days or shorter than two days) are identified with an asterisk in Figure 8-4.

Number of Off-Duty Periods	Alternative Partitionings	Number of Off-Duty Periods	Alternative Partitionings
9	1,1,1,1,1,1,1,1,1	3	7,1,1
8	2,1,1,1,1,1,1,1		6,2,1
7	3,1,1,1,1,1,1		5,3,1
	2,2,1,1,1,1,1		4,4,1
			5,2,2
			4,3,2*
			3,3,3*
6	4,1,1,1,1,1		
	3,2,1,1,1,1	2	8,1
	2,2,2,1,1,1		7,2
			6,3
			5,4
5	5,1,1,1,1		
	4,2,1,1,1	1	9
	3,3,1,1,1		
	3,2,2,1,1		
	2,2,2,2,1		
4	6,1,1,1		
	5,2,1,1		
	4,3,1,1		
	4,2,2,1		
	3,3,2,1		
	3,2,2,2*		

*Acceptable partitionings--all off-duty periods are between two and four days in length.

Figure 8-4

ALTERNATIVE PARTITIONINGS OF NINE OFF-DUTY DAYS
INTO OFF-DUTY PERIODS

It is important to note that the sum of the off-duty period lengths in each partition must equal the total number of off-duty days to be included in the schedule (i.e., the partition 4,3,2 consists of three off-duty periods, and the sum of the period lengths is nine--the number of off-duty days being scheduled). In reality, enumeration of all possible partitions by hand becomes increasingly difficult as the total number of off-duty days increases. For example, there are 30 ways to partition nine off-duty days into off-duty periods, 224 ways to partition 15 off-duty days, and more than 500 ways to partition 20 off-duty days. For this reason, Step 1 is usually done by simply identifying one or more acceptable partitionings of the off-duty days, rather than enumerating every possibility to find the "best" partition.

A simple way to find partitions of the off-duty days is to use the upper and lower limits placed on the length of off-duty periods and the requirement that the off-duty period lengths sum to the total number of off-duty days to be scheduled. For example, if nine off-duty days are to be scheduled and all off-duty periods must be either two, three, or four days in length, the constraints on acceptable partitions can be summarized as follows:

$$2 \times \left(\begin{array}{c} \text{number of} \\ \text{2-day off-duty} \\ \text{periods} \end{array} \right) + 3 \times \left(\begin{array}{c} \text{number of} \\ \text{3-day off-duty} \\ \text{periods} \end{array} \right) + 4 \times \left(\begin{array}{c} \text{number of} \\ \text{4-day off-duty} \\ \text{periods} \end{array} \right) = 9$$

By selecting various combinations of whole numbers of 2-, 3-, and 4-day off-duty periods, several partitions can be found quite quickly. Some sample calculations are illustrated in Figure 8-5.

<u>Number of 4-Day Off-Duty Periods</u>	<u>Number of 3-Day Off-Duty Periods</u>	<u>Number of 2-Day Off-Duty Periods</u>	<u>Sum of Off-Duty Period Lengths</u>	<u>Acceptable Partitionings</u>
2	0	0	8	
2	0	1	10	
2	0	2	12	
2	1	0	11	
1	0	0	4	
1	0	1	6	
1	0	2	8	
1	0	3	10	
1	1	0	7	
1	1	1	9	4, 3, 2
1	2	0	10	
0	0	0	0	
0	0	1	2	
0	0	2	4	
0	0	3	6	
0	0	4	8	
0	0	5	10	
0	1	0	3	
0	1	1	5	
0	1	2	7	
0	1	3	9	3, 2, 2, 2
0	2	0	6	
0	2	1	8	
0	2	2	10	
0	3	0	9	3, 3, 3

Figure 8-5

DETERMINING ACCEPTABLE PARTITIONINGS OF NINE DAYS
INTO TWO-, THREE-, AND FOUR-DAY OFF-DUTY PERIODS

When, as in Figure 8-5, several acceptable partitionings are found, each can be used to design one-shift PR schedules. Factors to consider in selecting which partitions of the off-duty days may yield the most desirable schedules include the following:

- uniformity of off-duty period lengths--there may be a preference among employees and management for off-duty periods that are uniform in length (e.g., three three-day off-duty periods rather than one two-day, one three-day and one four-day off-duty period);
- acceptability of resulting work period lengths--if too few off-duty periods are scheduled, unacceptably long work periods may be required (e.g., if only three off-duty periods are scheduled in the example, at least one work period must be seven or more days in length); and
- realization of the required personnel distribution--it may not be possible to associate the off-duty periods in the selected partitioning with consecutive days of the week (see below) in such a way that the desired personnel allocation is achieved.

Associating Off-Duty Periods with Off-Duty Days on Consecutive Days of the Week

The next step in designing PR schedules is to determine which days of the week to include in each off-duty period. That is, should a 3-day off-duty period be scheduled for Monday, Tuesday, and Wednesday, for Friday, Saturday, and Sunday, or for some other period of three consecutive days?

A convenient aid in associating off-duty periods with days of the week and ensuring that the desired distribution of on- and off-duty employees is achieved is the star diagram. Each ray of the diagram represents a specific day of the week, and each node placed on a ray represents an off-duty day to be scheduled once on that day of the week during the schedule

rotation period. Thus, the star diagram shown in Figure 8-3 specifies that during the rotation period, two off-duty days are to be scheduled on Tuesday and Sunday and one off-duty day is to be scheduled on Monday, Wednesday, Thursday, Friday, and Saturday.

Two-day off-duty periods are designated on a star diagram by drawing lines to connect nodes on adjacent rays. Similarly, three-day off-duty periods are designated by connecting nodes on three consecutive rays. Each resulting line represents an off-duty period that includes the days of the week that correspond to the connected rays. One-day off-duty periods are indicated by nodes that are not connected to nodes on either of the adjacent rays. For example, the star diagram shown in Figure 8-6 contains a two-day off-duty period beginning on Saturday and ending on

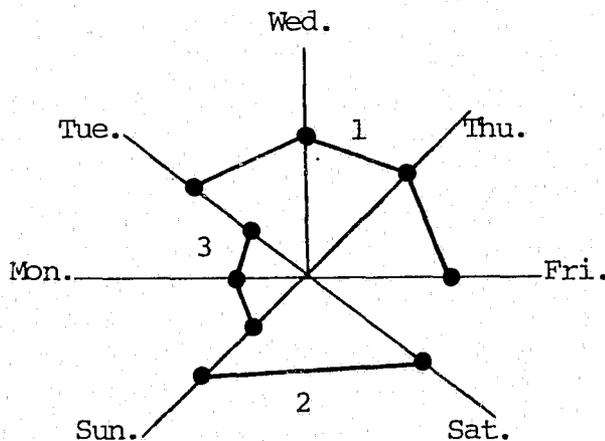


Figure 8-6

STAR DIAGRAM REPRESENTING THREE OFF-DUTY PERIODS

Sunday, a three-day off-duty period beginning on Sunday and ending on Tuesday, and a four-day off-duty period beginning on Tuesday and ending on Friday. No one-day off-duty periods are included.

The following rules of thumb can be used to simplify the process of designating off-duty periods on a star diagram:

- If the number of nodes on a ray exceeds the number of nodes on the preceding ray by some number n , then at least n off-duty periods must begin on that ray. For example, since there are two nodes on the ray representing Tuesday in Figure 8-6 and only one node on the ray representing Monday, at least one off-duty period must begin on Tuesday. Similarly, at least one off-duty period must begin on Sunday.
- If the number of nodes on a ray exceeds the number of nodes on the next ray by some number n , then at least n off-duty periods must end on that ray. In Figure 8-6, for example, at least one off-duty period must end on Tuesday, and at least one off-duty period must end on Sunday.
- If weekend off-duty periods are desirable, then they should be constructed first to ensure that they are included in the schedule.

In addition, the following rules must be observed in designating off-duty periods by connecting nodes on a star diagram:

- only nodes on adjacent rays may be connected (i.e., only consecutive days of the week can be included in a single off-duty period);
- a node may not be included in more than one off-duty period;
- a node may be left unconnected only if one-day off-duty periods are permitted; and
- the numbers of one-day periods, two-day periods, etc., designated on the star diagram must agree exactly with the numbers specified in the partition of off-duty days being used.

In some cases, it may not be possible to connect the nodes on a star diagram in such a way that these requirements are met.

For example, Figure 8-7 contains a star diagram for which one two-day off-duty period, one three-day off-duty period, and one four-day off-duty period cannot be designated. In such cases, a different partition of the off-duty days must be selected, or the specified personnel allocation must be altered. The results of applying these two approaches are illustrated in figures 8-8 and 8-9.

On the other hand, it may be possible to connect the nodes on a star diagram in several different ways which meet all of the above requirements. For example, Figure 8-10 contains two alternative ways of designating one two-day off-duty period, one three-day off-duty period, and one four-day off-duty period on the star diagram shown in Figure 8-3.

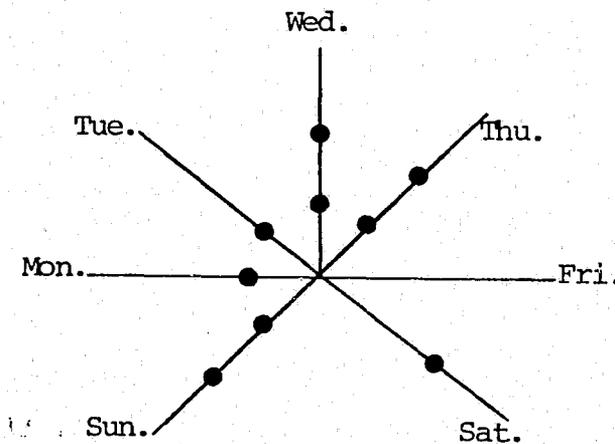


Figure 8-7

STAR DIAGRAM REPRESENTING A DISTRIBUTION OF OFF-DUTY DAYS FOR WHICH EXACTLY ONE TWO-DAY OFF-DUTY PERIOD, ONE THREE-DAY OFF-DUTY PERIOD, AND ONE FOUR-DAY OFF-DUTY PERIOD CANNOT BE DESIGNATED

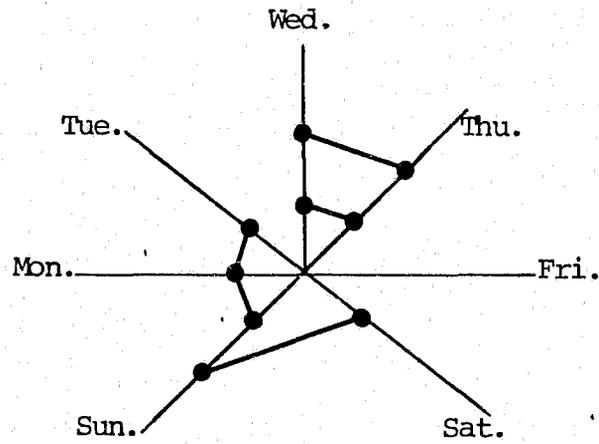


Figure 8-8

USE OF A DIFFERENT PARTITIONING OF OFF-DUTY DAYS TO
ACHIEVE A SPECIFIED DISTRIBUTION OF OFF-DUTY DAYS

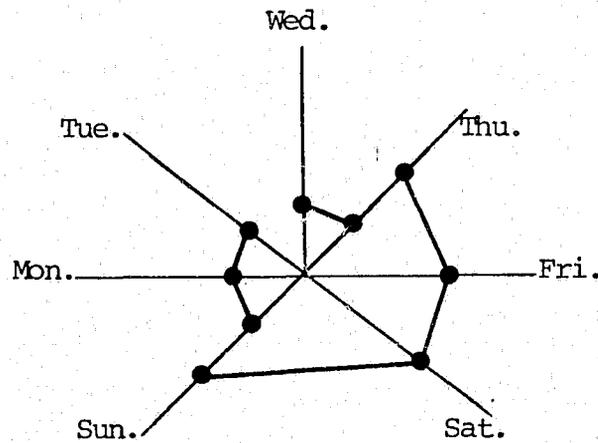


Figure 8-9

USE OF A DIFFERENT DISTRIBUTION OF OFF-DUTY DAYS TO
ACHIEVE A SPECIFIED PARTITIONING OF OFF-DUTY DAYS

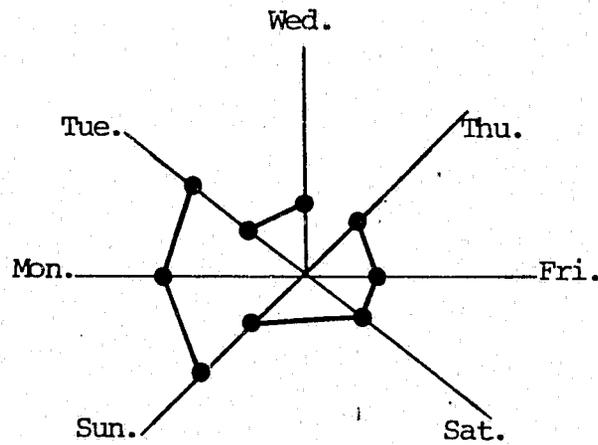
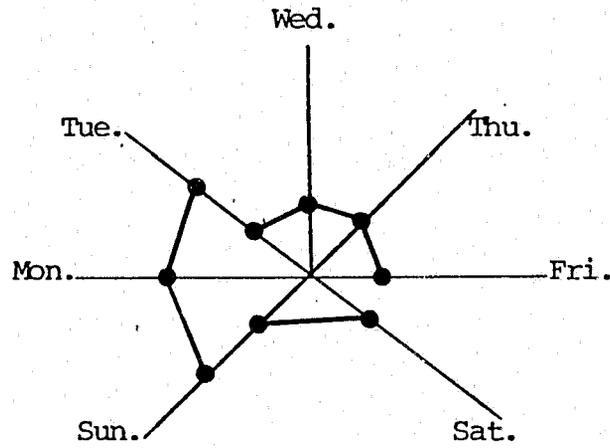


Figure 8-10

ALTERNATIVE DESIGNATIONS OF ONE TWO-DAY, ONE
 THREE-DAY, AND ONE FOUR-DAY OFF-DUTY PERIOD
 TO ACHIEVE A SPECIFIED PERSONNEL ALLOCATION

Identifying Acceptable Sequences of Off-Duty Periods

The final steps in designing one-shift PR schedules are (1) to identify acceptable sequences in which to schedule the designated off-duty periods, and (2) to select the sequence which provides the "best" schedule properties.

A sequence of off-duty periods refers to the order in which the off-duty periods are encountered in a schedule. For example, the sequence 1-2-3-4 denotes a schedule in which off-duty period 1 is followed by period 2 (after some number of on-duty days). Period 2 is then followed by period 3, which is followed, in turn, by period 4. Period 4 is followed by period 1 and the sequence repeats for the duration of the schedule design interval. There are several other sequences which can be used to schedule four off-duty periods. In fact, as the number of off-duty periods increases, the number of alternative sequences becomes very large (e.g., while there are only six alternative sequences of four off-duty periods, there are over 5,000 possible sequences of eight off-duty periods). A schematic representation of all alternative sequences of four off-duty periods--termed an off-duty tree--is illustrated in Figure 8-11. Each circle in the figure represents one off-duty period, and each path from the circle representing period 1 at the top of the tree* to one of the circles in the bottom row of the tree represents a different sequence of the off-duty periods (e.g., the sequence 1-2-3-4 is

*Note that, because of the cyclic nature of one-shift rotating schedules, all sequences represented can begin with period 1; that is, schedule properties depend on the order in which the periods are scheduled, and not on which period is scheduled first. Since each off-duty period appears exactly once during the schedule rotation period, the sequences 1-2-3-4 and 4-1-2-3, for example, produce the same schedule, and are considered identical.

CONTINUED

3 OF 5

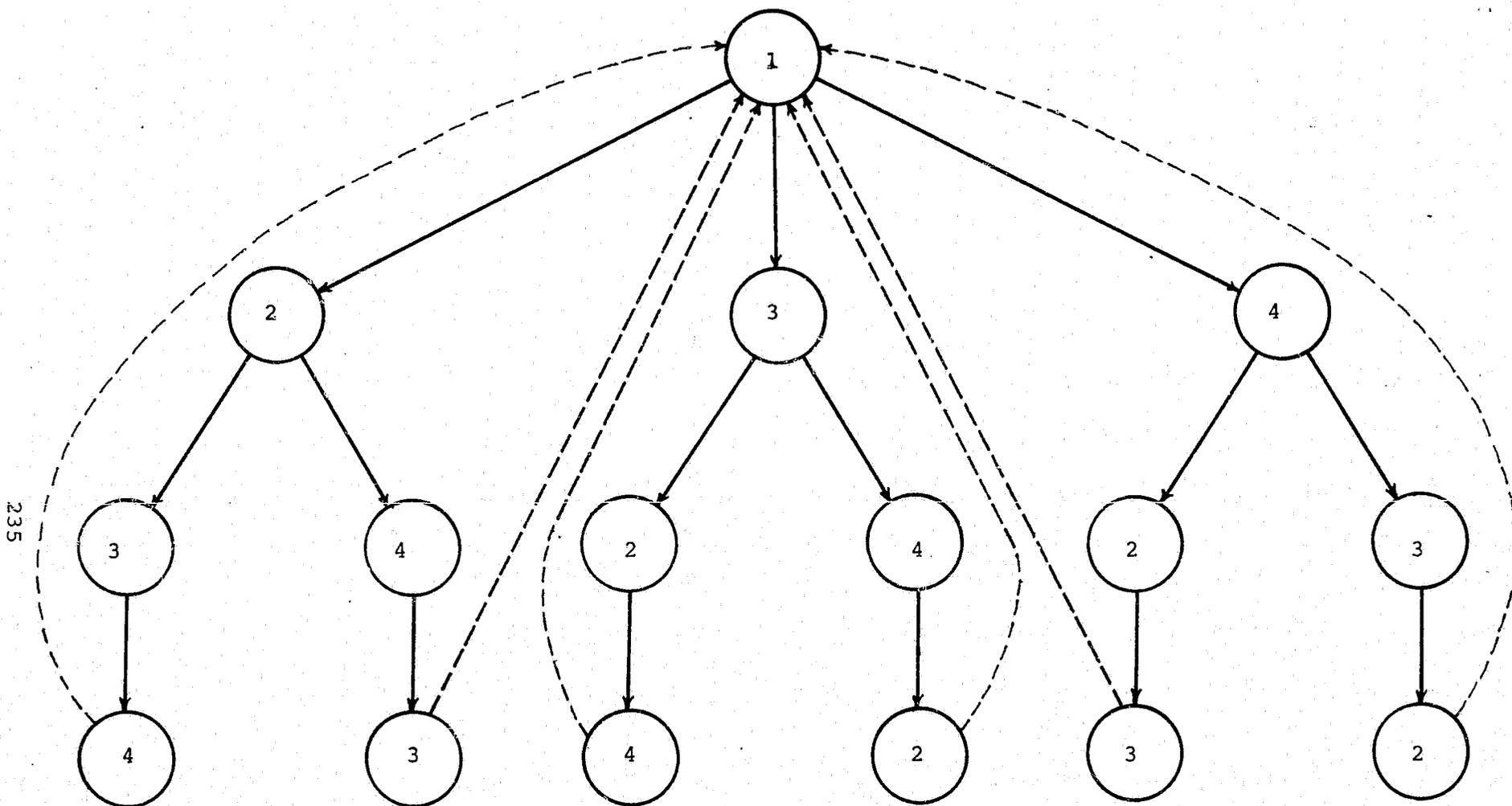


Figure 8-11

OFF-DUTY TREE REPRESENTING ALTERNATIVE SEQUENCES
IN WHICH TO SCHEDULE FOUR OFF-DUTY PERIODS

represented by the leftmost path in the tree). The dashed lines in the off-duty tree indicate that after the last off-duty period is encountered, the sequence is repeated.

