Transportation Management Center Staffing and Scheduling for Day-to-Day Operations

Final Report

January 2006

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16. Abstract

The Transportation Management Center Staffing and Scheduling for Day-to-Day Operations technical document provides managers, supervisors, human resource personnel, and private contractors who are responsible for TMC staffing and scheduling decisions with a reference that addresses the concepts, methods, processes, tasks, techniques, and other issues related to work analysis, scheduling, and staff planning. Several methods for analyzing aspects of work are covered, including job analysis, workload analysis, and demand analysis. Next, general scheduling practices are discussed, from who should have the responsibility for scheduling employees to manual methods for generating a schedule. Several chapters address issues associated with shiftwork and offer strategies associated with adjusting to a work schedule for employees and employers. The final chapter covers how to create a staffing plan and planning for emergencies.

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List of Acronyms and Abbreviations

ADA	Americans with Disabilities Act
Admin.	Administrative
APTS	Advanced Public Transportation Systems
AVC	Automated Vehicle Classification
BAC	Blood Alcohol Concentration
BEST	Bulletin of European Studies on Time
CCTV	Closed Circuit Television
CDC	Centers for Disease Control and Prevention
CMS	Changeable Message Sign
CPS	Current Population Survey
Dev.	Development
DHHS	Department of Health and Human Services
DMVS	Department of Motor Vehicle Safety
DOT	Department of Transportation
EEO	Equal Employment Opportunity
EIT	Electronic and Information Technology
Eng.	Engineer
Exp.	Experience
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FO	Field Office
GDOT	Georgia Department of Transportation

GTRI	Georgia Tech Research Institute
HAR	Highway Advisory Radio
HOV	High Occupancy Vehicle
IFTA	International Fuel Tax Agreement
ILO	International Labour Organization
IRP	Internal Registration Plan
IT	Information Technology
ITS	Intelligent Transportation Systems
KSA	Knowledge, Skills, and Abilities
KSAO	Knowledge, Skills, Abilities, and Other Characteristics
LCS	Lane Control Signal
MAD	Mean Absolute Deviation
MAE	Mean Absolute Error
Maint.	Maintenance
MFE	Mean Forecast Error
Mgt.	Management
MSE	Mean Square Error
NAPA	National Academy of Public Administration
NIOSH	National Institute for Occupational Safety and Health
NSF	National Sleep Foundation
O*NET	Occupational Information Network
OPM	Office of Personnel Management
Ops	Operations

OTA	Office of Technology Assessment
PAD	Passive Acoustic Detector
PM	Preventative Maintenance
PTZ	Pan, Tilt, Zoom
RSFE	Running Sum of Forecast Errors
RWIS	Road Weather Information System
SCADA	System Control and Data Acquisition
Serv.	Services
SMA	Simple Moving Average
SME	Subject Matter Expert
Tech.	Technician
TMC	Transportation Management Center
TMCOps	Transportation Management Operations Technician (TMOT) Position Description Creation Tool
TMOT	Transportation Management Operations Technician
Transp.	Transportation
U.S.	United States
VIDS	Video Imaging Detection System
VMS	Variable Message Sign
WMA	Weighted Moving Average

Chapter 1. Introduction and Overview

1.1. Purpose of the technical document

TMCs provide a public service to communities with traffic management needs. Traffic management helps to safeguard travelers by reducing the number of accidents and coordinating emergency responses to incidents within a service area, provides time and cost savings to residents by mitigating congestion, and decreases pollutants released into the air by motor vehicles. In the service industry, employees are often the most critical element in the delivery of the service, and their payroll costs typically account for the greatest portion of the budget. The efficient operation of a TMC depends on the effective management of human resources. Past developments in staff planning and scheduling systems used to support the day-to-day operations of TMCs have been limited. The purpose of this technical document is to provide guidance, useful strategies, suggested approaches and techniques, and recommended practices to ensure that TMCs staff an appropriate number of employees with the characteristics required to successfully perform their jobs and generate effective schedules to meet the demand for services.

1.2. Section 508 accessibility requirements

Section 508 of the Rehabilitation Act Amendments of 1998 requires that Federal agencies develop and maintain electronic and information technology (EIT) in compliance with the Section 508 standards developed by the Architectural and Transportation Barriers Compliance Board, unless doing so would place an undue burden on the Federal agency.[1,2,3] Section 508 standards guarantee that Federal employees and members of the general public who have disabilities (e.g., visual impairment) have access to and can use EIT in a comparable manner to those without disabilities. The Federal Highway Administration requires that all technical documents meet the requirements of the Section 508 standards in preparation for publication.

1.3. Intended audience

This technical document was specifically designed for TMCs in the United States and Canada. The primary audience includes managers, supervisors, human resource personnel, and private contractors who are involved with or responsible for work analysis, scheduling, and/or staff planning decisions within a TMC. Although not the target audience of the technical document,

other TMC employees may find sections of the document relevant to their jobs and in their personal lives. The technical document consolidates and integrates information from a variety of resources, including scientific research and past Federal Highway Administration publications, into a single source that is accessible to practitioners.

1.4. How to use

This technical document was designed to meet the varied demands of TMC employees, appreciating the assorted needs and backgrounds of potential readers. Readers may use the technical document as an educational tool to increase their understanding of work analysis, scheduling, and staff planning. Or, they may use it as a reference, consulting relevant chapters as questions arise. The technical document may also be used as a starting point from which to investigate a topic with additional resources. Finally, the technical document may be used as source material to develop a training program.

This document was designed to provide a foundation for conducting work analysis, scheduling, and staff planning. Readers with little knowledge of or experience with work analysis, scheduling, and/or staff planning would be well advised to read all chapters related to their specific needs, and potentially the entire document to gain a full understanding of how the different human resource decisions are related and support each other. In addition, readers who have little experience working in a TMC will find included throughout the document historical information and lessons learned from TMCs across North America.

Many readers will not need to read the entire document, especially if they already possess substantial knowledge of or experience with work analysis, scheduling, and/or staff planning. The layout of the technical document was developed to provide an easy-to-use reference. Each chapter covers a single topic, but is comprised of multiple sections to facilitate searches for information. It is anticipated that the primary function of the technical document will be to provide methods for creating a schedule. The sections of the technical document that cover the practices that are required to create a schedule are listed at the end of the next section, which also provides an overview of the entire document.

This document also includes a number of references to additional resources. The purpose of the additional resources is to provide a list of easily accessed documents and Web sites that offer more thorough descriptions of information contained in the technical document. Most of the additional resources are accessible through the Internet.

Finally, content from this document may be used to create a training program for TMC employees. Specifically, it is anticipated that Chapter 4 on Shiftwork and Chapter 5 on Strategies for the Employee may be used to offer TMC employees guidance, recommendations, and suggestions to facilitate their adjustment to work schedules, especially employees who work nontraditional hours (e.g., evening shift, night shift).

1.5. Overview of content[4,5]

This section presents an overview of the technical document, and describes how the content from each chapter is related. Figure 1.1 depicts a schematic representation of the content of the technical document, with the chapter that contains the information displayed on the right-hand

side. The purpose of the figure is to illustrate how the content of each chapter is related to the other chapters. In the short term, demands for services can be used to determine scheduling needs (Chapter 2). The scheduling demands and scheduling supply are used to generate an employee schedule (Chapter 3). Features of a work schedule affect how employees perform their jobs and more general life outcomes based on the characteristics of the work environment and the characteristics of the employees (Chapter 4). Employees can implement a number of strategies to facilitate their adjustment to work schedules (Chapter 5). Employers can also implement a number of strategies to improve the outcomes of their employees, including how the TMC is staffed and how the schedule is designed (Chapter 6). In fact, the employer may be able to affect scheduling demands (Chapter 2). In the long term, determining scheduling demands and allocating employees (i.e., scheduling supply) to meet demands for services requires staffing decisions (Chapter 7).

1.5.1. Overview

Chapter 1. Introduction and Overview. The first chapter provides an introduction to the content of the technical document. The chapter includes a discussion of the purpose of the technical document, Section 508 accessibility requirements, and the intended audience, concluding with a synopsis of each chapter.

Chapter 2. Work Analysis. The second chapter describes four techniques that may be used to support scheduling and staffing decisions. (1) Job analysis is used to determine the elements of a job and the attributes required to successfully perform each element. (2) Workload analysis is used to determine the human performance requirements of a work task. (3) Task allocation is used to determine how to assign work to employees. (4) Demand analysis is used to determine employee scheduling requirements.

Chapter 3. Scheduling Practices. The third chapter consists of sections on how to create an employee schedule, including determinants of a schedule (e.g., the size of the TMC, staffing arrangements such as the number of part-time employees), scheduling basics and terminology, examples of schedules, manual methods for creating a schedule, scheduling software, and strategies for making real-time scheduling decisions.

Chapter 4. Introduction to Shiftwork. The fourth chapter introduces the reader to principles associated with shiftwork, including biological factors and the circadian system, to provide a foundation for sections of the fifth and sixth chapters. The fourth chapter also contains an overview of how shiftwork affects employees in terms of individual differences (e.g., age differences), social responsibilities (e.g., children), health (e.g., gastrointestinal problems), and job performance and safety issues.

Chapter 5. Strategies for Employees. The fifth chapter identifies methods and practices employees can use to facilitate their adjustment to a work schedule, and includes strategies for sleeping during off hours and maintaining alertness during working hours. Finally, the importance of a social support system is discussed.