An off-duty tree can be constructed for other numbers of off-duty periods as follows:

- A single circle is drawn in the top row of the tree, and a number used to identify which off-duty period is assigned to it.
- One circle is drawn in the second row of the tree for each of the other off-duty periods. A line is drawn connecting the circle in the top row with each circle in the second row.
- The third and subsequent rows in the tree are constructed by drawing a circle under each circle in the preceding row for each off-duty period that does not appear in the path to that circle, and lines are drawn from that circle to the new circles below it.

The number of rows in the tree equals the total number of off-duty periods being scheduled.

Once the off-duty tree has been constructed, the number of on-duty days separating the end of one off-duty period and the beginning of the next can be computed. This number can be noted in the tree on the line connecting the two circles (off-duty periods) that are separated. The number of on-duty days between two off-duty periods is determined by counting the number of rays in a star diagram between the ray on which the first off-duty period ends and the ray on which the second off-duty period begins. Since the number of on-duty days must be greater than zero, the number of days between an off-duty period that ends on Friday and a period that begins on Saturday, for example, is recorded as seven days long rather than zero days. These work period lengths are used to identify acceptable sequences of

off-duty days. Figure 8-12 contains an off-duty tree for the three off-duty periods shown in Figure 8-6.

In order for a sequence of off-duty periods to be acceptable, the following conditions must be met:

- each off-duty period must appear exactly once in the sequence;
- the sum of the work period lengths must equal the total number of on-duty days to be scheduled in a rotation period (e.g., in the example cited above, the work period lengths must sum to 19); and
- the lengths of the work periods between successive off-duty periods must satisfy agency constraints (e.g., in the example cited above, all work periods must be between four and seven days in length).

If an off-duty tree has been properly constructed, all sequences generated will meet the first condition.

The work period lengths associated with a sequence of off-duty periods are simply the numbers beside the lines in the off-duty tree. By adding these numbers for a path from the first period through the last period and back to the first period, the sum of the work period lengths can be computed for each sequence and compared to the number of on-duty days being scheduled. For the leftmost path in Figure 8-12, this sum is 19 (7+6+6) and for the rightmost path, the sum is five (1+3+1). Therefore, the sequence 1-2-3 satisfies the second condition and the sequence 1-3-2 does not. Note, however, that periods 1 and 3 could also be placed in the rotation period in such a way that they would be separated by eight consecutive on-duty days (i.e., one day plus one week). Similarly, periods 2 and 1 could be separated by an eight-day work period. If these two changes were both made, the sum of the work period lengths for the

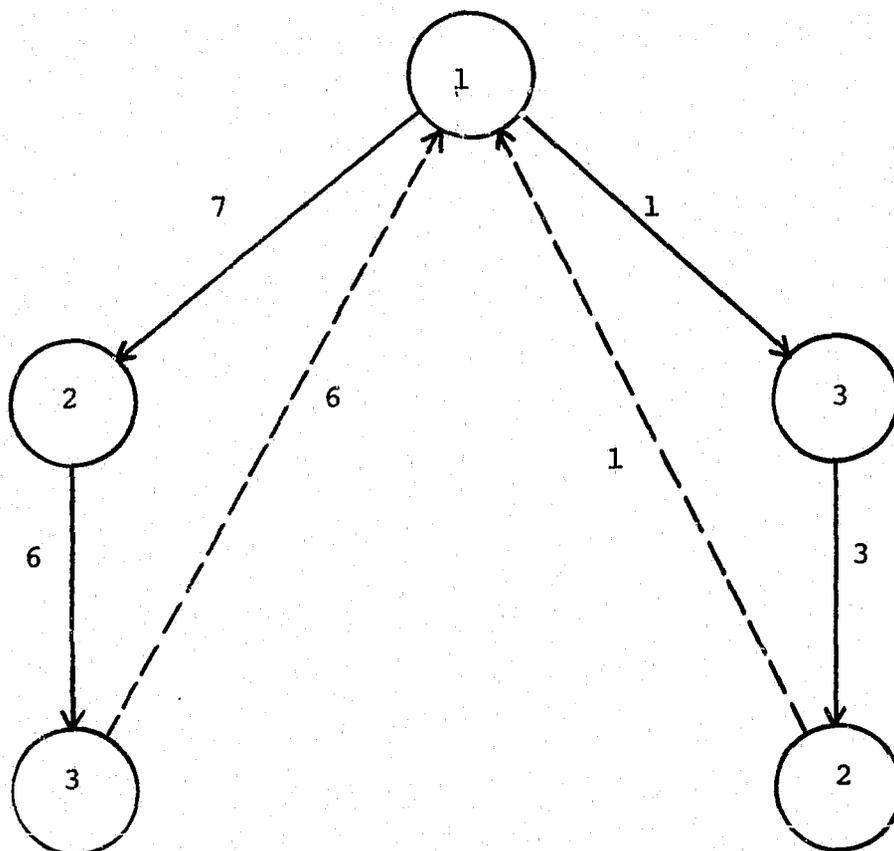


Figure 8-12

OFF-DUTY TREE FOR THE OFF-DUTY PERIODS
SHOWN IN FIGURE 8-6

sequence 1-3-2 would also be 19 (8+3+8), and the sequence would then satisfy the second condition.

The final condition is met for a sequence if all numbers beside the lines in the path for that sequence are within the agency's limits on work period lengths. Since these numbers for the leftmost path are all between four and seven, the sequence 1-2-3 satisfies the third condition. Since the modified work period lengths for the rightmost path (eight, three, and eight) are not between four and seven days, the sequence 1-3-2 does not satisfy the third condition and is, therefore, unacceptable.

This same procedure can be used to analyze other sets of off-duty periods. When the number of off-duty periods exceeds four or five, however, the procedure becomes time-consuming because the corresponding off-duty tree becomes very large. For this reason, an alternate way of representing the information in the off-duty tree is used.

Figure 8-13 illustrates a tabular way of summarizing the work period lengths associated with alternative sequences of off-duty periods. Each entry of the table--termed a separation table--specifies the smallest number of on-duty days between the final day of the off-duty period corresponding to the row of the table in which the entry appears, and the first day of the off-duty period corresponding to the column in which the entry appears. For example, the entry in row 1 and column 2 indicates that seven on-duty days must separate off-duty period 1 which ends on Friday (see Figure 8-6) and off-duty period 2 which begins on Saturday. Similarly, the entry in row 3 and column 2 indicates that three on-duty days separate the end of

		Next Period in Sequence		
		1	2	3
Initial Period	1	-	7	1
	2	1	-	6
	3	6	3	-

Figure 8-13

SEPARATION TABLE SHOWING NUMBER OF WORK DAYS
BETWEEN PAIRS OF OFF-DUTY PERIODS

off-duty period 3 and the start of period 2. Entries along the diagonal of the separation table are omitted since an off-duty period cannot follow itself in any acceptable sequence of the off-duty periods.

Limits on the acceptable lengths of work periods can be used to modify entries in the separation table as follows:

- Seven can be added to any entry in the table that is less than the length of the shortest acceptable work period (i.e., increase the length of short work periods by one week). For example, see Figure 8-14.
- Any entry that is greater than the length of the longest acceptable work period can be removed; this indicates that the off-duty period corresponding to that row in the table cannot be followed by the off-duty period corresponding to that entry's column in the table (see Figure 8-15).

A sequence of the off-duty periods is constructed from the separation table as modified by the rules above by placing a

	1	2	3
1	-	7	8
2	8	-	6
3	6	10	-

Figure 8-14

SEPARATION TABLE MODIFIED USING SHORTEST
ACCEPTABLE WORK PERIOD LENGTH

	1	2	3
1	-	7	-
2	-	-	6
3	6	-	-

Figure 8-15

SEPARATION TABLE MODIFIED USING LONGEST
ACCEPTABLE WORK PERIOD LENGTH

circle around one numeric entry in each row to indicate that the off-duty period corresponding to that row is followed by the off-duty period that corresponds to the column in which the circled entry appears. Most sequences are acceptable if the following conditions are met:*

- one and only one circle is placed in each column of the table; and
- the sum of the circled entries equals the total number of on-duty days to be scheduled in a rotation period.

If these conditions cannot be met with any placement of the circles in the separation table, then no acceptable sequence of the off-duty periods exists. In this case, agency constraints on work period lengths must be relaxed, or an alternative set of off-duty periods must be constructed.

It may be possible to identify several alternative placements of the circles within the table which meet both of the conditions cited above. In this case, several acceptable sequences of the off-duty periods can be constructed. Figure 8-16 illustrates the only placement of circles within the modified separation table in Figure 8-16 which meets all conditions.

The sequence of off-duty periods is constructed from the placement of the circled entries in a table like the one shown in Figure 8-16 as follows:

- Arbitrarily select one of the off-duty periods, say period 1, to be the first in the sequence.
- Determine the next period in the sequence by locating the circled entry in the row corresponding to period 1. The off-duty period corresponding to the column

*An exception is noted below in the discussion of how to construct the sequence of off-duty periods from the circled entries in the separation table.

	1	2	3
1	-	⑦	-
2	-	-	⑥
3	⑥	-	-

Figure 8-16

PLACEMENT OF CIRCLED ENTRIES IN A MODIFIED SEPARATION TABLE TO INDICATE AN ACCEPTABLE SEQUENCE OF OFF-DUTY PERIODS

of that entry is the second period in the sequence. In the case of the example above, this is period 2.

- Move to the row corresponding to the last period identified (i.e., row 2) and determine the next off-duty period in the sequence.
- Continue this procedure until the first off-duty period in the sequence is encountered a second time.

If all off-duty periods are included in the sequence constructed using this procedure, the sequence can be used to construct a one-shift PR schedule (e.g., the sequence 1-2-3 is an acceptable sequence for the sample design problem). If all of the periods have not been included, then the circled entries have been placed in the separation table in such a way that the off-duty periods are divided among two or more shorter sequences which never overlap. (For example, the circled entries in the separation table shown in Figure 8-17 form the two sequences 1-4-3 and 2-5.)

	1	2	3	4	5
1	-	-	8	⑥	-
2	6	-	-	8	⑤
3	⑦	6	-	-	6
4	-	8	⑥	-	8
5	5	④	-	7	-

Figure 8-17

PLACEMENT OF CIRCLED ENTRIES IN A MODIFIED SEPARATION
TABLE WHICH PRODUCES AN UNACCEPTABLE SEQUENCE
OF OFF-DUTY PERIODS

Such sequences are not acceptable and a different placement of the circled entries must be considered.

Constructing the Pattern of On- and Off-Duty Assignments to be Used in a Rotation Period

Once an acceptable sequence of the off-duty periods has been identified, all of the information needed to construct the pattern of on- and off-duty days for the rotation period is contained in the star diagram, such as the one shown in Figure 8-6, and the modified separation table, such as the one shown in Figure 8-16. This information is used to construct a bracket representation (see Chapter III) of the PR schedule as follows:

- A blank calendar having one row for each week in the rotation period* and one column for each day of the week--beginning with the first day of the work week--is constructed (see Figure 8-18(a)).

*Recall that the number of weeks in the rotation period equals the number of groups of employees being scheduled.

(a)

Week

	M	T	W	T	F	S	S
1							
2							
3							
4							

(b)

Week

	M	T	W	T	F	S	S
1		R	R	R	R		
2							
3							
4							

(c)

Week

	M	T	W	T	F	S	S
1		R	R	R	R		
2						R	R
3							R
4	R	R					

Figure 8-18

CONSTRUCTION OF A CALENDAR SHOWING OFF-DUTY
DAYS DURING A ROTATION PERIOD

- Days of the week included in the first off-duty period of the sequence are identified by referring to the star diagram (e.g., period 1 included the days Tuesday through Friday). The first day of this period is located in the first week of the rotation period. An "R" is entered in the calendar at this point to indicate an off-duty day. An "R" is similarly entered for subsequent days included in the first off-duty period. If the end of the first week is reached before all off-duty days in the period have been entered, the remaining off-duty days are entered in the next week of the rotation period (see Figure 8-18(b)).
- The number of on-duty days following the first off-duty period is given by the circled entry in the corresponding row of the separation table (i.e., seven days in the example). This number of days are skipped before indicating the days included in the second off-duty period. As before, whenever the end of a week is reached, continue skipping days or indicating off-duty days in the next week of the rotation period. If the end of the last week of the rotation period is reached, return to week 1.
- Continue entering off-duty days in the calendar in this way for the remaining off-duty periods. The result for the example is shown in Figure 8-18(c).
- After all of the off-duty days have been entered in the calendar, the remaining days are on-duty days. The calendar is completed by entering a "W" or some other symbol (e.g., "N" to indicate the night shift) for these days.

The completed calendar for the PR schedule in the example is shown in Figure 8-19.

To implement the resulting PR schedule, a different employee or group of employees is assigned to the pattern of assignments in each week of the schedule. At the end of the first week, each employee rotates to the next week in the rotation period and works the pattern of assignments shown for that week. The employee previously working the pattern for the last week in the rotation period rotates to the first week.

	M	T	W	T	F	S	S
1	W	R	R	R	R	W	W
2	W	W	W	W	W	R	R
3	W	W	W	W	W	W	R
4	R	R	W	W	W	W	W

Figure 8-19

CALENDAR SHOWING ON-DUTY AND OFF-DUTY ASSIGNMENTS
FOR EACH DAY OF THE ROTATION PERIOD

For example, the employee assigned to week 1 in the schedule in Figure 8-19 will be on duty Monday, Saturday, and Sunday, while the employee assigned to week 2 will be on duty on Monday through Friday. During the next week, the first employee will be on duty Monday through Friday, and the second employee will be on duty Monday through Saturday.

When designed and implemented in the way described, the resulting PR schedule satisfies all constraints identified in Section B (i.e., all off-duty periods are between two and four days long, all work periods are between four and seven days long, and the work week begins on Monday), and provides the required daily distribution of on-duty employees specified in Section C.

E. Designing Multishift Proportional Rotating Schedules

This section describes two methods for designing multishift

proportional rotating work schedules. Such schedules are used by agencies which (1) operate two or more shifts per day, (2) vary the number of on-duty employees by day of week on each shift, and (3) periodically rotate employee shift assignments. The first method uses the procedures described in Section D to design an acceptable one-shift PR schedule for each shift. These schedules are then combined to form multishift schedules by (1) identifying a sequence in which employees are to rotate through the shifts, (2) specifying a first and last week in each one-shift schedule, and (3) requiring employees to rotate from the last week in each one-shift schedule to the first week in the next one-shift schedule in the rotation sequence.

One advantage of this method is the fact that it does not require significantly greater effort than would be required to design a series of one-shift PR schedules. This advantage is lessened, however, by the fact that the resulting multishift schedules are often unsatisfactory in terms of shift change properties such as the number of hours off duty between shift assignments, the lengths of off-duty periods at shift changes, and the lengths of work periods that precede and follow shift changes. The second design method described below attempts to eliminate such undesirable properties by explicitly considering shift change properties in the design of PR schedules for each shift.

Designing Multishift PR Schedules by Combining One-Shift Schedules

Suppose that an agency with 10 employees operates three shifts daily, with four employees assigned to the day shift, and three employees assigned to the afternoon and night shifts. The

three one-shift schedules to be designed for this agency are shown schematically in Figure 8-20 where D1, D2, D3, and D4 represent the four one-week brackets in the schedule for the day shift, and A1 through A3 and N1 through N3 represent one-week brackets in the schedules for the afternoon and night shifts, respectively. Figure 8-21 schematically illustrates how a three-shift PR schedule could be constructed by combining the three one-shift schedules shown in Figure 8-20. In the schedule shown in Figure 8-21, employees rotate through the brackets in the following order:

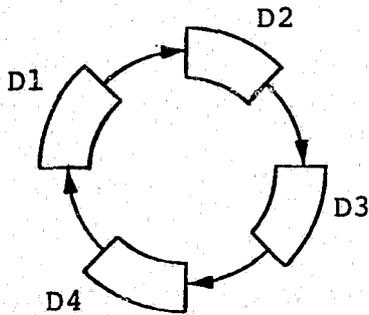
D1-D2-D3-D4-A1-A2-A3-N1-N2-N3.

After working bracket N3, each employee rotates to bracket D1. Other three-shift schedules can be constructed by breaking the one-shift schedules between different brackets (e.g., between brackets D1 and D2 instead of between brackets D4 and D1), and by changing the shift rotation sequence (e.g., from D-A-N to D-N-A). Two schedules obtained in this way are illustrated in figures 8-22 and 8-23.

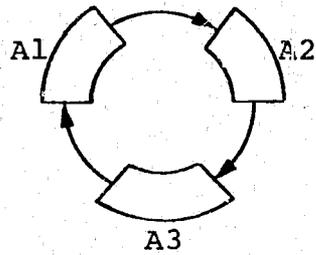
The total number of multishift schedules that can be constructed depends on the number of shifts and the number of weeks in the schedules for each shift. As an example, a total of 72 distinct multishift schedules can be constructed from the three one-shift schedules shown in Figure 8-20. Many of these multishift schedules, however, will be unacceptable for one or more of the following reasons:

- employees may be required to work consecutive days on different shifts, causing a short shift change-over (i.e., less than 16 hours off duty between

Day Shift



Afternoon Shift



Night Shift

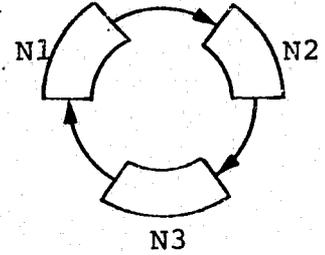


Figure 8-20

SCHEMATIC REPRESENTATION OF THREE ONE-SHIFT PR SCHEDULES

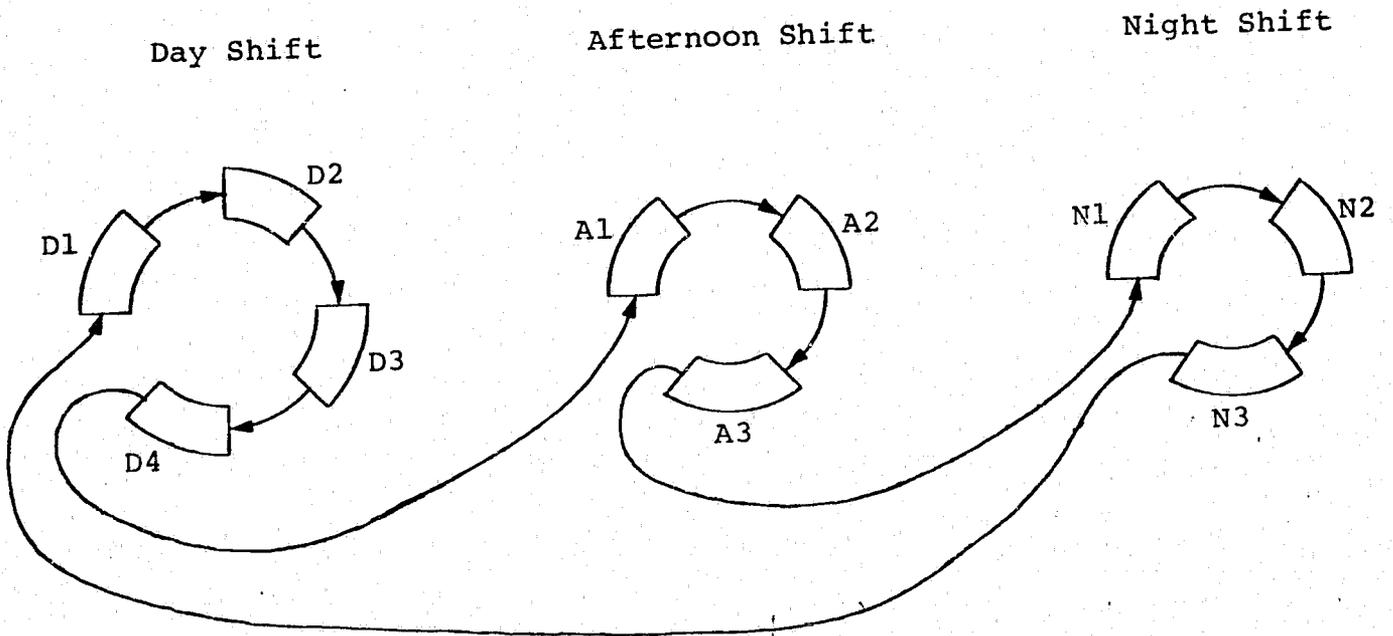


Figure 8-21

SCHEMATIC REPRESENTATION OF A THREE-SHIFT PR SCHEDULE
 CONSTRUCTED FROM THE THREE ONE-SHIFT SCHEDULES IN FIGURE 8-20.