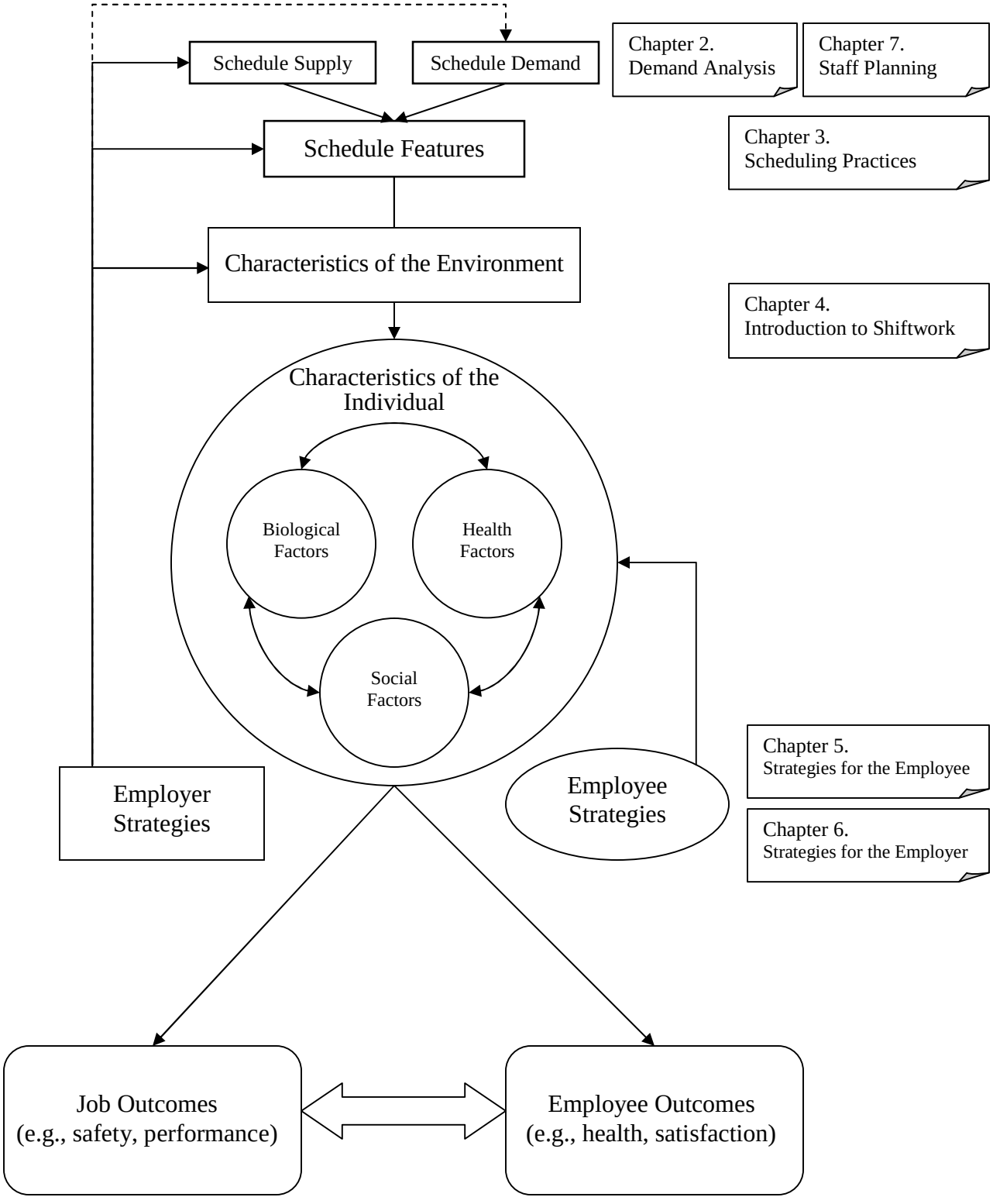

Figure 1.1. Schematic Representation of the Technical Document
(Adapted from references 4 and 5)

Chapter 6. Strategies for the Employer. The sixth chapter covers strategies that employers can implement to help employees adjust to their schedules. The first two sections discuss the importance of helping employees adjust to their work schedules. Next, a method for anticipating the effect of a strategy is offered, followed by suggested shift design principles and design principles for physical features of the work environment. The advantages and disadvantages of adopting explicit nap policies are discussed. The final section covers the importance of occupational health service provisions.

Chapter 7. Staff Planning. The seventh chapter begins with a description of the aspects of a TMC that have staffing implications. Next, the chapter outlines the different sections of a staffing plan and the steps that go into creating a staffing plan. The last section of the chapter covers emergency management planning.

1.5.2. Scheduling content

The purpose of this section is to describe the most basic elements that go into generating a schedule. The scheduling method that is described in the technical document was selected for several reasons. Because each TMC faces different scheduling challenges, a general solution was required that could address a range of scheduling needs. In addition, the scheduling method is easy to implement using a set of manual processes. The scheduling method requires a projection of future demand. The estimates of demand are used to determine the employee scheduling requirements. The relevant sections from Chapter 2 on demand analysis include the following sections.

- Section 2.7. *Demand Analysis*. Describes how to conduct a demand analysis to determine employee scheduling requirements.
    - Section 2.7.1. *Demand*. Describes how to quantify demand into measurable variables.
    - Section 2.7.2. *Translating demands into employee requirements.* Describes several methods that may be used to translate measurements of demand into meaningful and useful values.
    - Section 2.7.3. *Demand prediction methods.* Describes how to use historical data on demand to extrapolate demand into the future, and related methods to help ensure the utility and accuracy of the demand model extrapolated from the data.

After the demand for services is estimated, the employee requirements required to meet the demand can be calculated to create the schedule. The relevant sections from Chapter 3 on scheduling methods include the following sections.

- Section 3.7. *Manual scheduling.* Describes a method for creating an employee schedule by hand using estimated levels of demand that have been translated into employee requirements.
    - Section 3.7.2. *Manual shift-scheduling algorithm.* Describes how to assign shifts to the estimated levels of demand within a day.

- Section 3.7.3. *Days-off scheduling algorithm.* Describes how to assign employees to a work week based on the number of employees required each day of the week.

Although only the primary sections of the technical document that are required to generate an employee schedule have been listed above, the reader is advised to consult other related sections. For example, Section 3.2 on schedule administration describes the advantages and disadvantages associated with selecting different schedule administrators who oversee the generation and management of a schedule.

1.6. References

1. Center for Assistive Technology and Environmental Access under the Georgia Institute of Technology. *Information Technology Technical Assistance and Training Center*. Retrieved October 20, 2005, from http://www.ittatc.org/

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4. Folkard, S. (1993). Editorial. *Ergonomics, 36,* 1-2.