Day Shift

Afternoon Shift

Night Shift

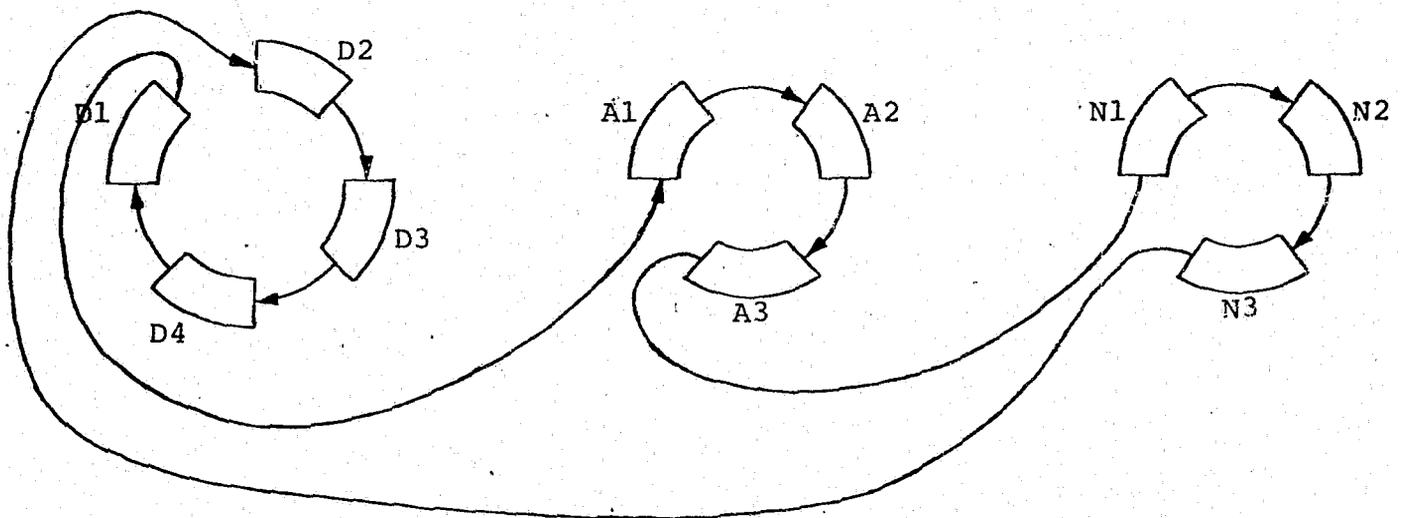


Figure 8-22

THREE-SHIFT PR SCHEDULE IN WHICH EMPLOYEES
ROTATE THROUGH THE BRACKETS IN THE ORDER
D2-D3-D4-D1-A1-A2-A3-N1-N2-N3

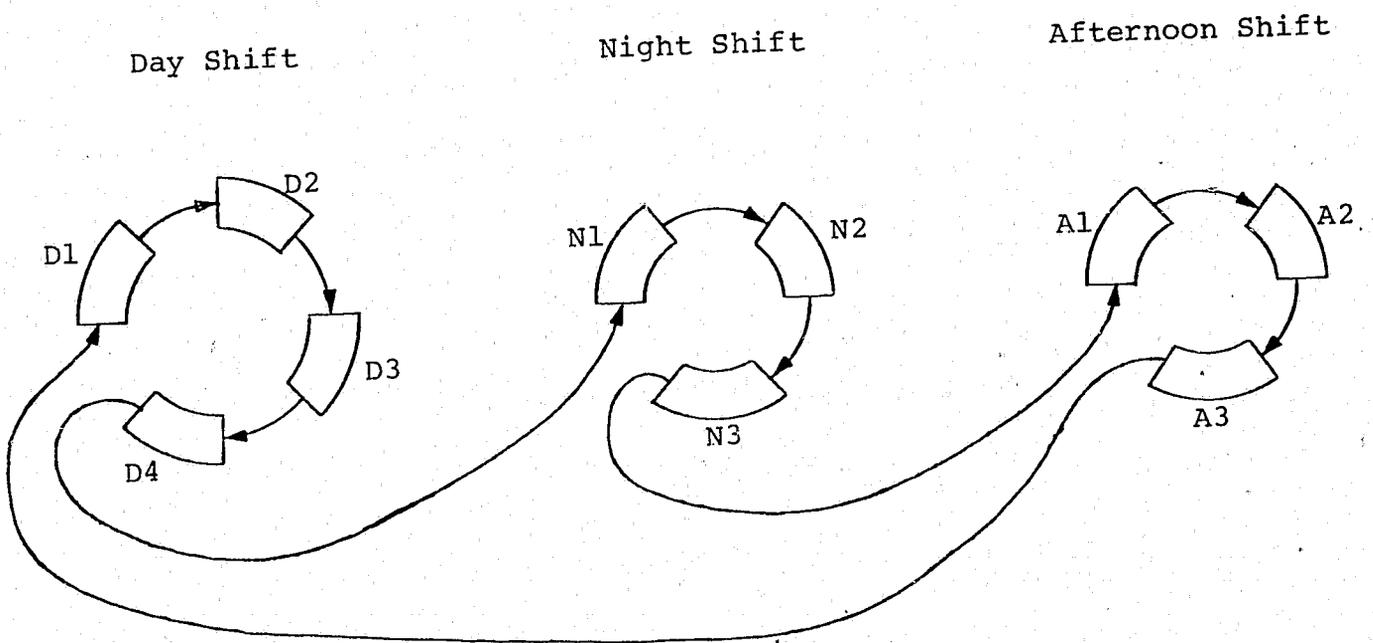


Figure 8-23

THREE-SHIFT PR SCHEDULE IN WHICH EMPLOYEES
 ROTATE THROUGH THE BRACKETS IN THE ORDER
 D1-D2-D3-D4-N1-N2-N3-A1-A2-A3

work assignments--see Chapter III);

- the lengths of changeover off-duty periods* may not satisfy agency constraints and objectives (see Section B); or
- the lengths of the work periods preceding or following a shift change may be unacceptably short.

For example, suppose that the one-shift PR schedules shown in figures 8-1 and 8-19 are combined to form the two-shift schedule shown in Figure 8-24. In this schedule, an employee rotating from bracket D6 to bracket A1 will work six consecutive days on the day shift, will be off duty for one day, will return to work for one day on the afternoon shift, and then be off duty again for the next four days. In contrast, the schedule properties that result in rotating from bracket A4 to bracket D1 are quite satisfactory (i.e., a five-day work period before the change, two days off at the changeover, and a six-day work period after the change).

Shift change properties (i.e., the lengths of on and off-duty periods before, during, and after the shift change) can be determined by using a chart which contains the lengths of the on- and off-duty periods at the beginning of the first bracket and at the end of the last bracket of each one-shift schedule. Such a chart for the schedule in Figure 8-24 is shown in Figure 8-25. The first line of the chart indicates that bracket D1 starts with a work period of length zero and an off-duty period that is two days long. (Note that either the work period or the

*Note that a schedule may provide adequate hours at a shift change without meeting minimal requirements for changeover off-duty periods. For example, an employee who rotates from a mid-night to 8:00 a.m. shift to a 4:00 p.m. to midnight shift is off duty for 32 hours, but actually works on consecutive calendar days.

Day of Week

	M	T	W	T	F	S	S
D1	R	R	D	D	D	D	D
D2	D	R	R	R	D	D	D
D3	D	D	D	R	R	D	D
D4	D	D	D	D	R	R	D
D5	D	D	D	D	D	R	R
D6	D	D	D	D	D	D	R
A1	A	R	R	R	R	A	A
A2	A	A	A	A	A	R	R
A3	A	A	A	A	A	A	R
A4	R	R	A	A	A	A	A

Bracket

Figure 8-24

TWO-SHIFT PR SCHEDULE CONSTRUCTED BY
COMBINING THE ONE-SHIFT SCHEDULES SHOWN IN
FIGURES 8-1 AND 8-19

Bracket	Day of Week							Start of Bracket		End of Bracket	
	M	T	W	T	F	S	S	Length of Work Period	Length of Off-Duty Period	Length of Work Period	Length of Off-Duty Period
	D1	R	R	D	D	D	D	D	0	2	-
D6	D	D	D	D	D	D	R	-	-	0	1
A1	A	R	R	R	R	A	A	1	0	-	-
A4	R	R	A	A	A	A	A	-	-	5	0

Figure 8-25

CHART USED TO ANALYZE SHIFT CHANGE PROPERTIES
IN THE TWO-SHIFT PR SCHEDULE IN FIGURE 8-24

off-duty period at the start of a bracket must be zero days in length.) Similarly, the last line in the chart indicates that bracket A4 ends with a five-day work period and a zero-day off-duty period. The length of the work period at this shift change (i.e., when an employee rotates from bracket A4 to D1) is the sum of the lengths of the work periods at the end of bracket A4 and the beginning of bracket D1; i.e.,

$$5 + 0 = 5 \text{ days.}$$

The length of the changeover off-duty period at the A4-D1 changeover is the sum of the off-duty period lengths at the end of bracket A4 and the beginning of bracket D1; i.e.,

$$0 + 2 = 2 \text{ days.}$$

The lengths of the changeover work and off-duty periods at the other shift change (i.e., from bracket D6 to bracket A1) are computed in a similar way:

$$\text{work period: } 0 + 1 = 1 \text{ day}$$

$$\text{off-duty period: } 1 + 0 = 1 \text{ day.}$$

If the lengths of all changeover work and off-duty periods satisfy agency constraints, then the multishift schedule is said to be acceptable since all other constraints were previously considered in constructing each one-shift schedule. If the multishift schedule is not acceptable, different ways of combining the one-shift schedules must be considered. To do this, a chart similar to that shown in Figure 8-25 is constructed which shows the lengths of the work and off-duty periods at both the beginning

and end of each bracket in the one-shift schedules (see Figure 8-26). This chart is then used to compute the lengths of the changeover work and off-duty periods for each of the 24 two-shift schedules that can be constructed. A convenient format for summarizing these lengths is illustrated in Figure 8-27.

This chart contains the following information:

- Column (1) identifies the first bracket worked by an employee after rotating to the day shift. For example, bracket D1 is the starting bracket for the alternative schedules represented on the first four lines of Figure 8-27.
- Column (2) identifies the last bracket worked by an employee before rotating to the afternoon shift.
- Columns (3) and (4) identify the first and last brackets worked by employees while assigned to the afternoon shift. For example, bracket A1 is the first bracket worked by employees after rotating to the afternoon shift, and A4 is the last bracket worked before rotating to the day shift, for the schedule represented on the first line.
- Column (5) specifies the length of the changeover work period when employees rotate from the day shift to the afternoon shift. This length is computed by summing the length of the work period at the end of the bracket identified in column (2) and the length of the work period at the start of the bracket identified in column (3). These lengths are given in Figure 8-26. For the first schedule in Figure 8-27 (line 1) for example,

$$\left(\begin{array}{l} \text{length of work} \\ \text{period at D-A} \\ \text{shift change} \end{array} \right) = \left(\begin{array}{l} \text{length of work} \\ \text{period at end} \\ \text{of bracket D5} \end{array} \right) + \left(\begin{array}{l} \text{length of work} \\ \text{period at start} \\ \text{of bracket A1} \end{array} \right)$$

$$= 0 + 1 = 1 \text{ day.}$$

- Similarly, column (6) specifies the length of the changeover off-duty period when employees rotate from the day shift to the afternoon shift. It is computed by summing the lengths given in Figure 8-26 for the off-duty periods at the end of the bracket identified in column (2) and the start of the bracket identified in column (3). For the first schedule in Figure 8-27 (line 1), this length is one day.

Bracket	Day of Week							Start of Bracket		End of Bracket	
	M	T	W	T	F	S	S	Length of Work Period	Length of Off-Duty Period	Length of Work Period	Length of Off-Duty Period
D1	R	R	D	D	D	D	D	0	2	5	0
D2	D	R	R	R	D	D	D	1	0	3	0
D3	D	D	D	R	R	D	D	3	0	2	0
D4	D	D	D	D	R	R	D	4	0	1	0
D5	D	D	D	D	D	R	R	5	0	0	2
D6	D	D	D	D	D	D	R	6	0	0	1
A1	A	R	R	R	R	A	A	1	0	2	0
A2	A	A	A	A	A	R	R	5	0	0	2
A3	A	A	A	A	A	A	R	6	0	0	1
A4	R	R	A	A	A	A	A	0	2	5	0

Figure 8-26

LENGTHS OF WORK AND OFF-DUTY PERIODS AT BEGINNING AND END OF EACH BRACKET IN THE ONE-SHIFT SCHEDULES IN FIGURE 8-24

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Schedule	Shift D		Shift A		Shift Change			
	(1) Starting Bracket	(2) Ending Bracket	(3) Starting Bracket	(4) Ending Bracket	D-A		A-D	
					(5) Length of Work Period	(6) Length of Off-Duty Period	(7) Length of Work Period	(8) Length of Off-Duty Period
1	D1	D6	A1	A4	1*	1*	5	2
2			A2	A1	5	1*	2*	2
3			A3	A2	6	1*	0	4
4			A4	A3	0	3	0	3
5	D2	D1	A1	A4	6	0*	6	0*
6			A2	A1	10*	0*	3*	0*
7			A3	A2	11*	0*	1*	2
8			A4	A3	5	2	1*	1*
9	D3	D2	A1	A4	4	0*	8*	0*
10			A2	A1	8*	0*	5	0*
11			A3	A2	9*	0*	3*	2
12			A4	A3	3*	2	3*	1*
13	D4	D3	A1	A4	3*	0*	9*	0*
14			A2	A1	7	0*	6	0*
15			A3	A2	8*	0*	4	2
16			A4	A3	2*	2	4	1*
17	D5	D4	A1	A4	2*	0*	10*	0*
18			A2	A1	6	0*	7	0*
19			A3	A2	7	0*	5	2
20			A4	A3	1*	2	5	1*
21	D6	D5	A1	A4	1*	2	11*	0*
22			A2	A1	5	2	8*	0*
23			A3	A2	6	2	6	2
24			A4	A3	0	4	6	1*

Note: Asterisks indicate work and off-duty periods which do not satisfy agency constraints.

Figure 8-27

ANALYSIS OF LENGTHS OF CHANGEOVER WORK AND OFF-DUTY PERIODS IN MULTISHIFT SCHEDULES

- Columns (7) and (8) specify the lengths of the changeover work and off-duty periods when employees rotate from the afternoon shift to the day shift. These lengths are computed by summing the lengths of the work and off-duty periods at the end of the bracket identified in column (4) and at the start of the bracket identified in column (1). For the first schedule in Figure 8-27 (line 1), for example,

$$\left(\begin{array}{l} \text{length of work} \\ \text{period at A-D} \\ \text{shift change} \end{array} \right) = \left(\begin{array}{l} \text{length of work} \\ \text{period at end} \\ \text{of bracket A4} \end{array} \right) + \left(\begin{array}{l} \text{length of work} \\ \text{period at start} \\ \text{of bracket D1} \end{array} \right)$$

$$= 5 + 0 = 5 \text{ days,}$$

and

$$\left(\begin{array}{l} \text{length of off-} \\ \text{duty period at} \\ \text{A-D shift change} \end{array} \right) = \left(\begin{array}{l} \text{length of off-} \\ \text{duty period at} \\ \text{end of bracket A4} \end{array} \right) + \left(\begin{array}{l} \text{length of off-} \\ \text{duty period at} \\ \text{start of bracket D1} \end{array} \right)$$

$$= 0 + 2 = 2 \text{ days.}$$

- Entries in columns (5) through (8) which do not satisfy agency constraints on work and off-duty period lengths are marked with an asterisk. (In Figure 8-27, work periods were constrained to be from four to seven days long, and off-duty periods were required to be from two to four days long.) Note that zero-day work periods are not marked since the zero indicates that the bracket preceding the shift change ends with an off-duty period and the bracket following the shift change starts with an off-duty period.

Once a chart like the one in Figure 8-27 has been constructed, acceptable multishift schedules are easily identified by locating lines in the chart for which no changeover work or off-duty period is marked as unacceptable. For example, only the schedules represented by lines 4 and 23 in Figure 8-27 have acceptable changeover properties. These schedules are illustrated in Figure 8-28.

Designing Multishift PR Schedules by Explicitly Considering Shift Change Properties in the Design of One-Shift Schedules

In some cases, there will be no way to combine previously

Bracket

	Day of Week						
	M	T	W	T	F	S	S
D1	R	R	D	D	D	D	D
D2	D	R	R	R	D	D	D
D3	D	D	D	R	R	D	D
D4	D	D	D	D	R	R	D
D5	D	D	D	D	D	R	R
D6	D	D	D	D	D	D	R
A4	R	R	A	A	A	A	A
A1	A	R	R	R	R	A	A
A2	A	A	A	A	A	R	R
A3	A	A	A	A	A	A	R

Bracket

	Day of Week						
	M	T	W	T	F	S	S
D6	D	D	D	D	D	D	R
D1	R	R	D	D	D	D	D
D2	D	R	R	R	D	D	D
D3	D	D	D	R	R	D	D
D4	D	D	D	D	R	R	D
D5	D	D	D	D	D	R	R
A3	A	A	A	A	A	A	R
A4	R	R	A	A	A	A	A
A1	A	R	R	R	R	A	A
A2	A	A	A	A	A	R	R

Figure 8-28

ALTERNATIVE MULTISHIFT PR SCHEDULES WITH ACCEPTABLE CHANGEOVER PROPERTIES, CONSTRUCTED BY COMBINING THE ONE-SHIFT SCHEDULES IN FIGURES 8-1 AND 8-19

designed one-shift schedules into a multishift schedule with acceptable shift change properties. For example, the one-shift schedules in Figure 8-29 cannot be combined into a two-shift schedule which has off-duty periods that are at least two days in length at each shift change. When no acceptable multishift schedule can be found, the procedure described above requires that alternate one-shift schedules be designed for one or more of the shifts, and the analysis of alternative ways of combining the resulting schedules into a multishift schedule be repeated. This section describes an alternate procedure for designing one-shift schedules having specific shift change properties which ensures the formation of acceptable multishift schedules.

The first step in this method is to identify the shift rotation sequence to be used, the minimum acceptable length for changeover off-duty periods, the minimum and maximum acceptable lengths of work and off-duty periods within each one-shift schedule, and the distribution of on-duty employees among the shifts and days of the week. For example, suppose that an agency requires a two-shift PR schedule with (1) four employees assigned to the day shift, (2) three employees assigned to the afternoon shift, (3) off-duty periods which are at least two days in length, (4) work periods that are from four to seven days long, (5) off-duty periods that are at least two days long at each shift change, and (6) a daily distribution of on- and off-duty employees on each shift as shown in Table 8-1.

The star diagrams corresponding to the sample distributions of off-duty employees on each shift are shown in Figure 8-30.