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Chapter 2. Work Analysis

2.1. Introduction to work analysis

For the purposes of this document, the term **work analysis** is used as a generic term to refer to the examination of job-related activities performed by an employee and includes three techniques: job analysis, workload analysis, and demand analysis. A fourth technique, referred to as task allocation, is an application of job analysis and workload analysis, and is also important for day-to-day TMC operations. Each of the four techniques serves a different purpose when generating a schedule (see Figure 2.1), and is discussed below in the context of making scheduling decisions.

- **Job analysis** is a method used to determine the elements of work and the employee characteristics necessary to perform each element. A job analysis can be used to ensure that employees possess the necessary attributes to perform the duties of their positions.

- **Workload analysis** yields design principles that maximize the performance capability of employees in a work system. The results from a job analysis and workload analysis may be used for task allocation.

- **Task allocation** is a method used to assign discrete work activities to employees. Based on the results from a job analysis and a workload analysis, task allocation can be used to ensure the optimum allocation of work to employees in different scheduling configurations.

- **Demand analysis** is a method used to determine employee scheduling requirements. Demand analysis forecasts the need for employees' time based on the demand for services by consumers.

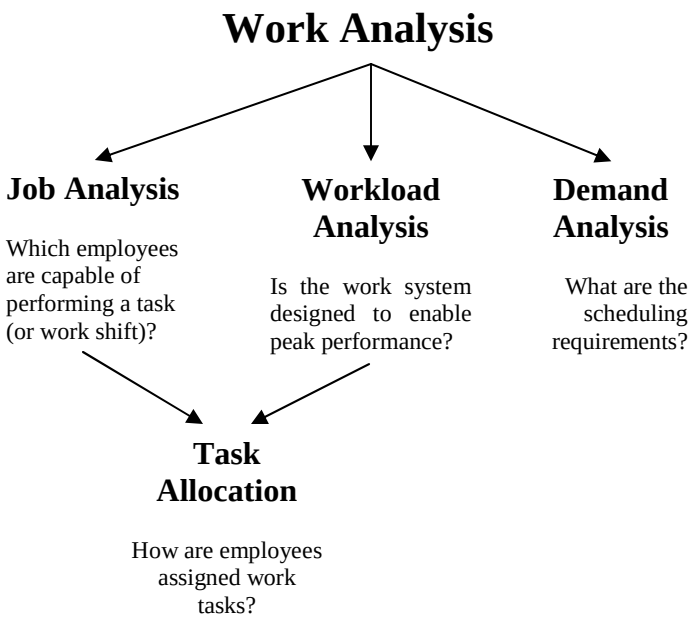

Figure 2.1. Work Analysis Techniques

2.2. Work analysis and TMCs

An important factor in conducting work analysis at a TMC is the services offered or functions supported by the TMC. A **function** is a capability or ongoing activity of a TMC that contributes to the accomplishment of the TMC's mission (e.g., Incident Management, Records Management).[1] The functions supported by a TMC and the amount of demand for services requested by consumers determine (1) the type of personnel needed and (2) the number of personnel needed.[2] However, staffing needs are limited by budgetary constraints. The purpose of this section is to provide an introduction to work analysis in TMCs and a starting point for conducting the work analysis methods reviewed below by briefly presenting some high level job analysis information.

A survey of TMCs in North America found that TMCs manage different modes of transportation: 23.8 percent monitored highways (high-speed/limited-access/toll roads), 22.4 percent monitored surface streets (arterial streets and intersections with traffic signals), 15.6 percent monitored tunnels and bridges, 5.4 percent monitored light rail/subway transit, 4.1 percent monitored bus transit, 3.4 percent monitored railroads (commuter/long-distance/freight rail), and 25.2 percent monitored two or more modes of transportation.[2] The number and type of personnel (e.g., junior-level operator, senior field technician) needed during different hours of operation vary by the type(s) of transportation mode covered. For example, TMCs dedicated to surface street management may only operate during peak congestion times, whereas many regional TMCs run by state or regional governments operate 24 hours a day/seven days a week.[2] TMCs may be further examined in terms of the functions they support.

A review of TMC source documents yielded the following list of functions.[3]

- Traffic monitoring
- Control of ITS devices
- Maintenance, repair, and troubleshooting
- Disseminate information
- Personnel management
- Data analysis
- Interface with media and public
- Plan, recommend, implement system and procedural upgrades
- Coordination with incident response agencies
- Coordination with other local and regional transportation agencies

The list above provides the functions supported by TMCs. Table 2.1 lists functions generated by a job analysis conducted specifically for the operator position. Three functions supported by TMCs but not integral to the operator position were eliminated (human resource management, maintenance management, and configuration management).[3] The functions listed in Table 2.1 may be used to initiate a job analysis or support another work analysis technique involving operators. For non-operator jobs, the list of functions above may be used.