		Day of Week						
		M	T	W	T	F	S	S
Bracket	D1	D	R	R	R	D	D	D
	D2	D	D	R	R	R	R	D
	D3	D	D	D	D	D	D	R
	D4	R	D	D	D	D	D	D

		Day of Week						
		M	T	W	T	F	S	S
Bracket	A1	A	A	A	A	R	R	R
	A2	A	A	A	A	A	A	A
	A3	R	R	R	R	A	A	A

Figure 8-29

ONE-SHIFT SCHEDULES WHICH CANNOT BE COMBINED
 INTO A MULTISHIFT SCHEDULE HAVING A
 TWO-DAY OFF-DUTY PERIOD AT EACH SHIFT CHANGE

Table 8-1

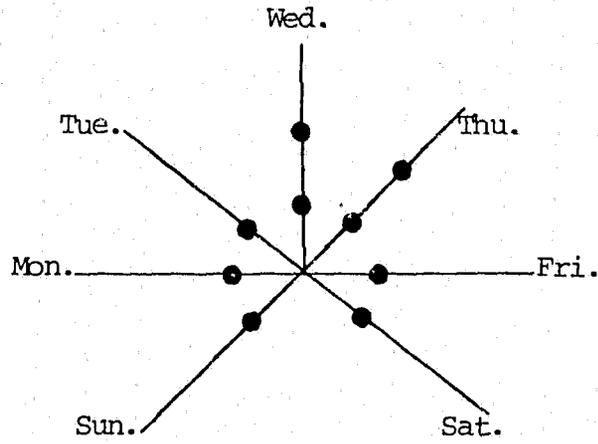
SAMPLE DAILY DISTRIBUTION OF
ON- AND OFF-DUTY EMPLOYEES

	Day of Week						
	<u>M</u>	<u>T</u>	<u>W</u>	<u>T</u>	<u>F</u>	<u>S</u>	<u>S</u>
<u>Day Shift</u>							
On-Duty Employees	3	3	2	2	3	3	3
Off-Duty Employees	1	1	2	2	1	1	1
<u>Afternoon Shift</u>							
On-Duty Employees	2	2	2	2	2	2	2
Off-Duty Employees	1	1	1	1	1	1	1

Next, off-duty days are assigned to the beginning and end of each one-shift schedule to ensure that the resulting change-over off-duty periods at each shift change satisfy the minimum length requirement. For example, two or more off-duty days can be provided at a shift change in any of following ways: (1) the shift from which employees rotate ends with a two-day off-duty period, (2) the shift to which employees rotate begins with a two-day off-duty period, or (3) the first shift ends with a one-day off-duty period and the next shift starts with a one-day off-duty period.

Assume in the example problem that the following assignments are made: (1) two off-duty days are assigned to the beginning of the day shift, (2) one off-duty day is assigned to the end of the day shift, (3) one off-duty day is assigned to the beginning of the afternoon shift, and (4) zero off-duty days are assigned to the end of the afternoon shift. These days can be indicated

Day Shift



Afternoon Shift

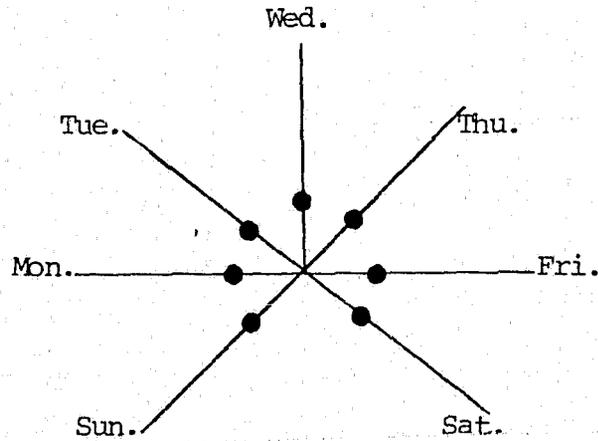


Figure 8-30

STAR DIAGRAMS REPRESENTING THE SAMPLE DISTRIBUTIONS OF OFF-DUTY EMPLOYEES IN TABLE 8-1

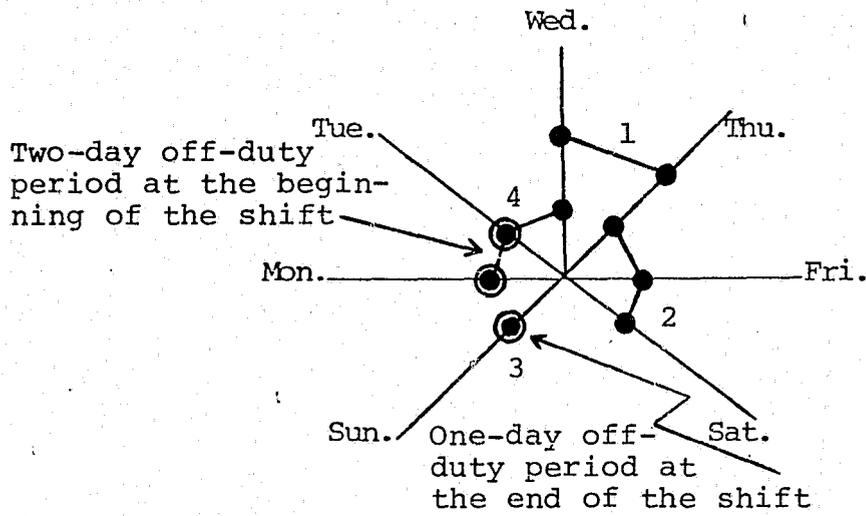
on the star diagrams in Figure 8-30 by circling nodes on the days of the week (i.e., the rays) which correspond to the beginning and end of the shift (see Figure 8-31). For example, a two-day off-duty period at the start of the day shift schedule is indicated by circling one node on the rays corresponding to Monday and Tuesday, while a one-day off-duty period at the end of the shift is indicated by circling a node on the ray corresponding to Sunday, and so on. The remaining off-duty days on each shift are then partitioned into off-duty periods of acceptable lengths, and assigned to specific days of the week as described in Section D.* One such designation of off-duty periods is indicated in Figure 8-31 for the example problem.

The next step is to identify an acceptable sequence of off-duty periods for each shift. As described in Section D, this is done by (1) constructing a separation table showing the number of work days between consecutive pairs of off-duty periods, (2) circling one entry in each row to indicate which off-duty period follows the period corresponding to that row, and (3) verifying that the resulting sequence includes each off-duty period and that the circled entries sum to the total number of on-duty days to be scheduled on the shift during the rotation period.

A separation table must be constructed for each shift.

*Note that these off-duty days can be combined with off-duty days previously allocated to the start and end of the one-shift schedules to provide extended changeover off-duty periods (i.e., periods that are longer than the minimum length requirement). The resulting off-duty periods, however, must not overlap the end of one work week and the beginning of the next work week. For example, the off-duty day on Monday at the start of the afternoon shift schedule can be extended by including Tuesday, but not Sunday.

Day Shift



Afternoon Shift

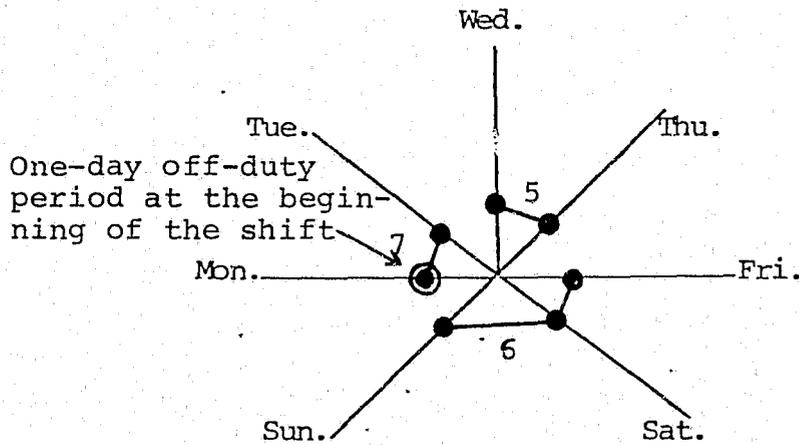


Figure 8-31

DESIGNATION OF OFF-DUTY PERIODS AT SHIFT CHANGEOVERS

In addition, each separation table must be expanded by including one additional row and column to represent the time employees are assigned to other shifts. This additional row and column is said to correspond to an artificial off-duty period (i.e., a period when employees are not on-duty on the shift represented by the separation table).^{*} Entries in the separation tables which do not conform to agency constraints on work period lengths can be modified or eliminated as described in Section D with the exception that zero entries in the row and column corresponding to the artificial off-duty period are not modified since these entries correspond to off-duty periods at a shift change (i.e., at the beginning or end of the shift schedule). Figures 8-32 and 8-33 contain the expanded and modified separation tables for the off-duty periods designated in Figure 8-31.

A sequence of off-duty periods on each shift is then specified by circling entries in the modified separation tables as described in Section D. This sequence must include certain entries, however, to assure that the proper off-duty periods appear at the beginning and end of each shift. For example, since period 4 shown in Figure 8-31 was previously assigned to the start of the day shift schedule, it must immediately follow the artificial period (i.e., there must be zero on-duty days between these periods). Hence, the zero-entry in row "a" and column 4 must be circled. Figure 8-34 illustrates the only acceptable sequence of off-duty periods in the separation tables in Figure 8-33. Entries in Figure 8-34 which are circled with

^{*}Note that the artificial off-duty period begins on the first day of the work week and ends on the last day of the work week.

Day Shift

	1	2	3	4	a*
1	-	6	2	3	3
2	3	-	0	1	1
3	2	3	-	0	0
4	6	0	3	-	4
a*	2	3	6	0	-

Afternoon Shift

	5	6	7	a*
5	-	0	3	3
6	2	-	0	0
7	0	2	-	5
a*	2	4	0	-

*Artificial off-duty period.

Figure 8-32

EXPANDED SEPARATION TABLES FOR OFF-DUTY PERIODS DESIGNATED IN FIGURE 8-31

Day Shift

	1	2	3	4	a
1	-	6	-	-	-
2	-	-	7	-	-
3	-	-	-	7	0
4	6	7	-	-	4
a	-	-	6	0	-

Afternoon Shift

	5	6	7	a
5	-	7	-	-
6	-	-	7	0
7	7	-	-	5
a	-	4	0	-

Work period lengths: 4-7 days

Figure 8-33

MODIFIED SEPARATION TABLES REFLECTING AGENCY CONSTRAINTS
ON WORK PERIOD LENGTHS

Day Shift

	1	2	3	4	a
1	-	6	-	-	-
2	-	-	7	-	-
3	-	-	-	7	0
4	6	7	-	-	4
a	-	-	6	0	-

Afternoon Shift

	5	6	7	a
5	-	7	-	-
6	-	-	7	0
7	7	-	-	5
a	-	4	0	-

Figure 8-34

DESIGNATION OF AN ACCEPTABLE SEQUENCE OF OFF-DUTY PERIODS

dashed lines are those required by the allocation of off-duty periods to the beginning and end of each shift schedule.

The pattern of on- and off-duty assignments in the multi-shift schedule is then constructed as described in Section D, with the shift rotation occurring when the artificial off-duty periods are encountered in the sequence of off-duty periods in the separation tables. Figure 8-35 illustrates the multishift PR schedule constructed for the example problem.

	M	T	W	T	F	S	S
1	R	R	R	D	D	D	D
2	D	D	R	R	D	D	D
3	D	D	D	R	R	R	D
Week 4	D	D	D	D	D	D	R
5	R	R	A	A	A	A	A
6	A	A	R	R	A	A	A
7	A	A	A	A	R	R	R

Figure 8-35

MULTISHIFT PR SCHEDULE SATISFYING ALL
CONSTRAINTS SPECIFIED IN THE EXAMPLE

APPENDIX A

GLOSSARY OF WORK SCHEDULING TERMINOLOGY

APPENDIX A

GLOSSARY OF WORK SCHEDULING TERMINOLOGY

- Accumulated Time Day (A. T. Day) - Same as "Compensatory Day."
- Average Work Week - The average number of scheduled work hours per week, with paid time off for vacations, holidays, and sick leave included as scheduled work hours.
- Bracket - See "Schedule Bracket."
- Call-Back - Recall of off-duty groups or individuals to duty. (Call-backs of individual staff members may also be referred to as "call-ins," "hiring back," or "subbing.")
- Call Shift - A shift worked by someone other than the regularly scheduled employee.
- Compensatory Time (Compensatory Day) - Time off (day off) with pay from a regularly scheduled on-duty shift, granted to an employee as compensation for extra hours worked on a previous date.
- Cyclic Schedule - A work schedule in which each group of employees works each schedule bracket in a specified sequence, and returns to the initial bracket after completing the final bracket in the sequence.
- Day - The 24-hour period used for scheduling purposes, not necessarily commencing at midnight.
- Day Cycle - Same as "Duty Cycle."
- Day Off - Same as "Off-Duty Day."
- Days-Off Scheduling - A staff allocation procedure which deals with the specification of on-duty and off-duty days for individual employees or groups of employees.
- Day Shift - (1) A daytime work shift. (2) The group(s) of employees assigned to daytime duty.
- Duty Cycle - The repeating pattern of shift assignments and days off in a work schedule.
- Duty Day - Same as "Work Day."
- Duty Schedule - Same as "Work Schedule."
- Fair Labor Standards Act (FLSA) - A federal law passed in 1938 setting conditions and standards concerning minimum wage rates, overtime pay rates, recordkeeping, equal pay, and child labor. In 1974 FLSA amendments attempted to extend

the Act's overtime and minimum wage provisions to state and local government employees, but these were declared unconstitutional.

FB Schedule - See "Fixed Bracket Schedule."

Fixed Bracket Schedule - A schedule in which each employee or group of employees works the same seven-day bracket every week (i.e., receives the same days off each week).

Fixed Post Staffing - Same as "Uniform Staffing."

Four-Ten (4/10) Schedule - A 40-hour per week schedule consisting of an average of four 10-hour shifts per week for each employee. (Also called "4/10 Plan.")

Group - One or more employees sharing identical shift assignments and days off. (See "Platoon.")

Group Schedule - The pattern of shift assignments and days off followed by a group of employees. (See "Platoon Schedule.")

Holdover - Retention of employees on duty beyond the end of their normally scheduled work shift.

Holiday - Time off with pay from a regularly scheduled work shift. Holidays may be scheduled as days off for individual employees or as agency holidays when all employees are off-duty with pay.

Holiday Pay - Bonus pay to individual employees for working on designated legal holidays. In some schedules, both on-duty and off-duty employees receive bonus pay for certain holidays.

Job Factor - Same as "Staffing Factor."

Kelly Day - An unpaid off-duty day, granted in lieu of a regularly scheduled work shift and in addition to regularly scheduled off-duty days, for the purpose of reducing the average work week. Kelly days are generally scheduled as off-duty days for individual group members rather than entire groups.

Multishift Proportional Rotating Schedule - A cyclic schedule which provides rotation of shifts and days off, and staffing levels proportional to service demands by shift and day of the week.

Multishift Schedule - A work schedule in which employees report for work at different times of the day.

Night Shift - (1) A nighttime work shift. (2) The group(s) of employees assigned to nighttime duty.

Off-Duty Day - A day during which an employee has no scheduled on-duty shifts.

Off-Duty Period - A sequence of consecutive off-duty days.

On-Duty Shift - A shift during which an employee is scheduled to be on duty.

On-Duty Day - A day during which an employee is scheduled to work at least one shift.

Overlay Shift - A shift whose duty hours overlap the duty hours of other shifts; usually used to achieve an increase in staffing level during the hours covered. For example, a schedule using eight-hour shifts with reporting times of 8:00 a.m., 4:00 p.m., and 12:00 a.m. might also have an overlay shift from 6:00 p.m. to 2:00 a.m. in order to meet increased demand for services during those hours.

Overtime - Time worked by an employee in addition to his normally scheduled duty hours, usually compensated at 1.5 times the normal rate of pay or with compensatory time off.

Partitioning - A grouping of off-duty days into off-duty periods.

Pay Period - A fixed and regularly recurring interval of time usually measured in days or weeks used for computing regular and overtime pay. (See "Work Period.")

Payback Day - Time worked by an employee in addition to his normally scheduled duty hours, due to the use of a duty schedule in which the average number of hours worked per week is less than the number required. For example, if an employee's schedule averages 38 hours per week when 40 hours per week are required, the employee owes two on-duty hours each week.

Paying Time - The practice of one employee paying another to work in his place on a shift when the substitute would otherwise be off duty. (See "Trading Time.")

Platoon - A group of employees whose pattern of on-duty and off-duty shifts is such that whenever the group is on duty all other groups are off duty. (See "Group.")

Platoon Schedule - (1) A schedule in which all groups are platoons. The term may include a reference to the number of platoons into which the total work force is divided, as in "Two-Platoon Schedule," "Three-Platoon Schedule," and "Four-Platoon Schedule." (An alternative usage, not used in this report, includes a number which refers to the number of shifts staffed during each 24-hour period, so that all schedules using 24-hour shifts are one-platoon schedules, those using eight-hour shifts are three-platoon schedules, etc.) (2) The pattern of shift assignments and days off followed by a given platoon.

Position - A defined role and set of duties to which one on-duty employee must be assigned. A position may be filled by different employees at different times of the day and on

different days of the week. A "Shift Position" is a position that is staffed during a specified shift on all days when service is offered.

PR Schedule - See "Proportional Rotating Scheduling."

Proportional Rotating Schedule - A cyclic schedule which provides rotating days off and staffing levels proportional to service demands by day of the week. (Sometimes used synonymously with "Multishift Proportional Rotating Schedule.")

Proportional Staffing - A personnel allocation procedure in which the number of on-duty personnel changes by time of day or day of week in proportion to cyclic variations in agency workload.

Recreation Day - Same as "Off-Duty Day."

Recreation Period - Same as "Off-Duty Period."

Relief Factor - The number of employees required to staff one position, taking into account all employee absences, including vacations, holidays, and sick leave. A shift relief factor is the number of employees needed to staff one position during one shift on all days that agency services are provided. A daily relief factor is the number of employees needed to staff one position during all shifts on all days that agency services are provided.

Rotation Period - See "Schedule Period."

Schedule Bracket - A sequence of on-duty and off-duty assignments for a specified number of days. Schedules may be represented as a set of equal-length brackets, usually seven days in length.

Schedule Changeover - The point at which an existing schedule is replaced with a new schedule.

Schedule Changeover Properties - Work schedule properties resulting from joining the final on-duty or off-duty periods of an existing schedule (i.e., the periods immediately preceding the changeover) with the first on-duty or off-duty periods assigned as part of a new schedule (i.e., the periods immediately following the changeover).

Schedule Design Interval - The length of time during which a schedule is used with only minor day-to-day adjustments for absences (i.e., the length of time between schedule implementation and schedule redesign or reassignment of employees to different schedule brackets).

Schedule Period - The number of weeks required for one complete cycle through all of the brackets in a cyclic schedule.

Schedule Rotation Period - See "Schedule Period."

Schedule Week - The seven-day period beginning on a specified day of the week, used for defining employee work hours and computing overtime compensation.

Separation Table - A tabular summary of the work period lengths associated with alternative sequences of off-duty periods. Used in designing proportional rotating schedules.

Shift - (1) One of the sets of hours into which the day is divided for scheduling purposes, constituting the time interval for on-duty services. Sometimes called a "tour" or "watch."
(2) The set of employees assigned to work during a specified time of the day (e.g., the employees assigned to daytime duty may be collectively referred to as the "day shift").
(3) An on-duty assignment worked by an employee (e.g., an employee may be scheduled to work five eight-hour shifts per week).

Shift Changeover - Same as "Shift Rotation."

Shift Changeover Properties - Work schedule properties resulting from joining an employee's final work or off-duty period on one shift with the first work or off-duty period on a different shift.

Shift Rotation - The reassignment of employees from one shift to a different shift.

Shift Rotation Sequence - The order in which new shift assignments are made--e.g., day-afternoon-night or day-night-afternoon.

Shift Scheduling - A personnel allocation procedure in which service demands are determined for small units of time (usually one hour periods) and then are used to find the best shift starting times for each day of the week and the number of employees to be assigned to each shift on each day of the week.

Shift Tour - For a multishift rotating schedule, the interval for which an employee is assigned to a specified shift, including on-duty and off-duty days, before being reassigned to another shift (e.g., a three-week tour on the day shift).