Table 2.1. List of TMC Functions Involving Operators

Function	No. of Tasks	Percent of Tasks	Percent of TMCs
1. Failure Management	171	16%	75% to 90%
2. Congestion Management	121	11%	75% to 90%
3. Incident Management	121	11%	75% to 90%
4. Special Event Management	108	10%	75% to 90%
5. Traffic Signal System Management	104	10%	50% to 75%
6. Rail Crossing Management	65	6%	50% or less
7. APTS System Management	62	6%	50% or less
8. Reversible and HOV Lane Management	52	5%	50% to 75%
9. Provide/Coordinate Service Patrols	45	4%	50% to 75%
10. Traffic Flow Monitoring	45	4%	75% to 90%
11. Records Management	37	3%	90% or more
12. Transit Vehicle Monitoring	35	3%	50% to 75%
13. Emergency Management	34	3%	50% to 75%
14. Provide Travel Information	30	3%	90% or more
15. Environmental and RWIS Monitoring	17	2%	50% or less
16. Overheight Vehicle Management	13	1%	50% or less
Totals	1060	100%	

(Adapted from reference 3)[3]

In general, TMCs that offer more services or support more functions will have correspondingly more complex operations and systems. As a consequence, there will be more work to examine when conducting a work analysis. For example, there may be more jobs or more levels within one job to examine. Table 2.1 gives the number of tasks that underlie the performance of each

function, which provides a rough assessment of the function's complexity. Functions with more tasks are generally more complex than functions with fewer underlying tasks. The percentage of TMCs gives an estimate of proportion of TMCs in North America that perform each function.

2.3. Job analysis

Job analysis is a method used to determine the elements of work (e.g., tasks) performed by employees and the attributes required of employees to perform the tasks successfully.(4) Although job analysis is commonly used to support a variety of human resource processes that aid in personnel decisions (e.g., designing a personnel selection instrument, generating criteria for a performance appraisal), in the context of scheduling, job analysis can be used to determine which employees possess the necessary characteristics to meet an acceptable level of performance to staff a work shift. During peak traffic conditions, for example, employees with training in congestion management may be necessary, whereas special event management training may be more important immediately following a sporting event (e.g., Super Bowl, NBA playoffs) on the weekend. Figure 2.2 provides a schematic representation of the job analysis procedures described below. Determining which employees are capable of maintaining an acceptable level of job performance during a work shift is based on the elements of the work (determined by task-oriented procedures), the worker attributes required to perform the work tasks (determined by worker-oriented procedures), and the specific employees who can work a shift (the linkage of task- and worker-oriented information). First, job analysis information is described, followed by methods and tools that can be used to collect job analysis information.

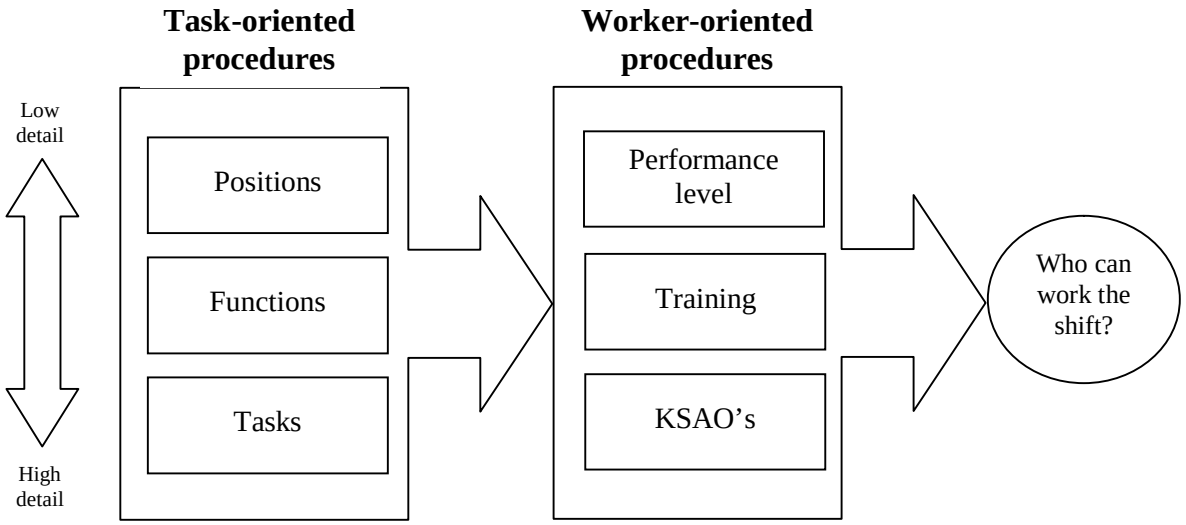

Figure 2.2. Job Analysis Schematic

2.3.1. Job analysis information

Task-oriented job analysis procedures are used to determine the elements of work.(4) The focus is on the work accomplished by employees. Three levels of work may be considered: tasks, functions, or positions. **Tasks** are the most basic, yet meaningful, elements of work. Tasks (e.g., "analyze sensor data for speeds and delays for traveler information update," "operate camera for congestion verification") include a specific work-related goal. Although a task may

be broken down into steps ("observe sensor data," "note speeds," "compare speeds with typical non-delay speeds," etc.), in general, these steps will be at a level of detail that is too fine to be useful. Tasks may be organized into functions supported by a TMC or **positions** occupied by employees. The level of effort required for a job analysis depends on the level of detail desired. For example, if any junior-level operator or any maintenance staff member at a TMC can cover a shift then the positions level may suffice. At a larger TMC, work may need to be examined in greater detail. The determination of who can work a specific shift may require an examination of the functions supported by the TMC during the shift or even the tasks performed by employees during the shift. The object of the task-oriented procedures is to generate a list of the positions, functions, or tasks (depending on the desired level of detail) that are relevant to the work shift under consideration.

Worker-oriented job analysis procedures focus on the characteristics of employees required for successful performance in a job.[4] Characteristics of employees may be examined at three levels of analysis: (1) knowledge, skills, abilities, and other characteristics (KSAO's), (2) training experience, or (3) performance level. KSAO's provide the basic elements of employee characteristics. **Knowledge** (e.g., "familiarity with highway capacity for freeways and metering rate selection") refers to the specific information necessary for a person to perform a job. **Skills** are proficiencies in performing tasks (e.g., "adept at selecting a camera, locating, and zooming in on an incident in a 360-degree field of view with a dome type PTZ"). **Abilities** are relatively enduring capabilities (e.g., "capable of scanning multiple monitors and noting changes over time to objects and images"). Other characteristics may include attitudes (e.g., job satisfaction) or personality factors (e.g., conscientiousness). For example, a customer service orientation may be necessary for successfully handling phone calls from stranded motorists or the press.

At a higher level of analysis than KSAO's, the training experience or performance levels of the employees (e.g., entry level, full performance level, advanced level) may be used. Training experience includes any training an employee has completed including training received on the job. The performance levels denote the level of training and experience attained and specific KSAO's acquired by the employee. For example, the day shift may require 2 interns or entry level employees, 1 advanced level employee, and 1 supervisor, and the night shift may only require 1 entry level employee and 1 advanced level employee. The objective of worker-oriented procedures is to associate KSAO's, training experience, or performance levels with each element of work generated from the task-oriented procedures. After using task-oriented procedures to generate a list of the elements of work during a specific shift, and worker-oriented procedures to determine the employee characteristics necessary to perform each element of work, the two procedures can be linked to determine which employees possess the necessary characteristics to successfully perform the elements of work during a specific shift.

2.3.2. Collecting job analysis information[5]

There are several methods that may be used to collect job analysis information. Those who are responsible for making scheduling decisions may be able to rely on their own judgment to determine who can work a shift, or they may use the methods described below. Table 2.1 provides a list of functions commonly found at TMCs across North America. The list of functions may be used for a variety of job analysis purposes. For example, functions could be associated with a shift, and employees associated with the functions to determine who can work the shift. In addition, the functions could be used to help generate underlying tasks. Job analysis procedures usually start with a review of written materials such as position descriptions, training materials, and operations manuals to collect background information (see Appendix B and Appendix C for an example of this type of information).[4] The bulk of the job analysis information is typically collected by interview, direct observation, or questionnaire. Interviews may be conducted individually, in small groups, or via panel discussions. Direct observation may be performed by an unobtrusive observer or with video equipment. Note 2.1 discusses a public resource that offers job-analysis questionnaires among other products to the public. The next section discusses subjective methods that may be used to elicit job analysis information from various stakeholders. In the following section, the Transportation Management Operations Technician (TMOT) Position Description Creation Tool is described.

Note 2.1. O*NET Questionnaires

The Occupational Information Network (O*NET) is a comprehensive database sponsored by the U.S. Department of Labor containing information on employee and workplace characteristics.[5] The database includes data on knowledge, skills, abilities, interests, general work activities, and work contexts for 380 jobs and is continuously updated. The questionnaires used to collect the job analysis information (among other resources) have been released to the public and are available at http://www.onetcenter.org/questionnaires.html. The O*NET Questionnaires may be administered to incumbents, supervisors, job analysts, or other subject matter experts to collect work-related data in support of various labor force and human resource management objectives. The questionnaires are easy to modify and may require additional questions to cover unique aspects of a job.

2.3.2.1. Subjective methods

Subjective methods for eliciting job analysis information, or other work analysis information, rely on the judgment of knowledgeable stakeholders (e.g., supervisors, consumers), in contrast to quantitative methods discussed later in this chapter, which rely on the measurement of variables and calculation of formulas. The purpose behind using subjective methods is to derive as much information as possible from individuals in a manner that is practical, valid, and free from bias.[6] Table 2.2 describes three subjective methods, with advantages and disadvantages listed for each method. The subjective methods can be used with any of the work analysis methods. Employees (e.g., supervisors, managers) who make scheduling decisions may serve as subject matter experts, and may be able to use their past experiences and judgment to make scheduling-related decisions.

Table 2.2. Subjective Methods for Work Analysis

Method	Description	Advantages	Disadvantages
Subject Matter Experts (SMEs)	Survey job incumbents (i.e., employees in a job with at least 6 months to 1 year of experience), supervisors, or job analysts.	Experienced job incumbents provide the most useful information; supervisors are more objective than incumbents; job analysts are the most objective and are more qualified to discern relations across jobs	Information provided by job incumbents is less useful if the job changes often
Jury of Executives	Survey knowledgeable executives or senior-level employees from various departments. Review results of survey.	Quick; variety of viewpoints; fosters teamwork	Requires the time of highly paid executives; subject to bias
Delphi Method	Form a panel with a panel coordinator. Preferably, do not reveal panel membership. Panel coordinator surveys each panel member anonymously. If differences exist, reveal results of survey (and all past surveys when applicable), and continue to survey each panel member anonymously until consensus emerges.	Attempts to eliminate bias; builds consensus	Time consuming

(Adapted from references 5, 7, and 8)[4,7,8]

2.3.2.2. The Transportation Management Operations Technician (TMOT) Position Description Creation Tool

Many of the steps involved in conducting a job analysis for operators are supported by the Transportation Management Operations Technician (TMOT) Position Description Creation tool (TMCOps; available at http://tmcops.gtri.gatech.edu). TMCOps is a Web site designed to assist TMC employees who are responsible for analyzing staffing requirements (e.g., administrators, managers) with preparing position descriptions, developing training plans, and determining selection criteria for the operator job. The TMCOps Interactive Dialog aids in the generation of position descriptions (and several other outputs) by guiding the user through the selection of functions supported by the TMC and the underlying tasks (composite tasks) and subtasks (discrete tasks) performed by TMC employees.