Shift Trade - The exchange of scheduled work shifts between employees, usually restricted to individuals of equal rank and skill. See "Trading Time."

Sick Day - The unit of on-duty time used in computing the length of sick leave.

Sick Leave - A period of paid absence from on-duty assignments arising from illness or injury.

Split Shift - A shift comprised of non-consecutive hours which are interrupted by a period of off-duty hours.

Staff-Day - A unit of measure consisting of the on-duty services of one employee for one shift. Used for assessing the amount of staff resources available or needed.

Staffing Factor - The number of employees needed to maintain one on-duty position for all hours during which service is provided, not taking into account absences due to vacations, paid holidays, sick leave, etc. The staffing factor is computed by dividing the number of hours per week for which service is provided by the average work week (e.g., for around-the-clock service, a 40-hour work week results in a staffing factor of 4.2).

Standard 40-Hour Week - A schedule consisting of five eight-hour shifts, Monday through Friday, with Saturday and Sunday off.

Straight Time - Work hours for which the regular rate of pay is received.

Swing Shift - (1) The afternoon shift, or the employees assigned to the afternoon shift. (2) A longer than normal day worked to change an employee or group from day to night duty or from one platoon to another. (3) An overlay shift, or the employees working an overlay shift.

Team Integrity - A personnel management principle that is achieved when a group of employees work together each time they are on duty (i.e., without absences of team members or assignment of "outsiders").

Tour of Duty - Same as "On-Duty Shift." (See "Shift Tour.")

Trading Time - The exchange of scheduled work hours between employees, usually limited to individuals of equal rank and skill. See "Shift Trade."

Uniform Staffing - A personnel allocation procedure in which the number of scheduled on-duty personnel is the same at all times when service is offered. Sometimes called "Fixed Post Staffing."

Unity of Command - A personnel management principle that is achieved when each subordinate reports to the same supervisor at all times. When supervisors' schedules are not identical to those of their subordinates, it is not possible to achieve complete unity of command for all personnel.

Vacation - An on-duty assignment or series of on-duty assignments from which an employee is excused with pay as an annual fringe benefit.

Vacation Day - The unit of on-duty time used in computing the length of a vacation.

Variable Staffing - A personnel allocation procedure in which the number of scheduled on-duty personnel changes cyclically by time of day or day of the week. See "Proportional Staffing."

Watch - Same as "Shift."

Week Cycle - The smallest number of weeks in which the duty cycle repeats a whole number of times. The length of the week cycle, in weeks, is equal to the number of days in the duty cycle, if this number cannot be divided evenly by seven; if it can be so divided, the length of the week cycle is given by the result of this division.

Weekend Off-Duty Period - An off-duty period which includes both Saturday and Sunday.

Weekend Recreation Period - Same as "Weekend Off-Duty Period."

Work Day - A day during which an employee is scheduled to be on duty. (Same as "On-Duty Day.")

Work Force - The set of employees that constitute the organization, division, or unit for which a work schedule or work schedules must be designed.

Work Period - (1) A sequence of consecutive work days. (2) A fixed and regularly recurring interval of time measured in days or weeks, used for computing work hours for purposes of compliance with the overtime provisions of the Fair Labor Standards Act; agency pay periods do not have to coincide with the agency work period declared for FLSA purposes.

Work Schedule - A specification of shift assignments and days off for individual employees or groups of employees.

Work Shift - Same as "On-Duty Shift."

Work Week - (1) A fixed and regularly recurring seven-day interval, used for computing regular and overtime work hours. (2) Same as "Average Work Week."

APPENDIX B

WORK SCHEDULE DESIGN
CASE STUDIES AND
LIST OF PROJECT PARTICIPANTS

APPENDIX B

WORK SCHEDULE DESIGN CASE STUDIES

A. Introduction

This section describes the experience of the ten agencies which participated in the project "Improved Work Scheduling for Urban Service Delivery System Personnel" (Department of Housing and Urban Development, grant number H-2576-RG). Project participants are listed at the end of this appendix.

The work scheduling project was implemented by the City of Santa Clara, California, in cooperation with the California Innovation Group (CIG) and The Institute for Public Program Analysis (TIPPA). CIG is an eleven-city consortium funded by the National Science Foundation to help local governments take advantage of new technologies. A CIG science advisor is assigned to the city manager's office in each city to provide leadership and guidance in the promotion of technology utilization. The agencies which participated in the project are all located in CIG cities:

- Anaheim Public Library,
- Fresno Fleet Maintenance Department,
- Fresno Transit Maintenance Department,
- Fresno Parks and Recreation Department,
- Fresno Wastewater Treatment Plant,
- Pasadena Paramedic Ambulance Service,
- San Diego Aquatics Division,
- San Jose Vehicle Maintenance Department,
- Santa Clara Electric Department, and
- Santa Clara Public Library.

Through the work scheduling project, these agencies explored the benefits (described below) of using innovative scheduling techniques developed by The Institute for Public Program Analysis. The agencies selected for the study represent different work settings, management environments, and scheduling needs.

The combined experience of these agencies illustrates the potential benefits to be derived from applying the work scheduling methods outlined in this handbook. These benefits include the following:

- improved agency ability to match on-duty staffing levels to workload patterns by shift and day of the week;
- improved ability to revise work schedules to meet changing workload patterns;
- improved ability to balance management's need for efficient allocation of agency personnel and employees' need for satisfactory schedule properties; and
- reduced amount of administrative time required to design schedules.

The experience of these agencies also reveals the complex nature of the work schedule design problem. In many cases, different employee classifications or skill levels must be combined. Many agencies are required to give each employee two consecutive days off each week, rather than using off-duty periods of varying lengths. It is often desirable that the same employees work together each time they are on duty. And schedule implementation can be affected by other management decisions that are not directly schedule-related.

Despite the complex nature of work scheduling and the potential benefits to be derived from improved scheduling techniques, none of the participating agencies had previously known of any resource material related to work schedule design. Management personnel are often unaware that schedule alternatives exist, and exchange of sched-

ule-related information between agencies is rare. As a result, even the agencies which were unable to implement new schedules during the life of the project were anxious to take advantage of the schedule design resources being developed by the work scheduling project.

The next section summarizes the activities of the work scheduling project. The remaining sections describe project outcomes in each of the agencies listed above.

B. Overview of the Work Scheduling Project

The purpose of the project was to test the application of the work scheduling methods developed by TIPPA. Six CIG cities participated in the project: Santa Clara (lead city), San Jose, Fresno, Pasadena, Anaheim, and San Diego. Project activities included:

- a survey of selected agencies in the participating CIG cities,
- selection of target agencies in which the scheduling methods would be applied,
- meetings of science advisors, target agency representatives, TIPPA staff, and other interested persons to review project activities and introduce participants to the scheduling methods,
- design of target agency work schedules,
- implementation of new work schedules in target agencies (where possible), and
- assessment of project outcomes.

These project activities are discussed in the following paragraphs.

Survey of CIG Agencies

At the start of the work scheduling project, personnel in selected agencies in the participating cities were surveyed by

TIPPA staff to determine their interest in the project and to assess the potential for applying innovative scheduling methods. The agencies surveyed were suggested by the science advisors, who had previously been given a brief introduction by TIPPA to the types of scheduling methods to be used. A total of 19 agencies were surveyed. Information collected from the agencies included:

- agency function and organizational structure,
- composition of the work force,
- demand for agency services,
- allocation of personnel by shift and day of the week,
- properties of the current work schedule,
- work scheduling constraints,
- schedule administration practices, and
- methods of designing and evaluating agency work schedules.

Selection of Target Agencies

The initial selection of the project's target agencies was based upon the results of the survey described above. Agencies were excluded for the following reasons: the scheduling methods were not appropriate for the work environment, new scheduling methods were not needed, or management personnel were not able to commit themselves to participation in the project. After careful screening, seven target agencies were selected: two in Fresno and one in each of the other cities. Three additional agencies were given limited schedule design assistance during the project.

Meeting of Project Participants

In June 1977, a two-day project meeting was held in Anaheim, California. Attending the meeting were CIG staff and science advisors, TIPPA staff, the HUD project manager, representatives from

each of the target agencies, and representatives from SRI International and the American Federation of State, County, and Municipal Employees (AFSCME). The agenda for the meeting included:

- review of project objectives and expected work with each of the target agencies;
- introduction to the work schedule design methods, distribution of the training materials, and a review of the potential benefits to be derived from the use of these methods;
- review of alternative work schedules designed by TIPPA for some of the target agencies; and
- discussion of initial outlines for the schedule design handbook.

Design of Target Agency Schedules

Following the Anaheim meeting, project efforts were focussed upon applying the scheduling methods to the target agencies. For most of the target agencies, alternative schedules were designed by TIPPA based on information supplied by agency personnel. In two instances, new work schedules were designed by agency representatives. Some schedule design work had been done prior to the Anaheim meeting. The TIPPA-designed schedules were reviewed by target agency representatives, who in most cases requested some schedule modifications. Table B-1 summarizes the schedule design and other services rendered by TIPPA to participating agencies.

Implementation of New Work Schedules

After a careful review process, two agencies implemented new work schedules based on TIPPA design methods. At the end of the project, several other agencies were still considering implementations. The case studies described below illustrate the varied and complex issues involved in the design, review, and implementation

Table B-1

A SUMMARY OF TIPPA SCHEDULE DESIGN WORK AND
OTHER SERVICES RENDERED TO TARGET AGENCIES

<u>Agency</u>	<u>Current Schedules Analyzed</u>	<u>Sample Schedules Designed</u>	<u>Other Services Provided</u>
1. Anaheim Public Library	4	4	
2. Fresno Fleet Maintenance	4	8	
3. Fresno Parks and Recreation	1	1	
4. Fresno Transit Maintenance	2	4	-Provided instructional material which enabled supervisor to design own schedules
5. Fresno Wastewater Treatment Plant	2	11	-Suggested procedures for systematizing periodic schedule changes
6. Pasadena Paramedic Ambulance Service	1	8	-Calculated saturation probabilities for various call rates and numbers of units
7. San Diego Aquatics Division	3	10	-Provided instructional material which enabled agency to design own schedules
8. San Jose Vehicle Maintenance	3	9	
9. Santa Clara Electric Department	2	3	
10. Santa Clara Public Library	<u>4</u>	<u>5</u>	-Provided detailed analyses of workload data
Total	26	63	

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of work schedules.

Assessment of Project Outcomes

The assessment of project outcomes was accomplished by several means: continuous science advisor contact with target agencies, site visits by TIPPA and SRI staff, and a project wrap-up meeting. The results of these efforts are incorporated in the case study material presented below.

C. Fresno Transit Maintenance Department

Background

The City of Fresno operates its own bus system, and maintenance work and road calls are provided 24 hours a day, seven days a week. Work performed in the maintenance shop includes daily servicing and washing, preventive maintenance, and mechanical and body repairs. At the time the work scheduling project was begun, shop personnel included: 10 mechanics, 8 service workers, 6 attendants, 7 specialists and other shop workers, 7 leadmen and foremen, and 3 management personnel.

The volume of transit maintenance workload varies by time of day and day of week. Each bus must be washed, inspected, and serviced before it is put into service each morning. Most mechanical problems are reported when drivers start the buses in the morning, when new drivers take over in the afternoon, and when buses are taken out of service at night. As a result, workload is heaviest between 4:00 a.m. and 7:00 a.m., 2:00 p.m. and 5:00 p.m., and 8:00 p.m. and midnight. The volume of daily workload depends upon the number of buses placed in service. Bus use is heaviest on Mondays and Thursdays and lightest on Sundays.

Scheduling Objectives Addressed

The entire transit system had been placed under new management approximately a year before the work scheduling project began, and all aspects of agency operation were being analyzed to identify needed improvements. A new manager of the maintenance shop had been hired three months before the project began, and he had already identified several problems related to work scheduling:

- the existing schedule did not provide on-duty staffing levels that were proportional to the cyclic variations in shop workload;
- periodic schedule revisions involved a time-consuming process of trial and error; and
- due to a lack of schedule design expertise and resource material, little could be done to adapt the schedule to temporary changes in workload.

The shop manager was very interested in exploring alternative scheduling methods. Of particular interest was the possibility of designing work schedules with rotating employee shift assignments and rotating days off which would provide a more proportional distribution of personnel by shift and day of the week.

Discussions with the maintenance shop manager revealed several scheduling objectives and constraints. These included the following:

- the proper mix of employee skills must be available at different times of the day and on different days of the week;
- to fully utilize the shop's limited space and personnel resources, the number of on-duty employees must be proportional to shop workload by shift and day of the week; and
- each employee must receive two consecutive days off each week, per the agreement between the City and the employee bargaining unit (Local 2051, American Federation of State, County, and Municipal Employees).

Application of Innovative Scheduling Methods

During the initial interviews conducted by TIPPA staff in February 1977 with transit personnel and the Fresno science advisor, it was agreed that new work schedules should be designed first for shop mechanics and servicemen, and later for attendants.

Based on workload data collected by shop personnel, several sample schedules for mechanics and servicemen were designed by TIPPA and were reviewed by the shop manager and selected employees. The schedules illustrated how proportional staffing by shift and day of the week could be achieved with either fixed or rotating days off and shift assignments. Employee reactions to these schedules convinced the shop manager that it would not be feasible to use rotating days off and shift assignments.

At the June 1977 project meeting in Anaheim, the shop manager was introduced to the TIPPA technique for designing fixed bracket schedules. Using what he learned and the draft materials distributed at the meeting, he used workload data to allocate personnel by shift and day of the week and designed fixed bracket schedules for shop mechanics and servicemen. The manager then asked each employee, in order of seniority, to select his own schedule bracket from among those available. The union steward in the maintenance shop and senior employees were consulted in an effort to acquaint them with the reasons behind the changes being made.

The new schedules were implemented in late summer with little disruption and few complaints. Some employees had to split their days off at the time of changeover to break up long work periods, but this was accepted as being unavoidable. Since that time, several staffing changes have been made in the shop, necessitating further

revision of some work schedules. These revisions were handled quickly and smoothly, using the same schedule design techniques.

Project Outcomes

In August 1977, TIPPA staff conducted a follow-up visit to the Fresno Transit Department. At that time, the shop manager reported continued success in using the new schedule techniques. He estimated that the amount of time required to design schedules had been cut in half--from two or three days to less than a day. Furthermore, he felt that he was producing better schedules; that is, he had scheduled extra personnel on duty during heavy workload shifts, had kept essential positions staffed during other hours, and had eliminated split days off. In addition, he believed the simplified scheduling procedures would eventually allow him to delegate scheduling to a lower supervisory level.

A later report from the Fresno science advisor confirmed that the transit agency was continuing to benefit from the new techniques.* Schedule design had been almost a monthly task, due to vacations, employee turnover, and the hiring of additional personnel. Since the start of the project, the number of buses to be maintained had doubled resulting in a massive increase in shop workload. The shop manager had been able to adjust easily to these changes, using the new schedule design procedures. The changing work environment, however, hampered efforts to isolate and measure productivity increases attributable to the new scheduling techniques.

*Personal correspondence between the author (A. Gill) and Dennis L. Megrditchian, City of Fresno Science and Technology Advisor, February 14, 1978.

Conclusions

Factors contributing to the success of the schedule design effort in the Fresno Transit Maintenance Department include the following:

- There was a recognized need for revision of the agency's work schedules.
- The shop manager designed and implemented schedules on his own, simplifying the schedule design and review process.
- Other organizational changes occurred about the same time, so a favorable climate for change had been established.
- Labor and management cooperated in reviewing proposed schedules to ensure that all contractual requirements were satisfied.

D. Fresno Wastewater Treatment Plant

Background

The Fresno Wastewater Treatment Plant, which processes all wastewater for the City of Fresno, operates 24 hours a day, seven days a week. Personnel at the plant are responsible for the maintenance of all of the wastewater treatment equipment and for daily monitoring of water pollution levels. At the start of the work scheduling project, plant personnel included: 12 plant operators, 5 operations leadmen (supervisors), 15 maintenance staff, 4 industrial monitoring staff, 8 laboratory staff, and 4 administrative staff. Plant operators and leadmen must be on duty around the clock. Most laboratory work is performed on the day shift, Monday through Friday. Personnel in administration, plant maintenance, and industrial monitoring work days, Monday through Friday.

Scheduling Objectives Addressed

The work scheduling project directly involved only operations

personnel (operators and leadmen) at the wastewater plant. The primary objective in scheduling operations personnel is to maintain uniform or nearly uniform staffing by shift and day of the week, while honoring the contractual obligation ~~to provide~~ each employee with two consecutive days off per week.* Separate schedules are designed for the operators and leadmen, so that each leadman supervises a different group of operators every few months.

Work schedules for the operations personnel use fixed shift and days off assignments. Every 12 weeks, new shift and days off assignments are made. This system provides for fixed assignments during each 12-week interval, yet allows for periodic rotation of shifts (day-afternoon-night) and days off. Prior to the work scheduling project, this scheduling system was generally well-received by the operators, although they had requested more frequent weekends off. (With the 12-week rotation system, employees receive either every weekend off or no weekends off during each rotation period.) However, the system was administratively time-consuming. Every 12 weeks, a new set of schedule brackets had to be designed, personnel had to be assigned to each bracket, and individual change-over properties had to be examined and adjusted. This process consumes 12 to 16 hours of the operations foreman's time each rotation period. Another difficulty with the system was that the operators did not know their schedules (especially days off) more than three months in advance.

Schedules for the five leadmen are similar to those used for

*Agreement between the City of Fresno and Local 2051 of the American Federation of State, County and Municipal Employees.

the operators. Leadmen's schedules are changed every 10 weeks, instead of every 12 weeks, and their shift rotation sequence is the opposite of that for the operators (i.e., day-night-afternoon rather than day-afternoon-night). During each rotation period, one leadman is assigned to each shift, and there is one "relief" leadman and one "floater" leadman. The relief leadman fills in for each of the shift leadmen on their days off, so that each week, he works three different shifts (usually two afternoons, two nights, and one day). The floater is assigned to day shift duty, but is the designated substitute when any other leadman is absent; thus, the floater may work any shift on any day of the week and may be called back to duty at any time.

The general objective of the project for the wastewater plant was to explore ways in which work scheduling for the leadmen and operators could be simplified. Specific objectives included:

- improved schedules for the relief leadman,
- improved alternatives to the 12-week rotation period for shifts and days off, and
- scheduling more off-duty weekends.

Application of Innovative Scheduling Methods

Based upon information supplied by the staff of the wastewater plant, the TIPPA staff designed two sample schedules for the plant operators and one for the leadman. These sample schedules differed from the existing schedules in that they contained longer and shorter on- and off-duty periods, more frequent rotation of shifts and days off, and increased variation in staffing levels by shift and day of the week.

Plant administrators discussed these sample schedules with the

operators and leadmen. Employee feedback indicated that the three-month rotation system was preferred, even though more frequent rotation would more evenly distribute each employee's off-duty weekends.

The TIPPA staff designed a second set of sample schedules suitable for use with a 12-week rotation system. These schedules provided two off-duty days per calendar week and fixed assignments to shifts and days off for 12 weeks, followed by a systematic rotation of employees from one schedule bracket to the next. This procedure provided acceptable changeover properties at rotation time and eliminated the need to redesign schedules every 12 weeks. The second set of operators' schedules differed only in the lengths of on-duty and off-duty periods when bracket assignments were changed, and the length of time employees were off duty between assignments on different shifts. One of the leadmen's schedules had one employee working three different shifts each week (as in the existing system), while a second leadmen's schedule had two employees each working two different shifts each week.