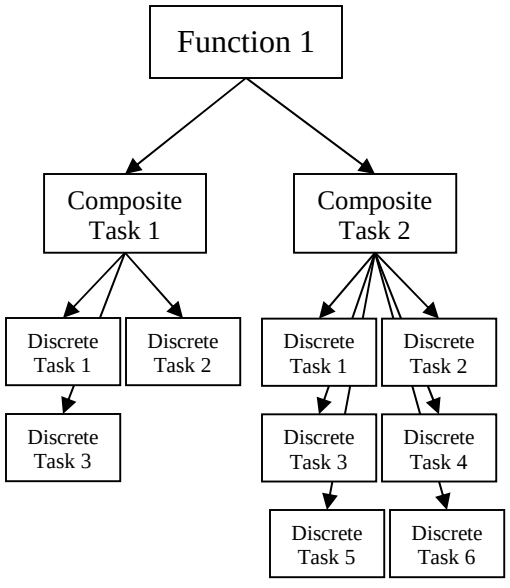

Figure 2.3. Function Tree

TMCOps uses three levels of breadth to describe work: (1) functions (as defined above), (2) composite tasks, and (3) discrete tasks (see Figure 2.3). A **composite task** is a set of one or more related discrete tasks that an operator must perform to support a given TMC function.[1] Composite tasks are

associated with general goals, whereas discrete tasks are associated with specific steps or procedures that contribute to reaching those goals. **Discrete tasks** are specific work objects, typically short in duration, and are the most basic meaningful elements of work performed by an employee. For example, "Respond to a Confirmed Major Incident" is a composite task associated with the function "Incident Management." This composite task consists of thirteen discrete tasks, such as "Determine number and configuration of incident lanes blocked" and "Confirm dispatch of ambulance to incident involving injury."

The List of Functions and Tasks page on the TMCOps Web site provides a comprehensive list of functions and tasks performed by operators at TMCs. A user can restrict the functions and tasks displayed to only those selected in the Interactive Dialog by (1) completing the Interactive Dialog and (2) checking the "Only show items selected in full dialog" check box on the List of Functions and Tasks page. Furthermore, Appendix B of the background document *TMC Operator Requirements and Position Descriptions* (available from TMCOps at http://tmcops.gtri.gatech.edu/background_home.php) includes a list of each function, composite task, and discrete task and the required performance level (TMOT KSA Level).[3] TMCOps includes several support features, including a number of useful tutorials (e.g., "Creating New Functions or Tasks," "Determining the Performance Level of a New Discrete Task," "Developing a Training Program").

2.4. Workload analysis

Workload analysis yields methods for optimizing human performance within a work system.[9] A consideration of workload and human performance reveals design principles in a work system (e.g., tasks, equipment) that can be used to optimize employees' performance. For example, multiple sources in divided attention tasks (i.e., attending to two or more sources of information simultaneously) should be designed to be as dissimilar as possible. Tasks that require the use of different senses (e.g., attending to a CCTV monitor [visual] and an auditory alarm) are more distinguishable than tasks that require the use of similar senses (e.g., attending to several computer displays). The *Preliminary Human Factors Guidelines for Traffic Management Centers* (*Guidelines*), available at http://www.fhwa.dot.gov/tfhrc/safety/pubs/99042/intro.htm, provides guidance for the development and operation of TMCs and a more comprehensive coverage of workload analysis and human performance. In addition, the companion Web site to the *Guidelines*, named ErgoTMC, includes a tutorial with content on workload analysis and is available at http://ergotmc.gtri.gatech.edu.

The remainder of this section covers TMC and employee workload. Sections on attention from the *Guidelines* are summarized to provide examples of how workload analysis can improve the design of the TMC work system. The *Guidelines* also cover the following areas related to human performance in TMCs: (1) vigilance, (2) stress, boredom, and fatigue, (3) memory, and (4) decision making constraints and biases.[9]

2.4.1. TMC workload

The workload a TMC handles can be assessed in a number of ways.[10,11] Common measures of workload are the number of centerline or lane miles, the number of intersections, the number of miles or routes, the number of incidents and incident severity, the number of vehicles in operation, and the number of vehicle miles traveled per day. A common workload measure for a bus or train control center is the number of people served during a certain time period. Determining the workload of a TMC may be necessary for predicting scheduling requirements, which is discussed below in Section 2.7 on demand analysis.

2.4.2. Employee workload

Workload analysis determines how best to design the work system for an employee or a group of employees.[9] For any period of time the work an employee performs requires a certain amount of resources (e.g., attention, physical strength) from the employee. For example, monitoring a stretch of highway requires a certain amount of attention to detect an incident. The employee may have the attentional resources demanded to monitor the highway at first, but several accidents and stalls may occur on the highway that require more attentional resources than the employee has to monitor all of them simultaneously. When the employee has enough resources to meet the demands of the task, the employee can perform the task at some maximum level of performance. As the amount of resources demanded by a task exceeds the resources the employee has, the peak level of task performance the employee can achieve decreases. A goal of workload analysis is to determine the resource requirements of tasks, and whether employees can meet the resource demands with a certain level of performance.