Project Outcomes

In October 1977 a new leadmen's work schedule based on one designed by TIPPA was implemented. The new schedule, shown in Figure B-1, is a fixed bracket schedule, and provides for a 40-hour average work week, with each employee receiving two days off each week, as required by the collective bargaining agreement. Originally, all schedules designed by TIPPA for the wastewater treatment plant used Saturday as the first day of each bracket. The schedule in Figure B-1 uses Monday as the first day. This modification was necessary to conform with a legal opinion that the work

Bracket	M	T	W	T	F	S	S
1 (Day)	D	D	D	D	R	R	D
2 (Night)	N	N	N	R	R	N	N
3 (Relief)	A	R	R	N	N	D	A
4 (Afternoon)	R	A	A	A	A	A	R
5 (Floater)	D	D	D	D	D	R	R

One leadman is assigned to each bracket of the above schedule and works the schedule shown for that bracket for 10 weeks. At the end of 10 weeks, each employee rotates down to the next bracket in the schedule. The leadman assigned to bracket 5 rotates to bracket 1.

"D" denotes the day shift, 8:00 a.m. to 4:30 p.m.

"A" denotes the afternoon shift, 4:00 p.m. to 12:30 a.m.

"N" denotes the night shift, 12:00 midnight to 8:30 a.m.

Figure B-1

FRESNO WASTEWATER TREATMENT PLANT:
 SCHEDULE FOR FIVE LEADMEN
 IMPLEMENTED OCTOBER 1977

week for Fresno city employees commences on Monday. This change did not affect the schedule assignments within each bracket, but did alter the changeover properties when employees rotate brackets. The TIPPA version was designed so that each employee would be off duty for at least 24 hours before starting work on a different shift; the schedule in Figure B-1, however, violates this constraint for the employee in bracket 1. Only 7.5 hours off duty are provided when rotating from bracket 1 (day shift) to bracket 2 (night shift). Some employees objected to this temporary inconvenience, and it was necessary to adjust days off for bracket 1 during the tenth week to allow more time off between different shift assignments.

One leadman is on duty at all times, except on the day shift, Monday through Thursday, when two leadmen are on duty. The extra man on these shifts is the "floater," who is the designated substitute for any of the other leadmen who are absent due to illness, injury, vacation, or training. The variability of the floater's schedule is partially offset by the fact that he is off duty every weekend if no absences occur. The new schedule still requires a "relief" man to work three different shifts each week, as in the old schedule. However, the shift rotation sequence for the relief man is reversed, so that he receives at least 24 off-duty hours between shift changes.

Although none of the operators' schedules designed by TIPPA were implemented, knowledge of the schedule design techniques has improved the kinds of schedules being designed by the plant managers. Several factors unrelated to the quality of the TIPPA schedules contributed to the decision not to implement new work schedules for the operators. The primary factors were: (1) an

expectation that the number of operators employed would change several times within the next year; (2) a desire to keep the operators in five-man teams; and (3) anticipated schedule irregularities to accommodate training programs for several of the operators.

Exposure to the TIPPA schedule design methods did enable plant managers to improve the procedure used in designing operator's work schedules. TIPPA techniques are used to assess schedule changeover properties and adjust individual schedules as needed. The person in charge of work scheduling at the wastewater plant has stated that schedule design has been greatly simplified as a result of the training and insight he gained through the work scheduling project. As a result, the rotation pattern for each operator has been regularized, each operator receives more weekend days off, and the amount of time needed to design new schedules has been reduced from two days to less than half a day.*

In addition, plant operators and leadmen have been able to anticipate their schedule assignments for future rotation periods with some degree of assurance. This has allowed them more freedom to plan family, recreational, and educational activities several months in advance.

An unexpected outcome of the project occurred when the wastewater plant in Sanger, a small city near Fresno, inquired about scheduling practices used at the Fresno plant. As a result of this contact, the Sanger plant began using some of the scheduling techniques adopted in Fresno.

*Telephone conversation between the author (A. Gill) and Donald Ashlock, Fresno Wastewater Treatment Plant Operations Foreman, April 3, 1978.

Conclusions

While no major changes were made in the kinds of schedules used at the Fresno Wastewater Treatment Plant, an improved leadmen's schedule was adopted and improvements were made in the methods used to design operators' schedules. The specific benefits derived from the plant's participation in the work scheduling project include the following:

- The new leadman's schedule eliminated the need to redesign schedules at each rotation period.
- Improved shift rotation properties for the relief leadman were achieved without sacrificing management policies regarding permanent shift assignments for three leadmen and use of a designated "floater" leadman.
- The amount of time required to design new operators' schedules every three months was reduced from two days to less than half a day.
- Plant operators now receive more weekend days off than they did with previous schedules.
- Plant operators and leadmen have been able to anticipate their schedule assignments for future periods.

The experience of the Fresno Wastewater Treatment Plant demonstrates that significant work scheduling improvements can be realized without changing basic personnel policies regarding days off and frequency of shift rotation. The use of simple schedule design techniques can result in the saving of considerable amounts of administrative time and the provision of schedule benefits not previously thought possible.

E. San Diego Aquatics Division

Background

The goals of the San Diego Aquatics Division are to develop, utilize, and improve the recreational potential of San Diego's natural and man-made aquatic resources; to provide comprehensive

marine safety service to Mission Bay, City beaches and community pools; and to encourage citizen participation in the development of all types of aquatic programs that benefit the total community. The Aquatics Program provides lifeguard protection and supervision at the City's public beaches; conducts instructional programs in sailing, surfing, swimming and other water sports; and maintains the La Jolla Underwater Park, the San Diego Fishing Pier, the community pools, and Harbor Patrol.

Of primary concern to the work scheduling project were the Mission Bay and Ocean Lifeguard services. The Mission Bay Lifeguard Service provides protection at Crown Point Shores, Leisure Lagoon and Santa Clara, Ventura, Bonita, South Vacation Island, Information Cove, and De Anza Cove. Service is provided daily during spring vacation and the summer months. Weekend service is provided during early fall and late spring.

Ocean lifeguards provide lifeguard protection on 17 miles of ocean beach from Ocean Beach north to La Jolla Shores. Shore supervision utilizes visual surveillance, electronic communications, and walking and vehicular patrol. In addition to protecting designated beaches, lifeguards respond to emergencies at any location on the ocean front, provide contractual lifeguard service at the University of California beach adjacent to Scripps Institute of Oceanography, and conduct water search inspections, recovery missions, and cliff rescues as requested.

The Aquatics Division employs both full-time (permanent) and part-time (seasonal) lifeguards. Full-time year-round lifeguards in 1977 numbered about 66, but with part-time staff, the complement

is 120 full-time equivalents in non-summer months and 352 in the summer. Part-time personnel may work 40 hours per week during the summer. Each working shift normally has a nucleus of permanent personnel, supplemented by seasonal lifeguards.

Staffing requirements vary by beach and by time of day and day of the week, according to beach attendance patterns, water conditions, and type of beach. For example, over 90 percent of the rescues that occur on bay beaches are due to the "drop off" of the ocean floor. Since these rescues require very rapid responses, visual surveillance is maintained by spacing guards every 300 feet. By contrast, over 90 percent of the rescues that occur on ocean beaches are due to rip currents. Since the need for such rescues can be somewhat anticipated, additional staff can be dispatched to rescue scenes by jeep or boat. Guard towers on ocean beaches are spaced 500-700 feet apart. In addition, the rocky or isolated nature of some beaches necessitates an increased level of staffing at these locations.

Scheduling Objectives Addressed

Schedules for Aquatics Division personnel must be flexible to meet varying beach conditions. Since workload patterns vary from beach to beach, separate schedules are used for each beach. Increased staffing is usually needed on weekends and holidays and either eight-hour or ten-hour shifts may be used.

Permanent and seasonal staff working full time generally have fixed working hours and days off. Work rules for part-time staff are more flexible, and may include split days off and variable work hours. Some part-time staff are scheduled only as needed to provide extra coverage.

Despite the availability of large numbers of part-time personnel,

it has been nearly impossible for Aquatics Division staff to design schedules that match on-duty staffing levels with daily workload levels. One reason for this is the fact that beach attendance is much higher on weekends. Separate schedules designed for each beach prior to the summer season are often revised to meet changing needs. Schedule revisions are quite frequent.

The primary purpose of the scheduling project was to improve the schedule design and evaluation skills of Aquatics Division staff by utilizing improved procedures to design lifeguard work schedules. It was anticipated that use of these procedures would provide a means for effectively combining permanent and part-time lifeguard personnel to meet beach workload and for achieving improved utilization of existing personnel through workload-based allocation of the lifeguards by shift and day of the week.

Another purpose of the project was to reduce the amount of administrative time spent in designing, reviewing, and approving work schedules. It was also desired to explore the possibility of delegating schedule design to lower-level administrative personnel and of establishing standard design procedures for training purposes. Also, it was hoped that there would be increased management and employee satisfaction with the work schedules used.

Application of Innovative Scheduling Methods

Based upon data supplied by the Aquatics Division, the TIPPA staff analyzed the agency's workload on 19 beaches and designed a new work schedule for lifeguards at Black's Beach. The workload analysis provided a description of the average demand for lifeguard services by beach, month, and day of the week. Workload was measured in terms of beach attendance, number of water rescues, and

number of persons given first aid.

The workload analysis for Black's Beach is shown in Figure B-2. It should be noted that beach attendance and the number of water rescues were five times greater on weekends than during the week. However, this increased workload on weekends was not reflected in the number of lifeguards scheduled to be on duty under the Division's old work schedule. The old schedule provided for three lifeguards during the week and only one additional lifeguard on weekends.

Black's Beach lifeguards were selected as the subject of TIPPA schedule design assistance for several reasons. The beach itself is rather isolated, so lifeguards are permanently assigned to the beach and back-up assistance is usually not available from other beaches. The beach is located a considerable distance from downtown San Diego, so it is more popular on weekends than during the week. In addition, the beach had been designated as a "bathing suit optional" beach, which had greatly increased its popularity. As a result, more lifeguards were scheduled to be assigned to the beach in 1977, and new work schedules were needed.

Four different schedules were designed for the 19 lifeguards scheduled to be assigned to Black's Beach in 1977. All were 4/10 schedules--that is, each person would work four ten-hour days each week. The schedules provided different levels of on-duty staffing with 9 to 11 on-duty lifeguards during the week and 13 or 14 on duty on weekends.

In addition to the work schedules designed for Black's Beach, sample schedules were also designed for Lifeguard I personnel at Ocean Beach to illustrate how revised work schedules could be used to increase weekend staffing without increasing the total number of

A. Beach Attendance (in 1,000's)

	M	T	W	T	F	S	S	Total	Average Per Day M-F	S-S
June 15-30	5	5	7	5	5	26	33	86		
July	9	4	7	11	14	44	57	146		
August	15	11	11	13	8	34	82	174		
<u>September 1-15</u>	5	12	3	2	1	4	10	37		
<u>Total</u>	34	32	28	31	28	108	182		2.3	11.2

B. Number of Water Rescues

	M	T	W	T	F	S	S	Total	Average Per Day M-F	S-S
June 15-30	8	15	6	7	7	22	55	120		
July	8	0	2	3	8	25	28	74		
August	0	0	1	2	2	5	8	18		
<u>September 1-15</u>	0	0	0	0	0	0	2	2		
<u>Total</u>	16	15	9	12	17	52	93		1.0	5.6

C. Number of Persons Given First Aid

	M	T	W	T	F	S	S	Total	Average Per Day M-F	S-S
June 15-30	2	3	2	6	0	12	2	27		
July	4	3	3	3	3	6	6	28		
August	3	12	4	1	1	5	7	33		
<u>September 1-15</u>	0	0	1	0	0	0	0	1		
<u>Total</u>	9	18	10	10	4	23	15		0.8	1.5

Figure B-2

SAN DIEGO AQUATICS DIVISION:
1976 PEAK SEASON WORKLOAD
AT BLACK'S BEACH

lifeguards assigned to the beach.

Project Outcomes

The schedules designed by TIPPA were favorably received by Aquatics Division personnel. Several administrative difficulties, however, prevented implementation of any of these schedules during 1977. The Aquatics Division superintendent resigned his position, delaying reallocation of aquatics personnel. During this same period, the State of California indicated that it was considering assuming control of its portion of Black's Beach, which would have reduced the number of Aquatics Division personnel needed at the beach. Finally, a city referendum was scheduled on the "bathing suit optional" policy at Black's Beach, and it was anticipated that a negative vote on the policy would substantially reduce beach attendance. This, in turn, would even further reduce the number of Aquatics Division personnel needed at the beach.

Even without implementation experience, Aquatics Division personnel stated that they benefitted from participation in the work scheduling project. They believed that the project demonstrated that systematic techniques could be used to design work schedules to match on-duty staffing levels to agency workload, and they anticipated that in-house use of such techniques in the future would reduce the amount of time required to design new schedules. It was also felt that new schedules would increase employee morale since the rationale used to design the schedules could be more easily explained.

Aquatics Division personnel intend to use the schedule design handbook as their primary resource in designing agency work schedules, and are confident that use of the schedule design

techniques will yield significant benefits.

Conclusions

Administrative complications prevented the San Diego Aquatics Division from implementing a new lifeguards' schedule during the work scheduling project, even though acceptable schedules had been designed and substantial benefits were anticipated from their use.

F. Other Participating Agencies

This section describes the scheduling project's involvement with target agencies for which suitable work schedules were not found. These included the libraries in Anaheim and Santa Clara, the Fresno Fleet Maintenance, and Parks and Recreation Departments, the Pasadena Paramedic Ambulance Service, the Santa Clara Electric Department, and the Vehicle Maintenance Division in San Jose.

Anaheim and Santa Clara Libraries. The work scheduling project explored the possibility of applying innovative scheduling methods to public library personnel in Anaheim and Santa Clara. Operations in both libraries fit the initial criteria for involvement in the work scheduling project:

- Service is offered six or seven days per week and up to 12 hours per day (although hours may be shortened on weekends).
- Workload is cyclic by shift and day of the week, although workload patterns may change with the seasons.
- All employees share in evening and weekend work.
- Variable staffing levels are used, especially in positions involving public contact.

- Schedule design is a constant administrative chore, requiring substantial amounts of time.

Several factors, however, prevented the direct application of TIPPA schedule design techniques. Library personnel generally work no more than two nights per week and keep the same on-duty nights each week if possible. Generally, supervisors adjust working hours and days off for full-time employees to accommodate their personal needs (class schedules, spouse's days off, etc.) and large numbers of part-time personnel are used to supplement the coverage provided by full-time employees. The most effective employees are scheduled to be on duty during the busiest hours. As a result, scheduling library personnel has developed into a highly individualized and subjective process intended to maximize the quality of service provided to the public with a minimal disruption of employees' personal lives. In contrast, the schedule methods described in this handbook assume that all employees are interchangeable and will follow the same or nearly the same schedule. Such scheduling methods are only marginally applicable to individualized scheduling environments.

Fresno Fleet Maintenance Division. The Fresno Fleet Maintenance Division services and repairs all non-transit city vehicles on a round-the-clock basis. It was not possible for the agency to participate in the project initially because of a pending administrative reorganization. Late in the project a request was made by the agency superintendent for work schedules that would provide personnel distributions by day of the week that were proportional to workload, and would help to reduce the backlog of work experienced on Mondays. It was also requested that the schedules include

rotating days off, with occasional extended off-duty periods to boost employee morale and reduce absenteeism. Eight alternative schedules were designed for mechanics and servicemen and were reviewed by the superintendent. No final decision was made on the implementation of any of the schedules during the work scheduling project.

Fresno Parks and Recreation Department. The Fresno Parks and Recreation Department is responsible for landscape maintenance and cleaning at a large downtown shopping mall. Landscaping work is done during the day, Monday through Saturday, but sweeping and cleaning must be done at night and on weekends after stores and theaters are closed. Two maintenance workers are permanently assigned to nights (midnight to 8:30 a.m.), Tuesday through Saturday, and six workers are assigned to the day shift (7:00 a.m. to 3:30 p.m.). Day shift personnel rotate Saturday assignments. The Parks and Recreation Director wanted to review a schedule that would provide for regular rotation of shifts and Saturday assignments. Such a schedule was designed by TIPPA, but after reviewing the schedule, agency managers decided that such a schedule change was not feasible at that time.

Pasadena Paramedic Ambulance Service. The Pasadena Paramedic Ambulance Service uses work schedules similar to those used in the fire service: 24-hour shifts, 56-hour work week, three platoons, and uniform staffing. In 1977, however, the agency was operating with four fewer staff than it needed to provide full around-the-clock coverage. The resulting overtime work was creating serious fatigue problems for the paramedics. Schedules were designed by TIPPA to illustrate several policy alternatives: a permanent reduction in

the number of authorized personnel; a reduced average work week; and reduced levels of coverage during periods of slack workload. These schedules were reviewed by agency and city management personnel to assess the implications of these policy issues. Implementation of a new schedule for the paramedics was deferred pending negotiations with the employee's bargaining unit.

Santa Clara Electric Department. Operations personnel at the Santa Clara Electric Department monitor electric power equipment 24 hours a day, seven days a week. The utility employs six operators, and at least one must be on duty at all times. Designed with the cooperation and input of all six operators, the schedule used at the Electric Department met the personal preferences of the six individuals involved.

The department superintendent stated that compelling reasons would have to be shown before implementation of a new schedule would be considered. However, he was interested in seeing how scheduling could be simplified by using a more formalized system of rotating shifts and days off. Several sample schedules were designed by TIPPA and reviewed by the operations personnel. None were considered superior to the existing schedule.

San Jose Vehicle Maintenance Division. The San Jose Vehicle Maintenance Division is responsible for maintaining all of the city's rolling stock except fire department vehicles, airport vehicles, and water pollution control equipment. Routine servicing and refueling for police vehicles must be available 24 hours a day, seven days a week. Fixed bracket schedules are used for vehicle service workers, mainly to comply with the requirement that each employee receives two consecutive days off each week. Agency admin-

istrators thought that employee boredom and low morale were contributing to employee absenteeism. It was hoped that a new work schedule including periodic shift rotation and extended off-duty periods would help alleviate these problems. Also, it was hoped that a more proportional allocation of personnel by shift and day of the week would help reduce occasional service backlogs.

Nine schedules were designed for the Vehicle Maintenance Division. The advantages of these schedules were: occasional 3-day off-duty periods; more weekends off; and greater variety in work assignments. The proposed schedules did present some drawbacks: shift rotation for all employees would mean the loss of some shift differential pay, and team integrity would decline (i.e., the same employees would not always work together).

Due to the fact that labor relations issues would be raised by changes in scheduling practices, agency management personnel decided to proceed with a test implementation for a specified period of time with only one unit of service workers. An assessment of the schedule tested would be based on employee and management reactions. However, the test implementation was not initiated during the scheduling project pending finalization of the assessment methods to be used by a separate HUD-sponsored evaluation of the work scheduling project.

G. List of Project Participants

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APPENDIX C

MANAGEMENT PRACTICES AFFECTING
WORK SCHEDULING

APPENDIX C

MANAGEMENT PRACTICES AFFECTING WORK SCHEDULING

Work scheduling is an essential part of organizational management that both affects and is affected by many management practices. Work scheduling is closely related to an organization's personnel policies, the composition and deployment of the work force, and the use of substitute employees to maintain minimum staffing levels. This appendix discusses common practices in each of these areas and their relationship to work scheduling.

A. Personnel Policies

Employee Leave

Holidays, vacations, and other forms of employee leave affect scheduling by contributing to employee absences which reduce the size of the on-duty work force. Since holidays and vacations are usually scheduled in advance, their effects can be anticipated and somewhat controlled. Many forms of personal leave, however, are unscheduled, such as sick leave, and tend to be more disruptive. Procedures for administering the various types of leave are discussed below.

Holidays. In most organizations, designated holidays are observed by closing the agency for the day. Employees whose normal day off happens to be a designated holiday generally receive their next scheduled on-duty shift as their "holiday" or receive a compensatory day off at a later date. Scheduling holidays is more complicated in agencies which must provide service 24 hours per day, 7 days per week. For these agencies, alternative procedures are used for scheduling holidays:

- use of part-time employees on designated holidays (part-time employees generally are not entitled to bonus pay rates for holiday work, but may require supervision by some full-time employees);
- cash payment in lieu of holiday leave, either for those working on holidays, or for all employees, with perhaps a bonus rate paid to those working on the holiday;
- compensatory time off at a later date--scheduled at the discretion of individual employees with supervisory approval, or added to employees' annual vacation--for those employees working on holidays; or
- addition of off-duty days to the work schedule in lieu of holiday leave; these additional off-duty days are usually built into the schedule to make extended off-duty periods.

Vacations. Vacation leave is defined as a series of scheduled work assignments from which an employee is excused with pay as an annual fringe benefit. The actual amount of annual vacation received by each employee may be computed as:

- a specified number of on-duty shifts,
- a specified number of on-duty hours, or
- a specified number of calendar days or weeks, regardless of the number of on-duty assignments during those weeks.

The amount of vacation awarded to each employee generally increases with the employee's length of service.

Employees tend to prefer to take vacation leave at certain times of the year. To minimize operational disruptions and ensure employees access to desired vacation dates, the scheduling of vacation leave is usually subject to pre-specified restrictions.

For example:

- the number of employees on vacation in a schedule group may be limited to a specified maximum which may depend on the season of the year, the demand for agency services, or the size of the groups involved;
- the number of segments into which an employee's vacation can be divided may be restricted; a

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maximum may be imposed on the length of individual segments; or a minimum length may be imposed to prevent employees from randomly scheduling single days off duty;

- limitations may be imposed on the amount of vacation carried over from one year to the next; and
- the trading of vacation days among employees may be restricted.

Subject to these constraints, there are several ways in which employee vacations can be scheduled. The most common method allows employees to request vacation leave at any time during the year, provided that the request is submitted earlier than a specified number of days prior to the start of leave. Requests are then approved or disapproved on the basis of established policies regarding the number of employees that can be on vacation at the same time. Another method assigns vacation dates to each employee. These assignments are usually made in advance for an entire year on the basis of each supervisor's discretion, a random drawing, or a yearly rotation system. A third method allows employees to designate their vacation dates in advance by submitting preferences in writing, or by choosing in order of seniority from a list of available vacation periods. If requests are made in writing, a schedule designer must review each request and schedule each employee's vacations according to the availability of the dates listed. When the number of employees scheduled to be on vacation during some period reaches a specified maximum, that period is "closed" to further requests.

Sick and injury leave. Employee fringe benefits usually include a specified amount of leave with pay from scheduled work assignments for personal or family illness. In addition, leave is usually allowed for work-related injuries.

Sick leave normally accumulates at a specified rate per year or month of employee service. The rates of accrual may increase with the employee's length of service. In some organizations, the amount of leave allowed in individual cases may be left to the discretion of supervisors or personnel officers. The amount of injury leave allowed may be virtually unlimited. Unused sick leave and injury leave may be allowed to accumulate to a specified maximum, or unused leave may be lost at the end of the year. Occasionally, cash bonuses or additional vacation leave may be granted to employees who do not use any sick leave during a calendar year.

Proper administration of sick and injury leave necessitates that procedures be established for controlling and recording the use of such leave. In addition, procedures must be established for handling cases in which an employee's absence extends beyond his accumulated sick or injury leave.

Other forms of employee leave. By contributing to personnel shortages, other forms of employee leave, whether paid or unpaid, directly impact work scheduling in the same way as holiday, vacation, sick, and injury leave. Other forms of employee leave include the following:

- personal leave--leave allowed for dealing with personal emergencies;
- funeral leave--days off allowed in case of a death in an employee's immediate family; in some organizations, funeral leave may be deducted from accumulated sick leave;
- jury leave--leave for serving on juries;
- military leave--leave for employees to fulfill military obligations;
- educational leave--leave to attend school or obtain advanced training; and

- terminal leave--leave immediately prior to retirement, usually accrued at a specified rate per year or based on an employee's unused sick leave at the time of retirement.

Pay Procedures

Pay procedures affect scheduling by placing restrictions on the time period over which work hours are computed for paying overtime. For example, payment at overtime rates may be required for all hours worked in excess of (1) 40 hours in any calendar week, (2) 40 hours in any seven-day period, or (3) 80 hours in any two-week pay period. In general, these restrictions limit the range of scheduling alternatives that can be considered (e.g., a schedule that averages 40 hours per week is not acceptable if overtime must be paid for hours worked in excess of 40 hours in any calendar week).

Pay procedures may also influence the kind of schedule used if the amount of each employee's paycheck depends upon the number of hours worked. For such employees, schedules which vary the number of work days within each pay period (and hence the total wages received) are generally considered unacceptable.

Employee Seniority

Employee seniority is often used as the basis for assigning duties and schedule brackets. Employees with the most seniority may receive their choice of available shift assignments and days off. Often, such employees have worked for years with undesirable hours and days off and feel their status is justified. In such cases, it may be difficult to introduce a schedule which requires all employees to rotate shifts and days off equally. Such schedule equity is usually accepted only if alternative seniority benefits are adopted.

Schedule Equity

Schedule equity refers to the degree to which all employees in a work force share equally in shift assignments, weekends off, off-duty periods, and other schedule properties. The importance of schedule equity varies among organizations. In some cases, equity may not be desirable, especially if preferred schedule assignments are given to senior employees. In other cases, it may be important, such as when all employees need to be familiar with all phases of agency operation, including nighttime and weekend duties.

Accommodation of Employees' Outside Activities

Accommodation of employees' outside activities can complicate schedule design and administration. Examples of such accommodation include: the employee who asks to be off every Saturday so he can work a second job; the employee who asks to be off on Tuesday evenings to attend a college class; and the employee who asks to be off on Sunday and Monday so his days off coincide with his spouse's days off. Agency policies normally indicate the extent to which such requests can be honored, assuming that no conflict occurs with other, higher priority scheduling objectives (e.g., minimum on-duty staffing levels).

Shift Trades

In some agencies, employees are permitted to trade scheduled work assignments. This enables an employee to be off duty on a particular day for personal business, or to extend the length of a scheduled off-duty period. Shift trades may be subject to the following kinds of restrictions:

- advance notice of both the initiation and completion of the trade is required;

- supervisory approval must be obtained;
- trades must be made between employees of equal skill levels;
- limits on the number of trades within a specified period or on the number of trades by employees on the same shift; and
- prohibition of trades which extend off-duty periods, obligate the employer to pay overtime, or cause an employee to work consecutive shifts.

B. Composition and Deployment of the Work Force

Use of Part-Time Employees

Part-time employees are used extensively in some services to increase on-duty staffing levels during heavy workload hours or on days, such as weekends, when most full-time employees prefer to be off duty. Part-time employees often represent an attractive source of additional personnel due to their lower pay rates and lack of fringe benefits. In addition, many restrictions on working hours and days off may not apply to part-time employees, allowing increased management flexibility in responding to workload variations.

On the other hand, part-time employees may not be fully qualified to perform all duties and may require more supervision. Also, the turnover among part-time employees may be high.

Part-time employees may be scheduled as needed or given regular schedule assignments. As-needed scheduling allows the greatest degree of management flexibility, but requires constant supervisory attention and a system for notifying part-time employees of their work assignments. If workload patterns are predictable, a set of part-time schedule brackets can sometimes reduce the amount of supervisory attention needed.

Rotation of Employee Work Assignments

Some agencies regularly reassign employees to different duties, geographic locations, or facilities. This is usually done to familiarize employees with all aspects of agency operations or to provide employees with variety in work assignments. This practice can affect work schedules. For example, if employees in different units have different schedules, reassigned employees may be required to change work hours and days off, giving rise to changeover problems such as unacceptably long work periods, insufficient time off prior to beginning work on a new shift, or insufficient or excessive work days in the pay period during which the changeover is made.

Minimum Staffing Levels

Employee absences may reduce the size of the on-duty contingent below the minimum number needed to perform the work of the organization. In many agencies, this simply results in the curtailment of services. For essential services, such as utilities, management must determine the minimum number of on-duty employees required to maintain service. When absences reduce the number of on-duty employees in a unit below the established minimum staffing level, administrative procedures must be activated to obtain the additional personnel needed. These procedures may include the following:

- on-duty personnel with the necessary skills can be temporarily reassigned from other units with more than the minimum number of on-duty personnel;
- designated employees--known as floaters, swing personnel, or relief personnel--may be used to fill in for absences;
- on-duty employees can be held beyond the end of their assigned work shift (such "holdovers" are generally used as a temporary measure until other minimum staffing

procedures can be activated); and

- off-duty personnel may be recalled, with the specific employees to be recalled selected by supervisory discretion or chosen from a rotating list of volunteers.

The extra hours worked by employees as a result of holdovers or call-backs may be compensated with time off at a later date or overtime pay, usually computed as 1.5 times the employees' normal rate of pay. The use of compensatory time off may produce personnel shortages on future dates, especially if the amount of time off is computed as 1.5 times the amount of time worked. On the other hand, the payment of overtime can be expensive, possibly exceeding the cost of hiring additional personnel. (See Section C, below.) Excessive use of call-backs or holdovers may also contribute to employee fatigue, and increased use of sick leave.

Unity of Command and Team Integrity

Unity of command is a personnel management principle that is achieved when each employee reports to the same supervisor at all times. When supervisors' schedules are not identical to those of their subordinates, it may not be possible to achieve complete unity of command for all personnel.

Team integrity is a personnel management principle that is achieved when a group of employees who must work together as a team are on and off duty at the same times--in other words, whenever the group is on duty, no team members have scheduled days off and no "outsiders" are scheduled to serve as on-duty members of the team. Unity of command and team integrity are usually considered to be desirable in that they are conducive to good teamwork and effective supervision. However, it is sometimes desirable to avoid these conditions so that all agency personnel have

an opportunity to familiarize themselves with other supervisors and employees and to help standardize supervisory practices.

If unity of command and team integrity are important to the management and operations of a particular work force, proposed work schedules should be reviewed to determine the extent to which these objectives are achieved. For example, Kelly days and payback days will disrupt team integrity by causing some members of a team to be on or off duty when other team members are not. This can only be avoided when all members of a team have the same Kelly or payback days, a condition which usually results in excessive variations in the number of on-duty personnel.

C. The Cost of Using Substitute Employees to Maintain Minimum Staffing Levels

The need to have at least a minimum number of employees on duty at all times usually introduces additional administrative problems and costs. These arise when substitute employees must be used to meet minimum staffing levels due to the absence of one or more regularly-scheduled employees. This section briefly reviews the advantages and disadvantages of using substitute workers, and introduces a method for estimating the number of staff-days for which substitute workers will be needed. Using this method, it is possible to examine the economic tradeoffs involved in using substitute workers instead of hiring additional full-time employees.

Full-Time Versus Substitute Employees--An Administrative Tradeoff

Maintaining only a minimum number of full-time employees and relying on substitute workers to fill in whenever necessary is often seen as a way to hold down personnel costs. Frequent use of substitute employees, however, can be expensive; considerable

administrative effort may be required to find and schedule substitute personnel on short notice, substitute workers may not have the same skills as full-time personnel or may not fit well into team-oriented operations, and substitute workers may require overtime payment if full-time employees are used. In addition, use of full-time employees as substitute workers may result in lower employee productivity and higher accident rates due to employee fatigue. In contrast, the expense of hiring additional full-time employees to lessen the need for substitute workers is usually not viewed as a viable alternative by many agencies.

No single solution to this problem can be given for all situations. Factors which are likely to influence the policy followed are the employee absentee rate, the cost of each full-time employee, the daily cost of a substitute worker, the skills required for a job, the availability of substitute workers, and the administrative policies and traditions of an agency.

Estimating How Often Substitute Employees Will Be Needed

The frequency with which one or more substitute workers will be needed is related to three factors:

- (1) the employee absentee rate,
- (2) the number of employees scheduled to report for work,
and
- (3) the minimum number of employees required to be on duty.

The employee absentee rate for an agency can be calculated using the following information and terms:

ERDO - number of employee regular days off per year (e.g., if a worker receives two days off per week, he will receive 104 regular days off per year).

EBDO - average number of employee benefit days off per year including holidays, vacation days, sick leave, etc.

AH - number of agency holidays per year; the annual number of days when all employees are off duty at the same time with pay (e.g., Christmas, Thanksgiving, the Fourth of July, etc.).

AR - absentee rate; the fraction of time that an employee will be absent due to illness, vacation, individual holidays, etc.

Using these terms, the employee absentee rate can be determined with the following formula:

$$\left(\begin{array}{c} \text{absentee} \\ \text{rate} \end{array} \right) = \frac{\left(\begin{array}{c} \text{number of absences/} \\ \text{employee/year} \end{array} \right)}{\left(\begin{array}{c} \text{number of scheduled} \\ \text{work days/employee/year} \end{array} \right)}$$

$$AR = \frac{EBDO - AH}{365 - ERDO - AH} \quad (C-1)$$

It should be noted in formula (C-1) that employee absences per year include both scheduled and unscheduled time off (e.g., vacation days and sick leave), and individually scheduled time off for holidays. Employees absences, however, do not include days off for agency holidays or regular days off. To illustrate how formula (C-1) is used, consider an agency with the following characteristics:

- the agency provides 11 common holidays per year (AH = 11);
- each employee receives an average of 33.5 benefit days off per year (EBDO = 33.5); these benefit days include the 11 common holidays; and
- each employee receives 104 regular days off per year (ERDO = 104).

Using these data, the absentee rate is calculated as

$$\begin{aligned} AR &= \frac{EBDO - AH}{365 - ERDO - AH} \\ &= \frac{33.5 - 11}{365 - 104 - 11} \\ &= \frac{22.5}{250} \end{aligned}$$

$$\text{AR} = .09.$$

For this agency, the average employee is absent nine percent of the time. Employee absentee rates usually fall between 5 and 15 percent (i.e., AR values are between .05 and .15).

Once the employee absentee rate is known for an agency, the amount of time substitute employees will be needed to maintain a minimum staffing level for any period of time can be estimated by referring to tables like the one shown on Table C-1. Each entry in this table indicates the average number of staff-days that will have to be provided by substitute workers on each service day in order to maintain a specified minimum staffing level. All of the entries in Table C-1 correspond to an employee absentee rate of nine percent.* To find the table entry that corresponds to a specified number of scheduled employees and a required minimum staffing level, first locate the column that corresponds to the minimum staffing level. Next read down that column and locate the entry that corresponds to the number of employees scheduled to work. To determine the annual number of staff-days that will have to be filled by substitute workers, multiply the table entry by the number of agency service days per year.

As an example, suppose that an agency with a nine percent employee absentee rate must have at least 18 employees on duty on every service day of the year. To protect itself against employee absences, the agency routinely schedules 20 employees to report for work. Despite the fact that more employees are scheduled to report

*A series of tables corresponding to employee absentee rates from 5 to 15 percent are presented in Appendix D.

Table C-1

DAILY AVERAGE NUMBER OF STAFF-DAYS COVERED BY SUBSTITUTE WORKERS TO
 MAINTAIN A SPECIFIED MINIMUM STAFFING LEVEL,
 EMPLOYEE ABSENTEE RATE OF 9 PERCENT

(AR = .09)

Minimum Staffing Level (Number of Employees)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.090	<u>1.090</u>																		
2	.008	.180	<u>1.180</u>																	
3	.001	.024	.270	<u>1.270</u>																
4		.003	.046	.360	<u>1.360</u>															
5			.007	.074	.450	<u>1.450</u>														
6			.001	.013	.108	.540	<u>1.540</u>													
7				.002	.021	.147	.630	<u>1.630</u>												
8					.004	.033	.190	.720	<u>1.720</u>											
9					.001	.006	.047	.238	.810	<u>1.810</u>										
10					.001	.010	.064	.289	.900	<u>1.900</u>										
11						.002	.015	.084	.344	.990	<u>1.990</u>									
12							.003	.021	.108	.402	<u>1.080</u>	<u>2.080</u>								
13							.001	.005	.029	.134	.463	<u>1.170</u>	<u>2.170</u>							
14								.001	.007	.038	.164	.537	<u>1.260</u>	<u>2.260</u>						
15									.001	.010	.050	.197	.593	<u>1.350</u>	<u>2.350</u>					
16										.002	.013	.063	.232	.661	<u>1.440</u>	<u>2.440</u>				
17											.003	.018	.078	.271	.731	<u>1.530</u>	<u>2.530</u>			
18											.001	.005	.023	.095	.312	.803	<u>1.620</u>	<u>2.620</u>		
19												.001	.006	.030	.115	.356	.877	<u>1.710</u>	<u>2.710</u>	
20													.002	.008	.037	.137	.403	.952	<u>1.800</u>	
21														.002	.011	.046	.161	.453	<u>1.030</u>	
22															.003	.014	.057	.187	.504	
23															.001	.004	.018	.068	.216	
24																.001	.005	.022	.082	
25																	.001	.007	.028	

Omitted entries in each row in the upper right-hand portion of the table can be determined by adding 1.000 to each successive entry to the right beginning at the underlined entry in each row (e.g., the entry for 7 scheduled employees and a minimum staffing level of 10 is 3.630).

All entries in lower left equal .000

334

Number
of
Employees
Scheduled
To
Work

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
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24
25

for work than are absolutely needed, the agency will occasionally need to use substitute workers--more precisely, it will need substitute workers whenever three or more regularly-scheduled employees are absent. An estimate of the number of staff-days that will need to be provided by substitute workers per service day can be obtained by finding the entry in Table C-1 that corresponds to 20 regularly-scheduled employees and a minimum staffing level of 18 workers. The appropriate entry in Table C-1 equals .403 which indicates that, on the average, .403 staff-days will be covered by substitute workers each day. Since the agency provides service on 254 days of the year, the annual number of staff-days that will have to be covered by substitute employees equals 102.36 (i.e., $254 \times .403$) or 818.88 staff-hours if eight-hour shifts are used.*

If an agency knows the daily cost of one substitute worker, the annual cost for substitute employees can be easily computed by multiplying the daily or hourly cost by the annual number of staff-days or hours to be covered. For example, if the agency described above pays \$12 per hour for substitute help, the annual cost to the agency will equal \$9,826.56 (i.e., \$12 per hour \times 818.88 staff-hours).

With estimates of the annual cost of using substitute workers, it is possible to examine the cost impact of using different numbers of full-time and substitute workers to maintain a specified staffing level. Total staff cost can be considered as the sum of two parts: the annual cost of the full-time staff including direct salary or wages and fringe benefits, and the annual cost of using

*The annual number of staff-days can be converted to staff-hours by multiplying the number of staff-days by the shift length in hours.

substitute workers; i.e.,

$$\left(\begin{array}{l} \text{total annual} \\ \text{staff cost} \end{array} \right) = \left(\begin{array}{l} \text{annual cost for} \\ \text{full-time staff} \end{array} \right) + \left(\begin{array}{l} \text{annual cost for} \\ \text{substitute workers} \end{array} \right) \quad (\text{C-2})$$

The annual cost for the full-time staff can be estimated with the following terms:

NFE - number of full-time employees

CFE - annual cost (direct and overhead) for each full-time worker.

The annual cost for full-time staff is given by

$$\left(\begin{array}{l} \text{annual cost for} \\ \text{full-time staff} \end{array} \right) = \text{CFE} \times \text{NFE}. \quad (\text{C-3})$$

The annual cost for substitute workers can be estimated using the procedure described above. This procedure can be summarized using the following terms:

ASD - number of agency service days per year

SD - average number of staff-days covered by substitute workers each day

CS - daily cost of one substitute worker.

The total annual cost for substitute workers is given by

$$\left(\begin{array}{l} \text{annual cost for} \\ \text{substitute workers} \end{array} \right) = \text{ASD} \times \text{SD} \times \text{CS}. \quad (\text{C-4})$$

The value for SD is obtained by calculating the employee absentee rate, selecting the appropriate table in Appendix D (i.e., the table based on an absentee rate closest to the actual agency rate), and finding the table entry corresponding to the number of regularly-scheduled employees and specified minimum staffing level.

The number of regularly-scheduled employees (NRSE) used to determine SD is based on the total number of full-time employees

(NFE), the employee absentee rate (AR), and the agency shift relief factor (SRF). The formula for determining NRSE is

$$\text{NRSE} = \frac{\text{NFE}}{(1-\text{AR}) \times \text{SRF}} \quad (\text{C-5})$$

When formula (C-5) is used, the resulting value for NRSE often is not a whole number. Such a result indicates that it is not possible to schedule the same number of on-duty employees on every agency service day. When this occurs, the appropriate value for SD must be estimated by interpolating between the SD values associated with the two whole numbers closest to NRSE.

As an example, assume that an agency with 25 full-time employees (NFE = 25) has a shift relief factor of 1.7 (SRF = 1.7) and an employee absentee rate of 12 percent (AR = .12). Using formula (C-5) the average number of regularly-scheduled employees is

$$\begin{aligned} \text{NRSE} &= \frac{\text{NFE}}{(1-\text{AR}) \times \text{SRF}} \\ &= \frac{25}{(1-.12) \times 1.7} \\ &= \frac{25}{1.496} \end{aligned}$$

$$\text{NRSE} = 16.71 \text{ employees.}$$

This value for NRSE indicates that the agency will be able to schedule 16 employees on some days and 17 employees on others. If the agency has a minimum staffing requirement of 15 workers, an estimate of SD for NRSE = 16.71 can be obtained by interpolating between the SD values for 16 and 17 on-duty employees using Table D-8.

Interpolating between SD values is done by noting that if the value for NRSE is not a whole number, it can be expressed as the

sum of a whole number and a fraction; i.e.,

$$\text{NRSE} = (\text{whole number}) + (\text{fraction}).$$

In the example above, the NRSE value of 16.71 employees can be expressed as the sum of 16 and .71; i.e.,

$$\text{NRSE} = 16 + .71.$$

An estimate of the SD value for NRSE can be determined using the following terms:

SDL - SD value based on the (whole number) of employees

SDH - SD value based on the 1 + (whole number) of employees

F - fraction part of NRSE.

The interpolated value of SD is given by

$$\text{SD} = \text{SDL} + F \times (\text{SDH} - \text{SDL}). \quad (\text{C-6})$$

To continue the example for the agency with a value of NRSE = 16.71 employees, the interpolated value for SD is given by

$$\begin{aligned} \text{SD} &= \text{SDL} + F \times (\text{SDH} - \text{SDL}) \\ &= 1.049 + .71 \times (.531 - 1.049) \\ &= 1.049 + .71 \times (-.518) \\ &= 1.049 - .368 \\ \text{SD} &= .681 \end{aligned}$$

where SDL = 1.049 is the SD value in Table D-8 when 16 employees are scheduled to be on duty and SDH = .531 is the SD value in Table D-8 when 17 employees are scheduled to be on duty.

To illustrate how formulas (C-3), (C-4), and (C-5) can be used to analyze the relative costs of full-time and substitute workers,

consider an agency with the following characteristics:

- an employee absentee rate of 12 percent (AR = .12),
- a shift relief factor of 1.7 (SRF = 1.7),
- an annual cost for each full-time employee of \$15,000 (CFE = 15,000),
- service provided on 365 days a year (ASD = 365), and
- a daily cost of \$90 for one substitute worker (CS = 90).

Putting these values into formula (C-3) yields

$$\begin{aligned} \left(\begin{array}{l} \text{annual cost for} \\ \text{full-time staff} \end{array} \right) &= \text{CFE} \times \text{NFE} \\ &= 15,000 \times \text{NFE}. \end{aligned}$$

Using the other data in formula (C-4) yields

$$\begin{aligned} \left(\begin{array}{l} \text{annual cost for} \\ \text{substitute workers} \end{array} \right) &= \text{ASD} \times \text{SD} \times \text{CS} \\ &= 365 \times \text{SD} \times 90 \\ &= 32,850 \times \text{SD}. \end{aligned}$$

This result indicates that it would cost the agency \$32,850 to use one substitute worker for an entire year. Combining these results yields

$$\begin{aligned} \left(\begin{array}{l} \text{total annual} \\ \text{staff cost} \end{array} \right) &= \left(\begin{array}{l} \text{annual cost for} \\ \text{full-time staff} \end{array} \right) + \left(\begin{array}{l} \text{annual cost for} \\ \text{substitute workers} \end{array} \right) \text{(C-7)} \\ &= 15,000 \times \text{NFE} + 32,850 \times \text{SD}. \end{aligned}$$

Formula (C-7) can be used to calculate the total annual staff cost for any number of full-time employees and minimum staffing level.

As an example, assume that this agency must have at least 15 employees on duty on each day of the year. To determine how many full-time employees the agency should have, formula (C-7) is used to

determine what number of full-time employees will produce the lowest total annual staff cost. The results of these calculations are shown in Table C-2. The total annual cost for a full-time staff of from 22 to 27 employees is shown in column (2). The average number of regularly-scheduled employees (NRSE) is shown in column (3). The average number of staff-days per service day (SD) covered by substitute employees for each value of NRSE is shown in column (4). Each SD value is obtained by using formula (C-6) and Table D-8 in Appendix D. To illustrate how the values in columns (3) and (4) are derived, consider the case when 22 full-time employees are available. The average number of regularly-scheduled employees is given by formula (C-5):

$$\begin{aligned}
 \text{NRSE} &= \frac{\text{NFE}}{(1-\text{AR}) \times \text{SRF}} \\
 &= \frac{22}{(1-.12) \times 1.7} \\
 &= \frac{22}{.88 \times 1.7} \\
 &= \frac{22}{1.496} \\
 \text{NSE} &= 14.706 \text{ employees.}
 \end{aligned}$$

This result indicates that the agency will be able to schedule 14 employees on some days and 15 employees on others. The SD value for 14.706 employees is determined with formula (C-6):

$$\begin{aligned}
 \text{SD} &= \text{SDL} + \text{F} \times (\text{SDH} - \text{SDL}) \\
 &= 2.680 + .706 \times (1.800 - 2.680) \\
 &= 2.680 + .706 \times (-.880) \\
 &= 2.680 - .621 \\
 \text{SD} &= 2.059 \text{ staff-days/service-day.}
 \end{aligned}$$

Table C-2

TOTAL STAFF COSTS TO MAINTAIN A MINIMUM STAFFING
LEVEL OF 15 ON-DUTY EMPLOYEES

Number of Full-Time Employees, NFE (1)	Annual Cost for Full-Time Employees, 15,000 x NFE (2)	Avg. No. of Scheduled Employees Per Day NRSE ^a (3)	Avg. No. of Staff-Days Covered By Substitute Workers Per Day SD ^b (4)	Annual Cost for Substitute Workers 32,850 x SD ^c (5)	Total Annual Staff Cost((2)+(5)) (6)
22	330,000	14,706	2.059	67,638	397,638
23	345,000	15,374	1.519	49,899	394,899
24	360,000	16,043	1.027	33,737	393,737
25	375,000	16,711	0.681	22,371	397,371
26	390,000	17,380	0.419	13,764	403,764
27	405,000	18,048	0.230	7,556	412,556

^aBased on a shift relief factor of 1.7 and an employee absentee rate of 12 percent. See formula (C-5).

^bBased on an employee absentee rate of 12 percent, a minimum staffing level of 15 employees, and the average number of scheduled employees shown in column (3). See formula (C-6) and Table D-8.

^cAssume the agency provides service 365 days a year, and a daily cost of \$90 for one substitute worker.

The annual cost for substitute workers is shown in column (5), and the total annual staff cost is shown in column (6). Examination of the costs in column (6) indicate that the lowest total staff cost is obtained with a full-time staff of 24 employees which will allow the agency to schedule between 16 and 17 on-duty employees each day. These cost estimates can now be used with other factors of the decision process (e.g., the availability of substitute workers and the amount of administrative time needed to schedule such workers) to determine what mix of full-time and substitute employees is most appropriate for this agency.

APPENDIX D

TABLES FOR ESTIMATING THE DAILY AVERAGE
NUMBER OF STAFF-DAYS COVERED BY SUBSTITUTE
WORKERS TO MAINTAIN A SPECIFIED MINIMUM
STAFFING LEVEL

TABLE D-2

DAILY AVERAGE NUMBER OF STAFF-DAYS COVERED BY SUBSTITUTE WORKERS TO
 MAINTAIN A SPECIFIED MINIMUM STAFFING LEVEL,
 EMPLOYEE ABSENTEE RATE OF 6 PERCENT

(AR = .06)

Minimum Staffing Level (Number of Employees)

346

Number
 Of
 Employees
 Scheduled
 To
 Work

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	.060	<u>1.060</u>																			
2	.004	<u>.120</u>	<u>1.120</u>																		
3		.011	<u>.180</u>	<u>1.180</u>																	
4		.001	.021	<u>.240</u>	<u>1.240</u>																
5			.002	.034	<u>.300</u>	<u>1.300</u>															
6				.004	.050	<u>.360</u>	<u>1.360</u>														
7					.007	.068	<u>.420</u>	<u>1.420</u>													
8					.001	.010	.090	<u>.480</u>	<u>1.480</u>												
9						.001	.015	.113	<u>.540</u>	<u>1.540</u>											
10							.002	.021	.139	<u>.600</u>	<u>1.600</u>										
11								.003	.028	.166	<u>.660</u>	<u>1.660</u>									
12									.005	.036	.196	<u>.720</u>	<u>1.720</u>								
13									.001	.007	.046	.227	<u>.780</u>	<u>1.780</u>							
14										.001	.009	.057	.261	<u>.840</u>	<u>1.840</u>						
15											.002	.012	.069	.295	<u>.900</u>	<u>1.900</u>					
16												.002	.015	.083	.332	<u>.960</u>	<u>1.960</u>				
17													.003	.019	.098	.369	<u>1.020</u>	<u>2.020</u>			
18														.004	.024	.114	.408	<u>1.080</u>	<u>2.080</u>		
19														.001	.005	.029	.132	.449	<u>1.140</u>	<u>2.140</u>	
20															.001	.007	.036	.151	.490	<u>1.200</u>	
21																.001	.008	.042	.171	.533	
22																	.002	.010	.050	.193	
23																		.002	.013	.059	
24																			.003	.016	
25																				.001	.004

Omitted entries in each row in the upper right-hand portion of the table can be determined by adding 1.000 to each successive entry to the right beginning at the underlined entry in each row (e.g., the entry for 7 scheduled employees and a minimum staffing level of 10 is 3.420).

All entries in lower left equal .000

Table D-4

DAILY AVERAGE NUMBER OF STAFF-DAYS COVERED BY SUBSTITUTE WORKERS TO
 MAINTAIN A SPECIFIED MINIMUM STAFFING LEVEL,
 EMPLOYEE ABSENTEE RATE OF 8 PERCENT

(AR = .08)

Minimum Staffing Level (Number of Employees)

348

Number
 of
 Employees
 Scheduled
 To
 Work

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	.08	1.080																			
2	.006	<u>.160</u>	1.160																		
3	.001	.019	.240	<u>1.240</u>																	
4		.002	.036	.320	<u>1.320</u>																
5			.005	.059	.400	<u>1.400</u>															
6			.001	.009	.086	.480	<u>1.480</u>														
7				.001	.015	.118	.560	<u>1.560</u>													
8					.002	.023	.153	.640	<u>1.640</u>												
9						.004	.034	.192	.720	<u>1.720</u>											
10						.001	.006	.047	.234	.800	<u>1.800</u>										
11							.001	.010	.062	.280	.880	<u>1.880</u>									
12								.002	.014	.079	.328	.960	<u>1.960</u>								
13									.003	.019	.099	.378	1.040	<u>2.040</u>							
14										.004	.025	.121	.431	1.120	<u>2.120</u>						
15										.001	.006	.033	.146	.486	1.200	<u>2.200</u>					
16											.001	.008	.042	.173	.543	1.280	<u>2.280</u>				
17												.002	.011	.053	.203	.602	1.360	<u>2.360</u>			
18													.002	.014	.065	.235	.663	1.440	<u>2.440</u>		
19														.003	.018	.078	.269	.725	1.520	<u>2.520</u>	
20															.001	.005	.023	.093	.306	.789	1.600
21																.001	.006	.029	.110	.344	.854
22																	.001	.008	.035	.129	.385
23																		.002	.010	.043	.150
24																			.003	.013	.051
25																			.001	.003	.016

Omitted entries in each row in the upper right-hand portion of the table can be determined by adding 1.000 to each successive entry to the right beginning at the underlined entry in each row (e.g., the entry for 7 scheduled employees and a minimum staffing level of 10 is 3.560).

All entries in lower left equal .000

Table D-6

DAILY AVERAGE NUMBER OF STAFF-DAYS COVERED BY SUBSTITUTE WORKERS TO
 MAINTAIN A SPECIFIED MINIMUM STAFFING LEVEL,
 EMPLOYEE ABSENTEE RATE OF 10 PERCENT

(AR = .10)

Minimum Staffing Level (Number of Employees)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.100	<u>1.100</u>																		
2	.010	.200	<u>1.200</u>																	
3	.001	.029	.300	<u>1.300</u>																
4		.004	.056	.400	<u>1.400</u>															
5			.009	.090	.500	<u>1.500</u>														
6			.001	.017	.131	.600	<u>1.600</u>													
7				.003	.029	.178	.700	<u>1.700</u>												
8					.005	.044	.230	.800	<u>1.800</u>											
9					.001	.009	.062	.287	.900	<u>1.900</u>										
10						.002	.015	.085	.349	1.000	<u>2.000</u>									
11							.003	.022	.111	.414	1.400	<u>2.400</u>								
12							.001	.005	.031	.141	.482	1.200	<u>2.200</u>							
13								.001	.007	.042	.176	.554	1.300	<u>2.300</u>						
14									.002	.011	.055	.213	.629	1.400	<u>2.400</u>					
15										.003	.015	.071	.255	.706	1.500	<u>2.500</u>				
16										.001	.004	.021	.089	.300	.785	1.600	<u>2.600</u>			
17											.001	.006	.028	.110	.349	.867	1.700	<u>2.700</u>		
18												.001	.008	.036	.134	.400	.950	1.800	<u>2.800</u>	
19													.002	.011	.046	.161	.455	1.040	1.900	<u>2.900</u>
20														.003	.014	.057	.190	.513	1.120	2.000
21														.001	.004	.018	.071	.223	.574	1.210
22															.001	.005	.024	.086	.258	.638
23																.001	.007	.030	.103	.296
24																	.002	.010	.037	.122
25																		.003	.012	.046

Omitted entries in each row in the upper right-hand portion of the table can be determined by adding 1.000 to each successive entry to the right beginning at the underlined entry in each row (e.g., the entry for 7 scheduled employees and a minimum staffing level of 10 is 3.700).

All entries in lower left equal .000

350
 Number
 of
 Employees
 Scheduled
 To
 Work

1
 2
 3
 4
 5
 6
 7
 8
 9
 10
 11
 12
 13
 14
 15
 16
 17
 18
 19
 20
 21
 22
 23
 24
 25

Table D-7

DAILY AVERAGE NUMBER OF STAFF-DAYS COVERED BY SUBSTITUTE WORKERS TO
 MAINTAIN A SPECIFIED MINIMUM STAFFING LEVEL,
 EMPLOYEE ABSENTEE RATE OF 11 PERCENT

(AR = .11)

Minimum Staffing Level (Number of Employees)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Number	.100	<u>1.110</u>																		
of	.012	<u>.220</u>	<u>1.220</u>																	
Employees	.001	.035	<u>.330</u>	<u>1.330</u>																
Scheduled		.005	.067	<u>.440</u>	<u>1.440</u>															
To		.001	.012	.108	<u>.550</u>	<u>1.550</u>														
Work			.002	.023	.157	<u>.660</u>	<u>1.660</u>													
				.004	.037	.212	<u>.770</u>	<u>1.770</u>												
				.001	.008	.057	.274	<u>.880</u>	<u>1.880</u>											
					.002	.013	.080	.340	<u>.990</u>	<u>1.990</u>										
						.003	.021	.109	.412	<u>1.100</u>	<u>2.100</u>									
							.005	.030	.142	.488	<u>1.210</u>	<u>2.210</u>								
							.001	.008	.043	.180	.567	<u>1.320</u>	<u>2.320</u>							
								.002	.011	.058	.223	.650	<u>1.430</u>	<u>2.430</u>						
									.003	.017	.176	.270	.736	<u>1.540</u>	<u>2.540</u>					
									.001	.004	.023	.097	.321	.824	<u>1.650</u>	<u>2.650</u>				
										.006	.031	.122	.376	.915	<u>1.760</u>	<u>2.760</u>				
										.002	.009	.041	.150	.436	1.008	<u>1.870</u>	<u>2.870</u>			
											.002	.013	.053	.181	.499	1.103	<u>1.980</u>	<u>2.980</u>		
											.001	.004	.017	.067	.216	.565	1.199	<u>2.090</u>	<u>3.090</u>	
												.001	.005	.023	.084	.255	.635	1.297	<u>2.200</u>	
													.001	.007	.029	.102	.296	.708	1.397	
														.002	.009	.037	.124	.342	.783	
															.003	.013	.047	.148	.390	
															.001	.004	.016	.058	.174	
																.001	.005	.021	.071	

Omitted entries in each row in the upper right-hand portion of the table can be determined by adding 1.000 to each successive entry to the right beginning at the underlined entry in each row (e.g., the entry for 7 scheduled employees and a minimum staffing level of 10 is 3.770).

All entries in lower left equal .000

Table D-8

DAILY AVERAGE NUMBER OF STAFF-DAYS COVERED BY SUBSTITUTE WORKERS TO
 MAINTAIN A SPECIFIED MINIMUM STAFFING LEVEL,
 EMPLOYEE ABSENTEE RATE OF 12 PERCENT

(AR = .12)

Minimum Staffing Level (Number of Employees)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.120	<u>1.120</u>																		
2	.014	.240	<u>1.240</u>																	
3	.002	.041	.360	<u>1.360</u>																
4		.006	.080	.480	<u>1.480</u>															
5		.001	.015	.128	.600	<u>1.600</u>														
6			.003	.029	.184	.720	<u>1.720</u>													
7				.006	.047	.249	.840	<u>1.840</u>												
8				.001	.011	.072	.320	.960	<u>1.960</u>											
9					.002	.018	.101	.396	1.080	<u>2.080</u>										
10						.004	.028	.137	.479	1.200	<u>2.200</u>									
11						.001	.007	.041	.178	.565	1.320	<u>2.320</u>								
12							.002	.011	.058	.224	.656	1.440	<u>2.440</u>							
13								.003	.017	.078	.276	.750	1.560	<u>2.560</u>						
14								.001	.004	.024	.101	.333	.847	1.680	<u>2.680</u>					
15									.001	.007	.033	.129	.395	.947	1.800	<u>2.800</u>				
16										.002	.010	.045	.161	.461	1.049	1.920	<u>2.920</u>			
17											.003	.014	.059	.197	.531	1.154	2.040	<u>3.040</u>		
18											.001	.004	.019	.075	.237	.606	1.260	2.160	<u>3.160</u>	
19												.001	.006	.026	.095	.281	.685	1.368	2.280	<u>3.280</u>
20													.002	.008	.034	.117	.330	.767	1.478	<u>2.400</u>
21														.003	.012	.044	.143	.382	.852	<u>1.588</u>
22														.001	.004	.015	.056	.171	.439	<u>.940</u>
23															.001	.005	.020	.070	.203	<u>.499</u>
24																.002	.007	.026	.086	<u>.239</u>
25																	.002	.009	.033	<u>.104</u>

Omitted entries in each row in the upper right-hand portion of the table can be determined by adding 1.000 to each successive entry to the right beginning at the underlined entry in each row (e.g., the entry for 7 scheduled employees and a minimum staffing level of 10 is 3.840).

All entries in lower left equal .000

352

Number
of
Employees
Scheduled
To
Work

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

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