Workload will vary depending on the number and combination of tasks performed, the difficulty of the tasks, the characteristics of the employee, etc.[9] Predicting performance is a complex task that is never exact. When information sources overwhelm available resources, overload occurs.[12] For example, the TMC in Atlanta initially developed a system of alarms to indicate a device failure, but found in operation that numerous simultaneous alarms caused an overload of information for an operator.[11] Operators could not distinguish all of the simultaneous alarms. In an overload situation, an employee may compensate with one of several tactics.[12] The employee may filter the information sources based on some level of priority. The employee may try to provide simplified, approximate responses. The employee may allow the work to accumulate and attempt to catch up later. The employee may fail to respond to several sources. Errors in responding to information may occur. Finally, the employee may attempt to escape from the situation. Workload analysis helps to avoid overloading employees and to optimize performance.

2.4.3. Attention

A primary task performed by TMCs is monitoring, which requires attention.[9] A common problem reported by TMC operators is “image overload,” which occurs when the information operators must process at their workstations becomes cluttered with an excessive level of detail.[11] Operators prefer to have control over the level of detail at their workstations. Tasks that require attention can be categorized into three types: (1) selective attention, (2) focused attention, and (3) divided attention.[9] Tasks performed by operators most often require selective attention.

Selective attention is required when an individual's attention must alternate between two or more sources of information.[9] There are two sources of stress (or workload) that result from selective attention. Load stress increases as the number of sources from which information is presented increase, and speed stress increases as the rate at which the information is presented increases. Performance degrades quicker as a result of increased load stress rather than speed stress.

There are a number of problems associated with selective attention.[9] In general, people tend to monitor sources of information that update more frequently, and neglect sources that update less frequently regardless of the importance of the content. In fact, while attending to multiple sources of information, people often forget to attend to sources of information that update infrequently. During high stress situations, people tend to attend to only those sources that they perceive as being the most important and salient, and tend to ignore information that is contradictory to their understanding of the environment. In general, the problem with selective attention is that people tend to focus on the wrong aspects of the situation. Several strategies based on human factors principles of workload analysis can be implemented.[9] Prioritize information sources to ensure more optimal use of employees' attentional resources and train employees to effectively scan multiple information sources to ensure the development of optimal scan patterns (for more design recommendations see reference the *Guidelines* and ErgoTMC).

2.5. Task allocation

Human factors principles can be used to determine optimal guidelines for assigning tasks to employees in different scheduling configurations.[9] The following discussion of task allocation provides a general description of how to assign work to employees and is based on a discussion of using task allocation to design TMC work systems from the *Preliminary Human Factors Guidelines for Traffic Management Centers* (*Guidelines*); also see ErgoTMC at http://ergotmc.gtri.gatech.edu/home.html.[9] The results from a job analysis and a workload analysis help determine how to assign work to employees or groups of employees.

Task allocation procedures assume that an employee who is assigned a task is capable of performing the task. Job analysis procedures can be used to verify that an employee can successfully perform the work required during a shift. Workload analysis can be used to ensure that the work system does not constrain employee performance. For example, the number of tasks assigned to one operator should not overwhelm an operator's ability to perform the tasks accurately. Task allocation procedures can be used to help alleviate an overload in workload.

2.5.1. Default task allocation

Default task allocation principles provide general guidelines for assigning tasks to employees. To protect employees from experiencing an overload, start by identifying scenarios of work that are vulnerable to overload and procedures for managing and alleviating the workload. For instance, relief tasking provides an employee with the option to request assistance from another employee when the workload becomes overwhelming. Also, distribute tasks over time as evenly as possible. Tasks that are not time dependent or tasks with a longer window of opportunity for completion can be assigned during non-peak workload times. However, tasks may require immediate attention if not completed until near the end of the window of opportunity. More than one operator should be assigned to tasks that require conflicting actions or simultaneous attention

to multiple sources of information (e.g., simultaneous observation of a desk monitor and a view screen on a wall).

2.5.2. Dynamic task allocation

Whereas the principles of default task allocation cover when a task should be assigned to an employee in general, **dynamic task allocation principles** cover how to assign a task to more than one employee in the same job on duty at the same time. That is, as the need to perform a task arises, if there is more than one employee who can perform the task on duty, a determination of who should perform the task needs to be resolved. An examination of dynamic task allocation procedures in TMCs revealed that task allocation in a group situation was mainly idiosyncratic to the group.[9] Each group employed their own guidelines and styles of task management. Three general schemes for allocating tasks were evident. The most common form of task allocation was by function. For example, one operator would identify and verify all incidents covered by the TMC and another operator would handle the remaining incident management. In a second scheme, responsibility was divided by geography. Each operator was responsible for a section of the area covered by the TMC. In the third scheme, operators sought and addressed transportation problems on an as needed basis without a predetermined scheme.

Research results tend to favor dividing by function rather than geography. Handling tasks on an as needed basis is not recommended. Specialization by function was associated with quicker response times, higher quality decisions, and less incident-related congestion. However, divide-by-function teams required more communication to coordinate the operators' different roles. The operator who identifies and verifies the incident must communicate this information to the operator who will manage the incident. Rules and guidelines for communication by voice, computer, and gesture are highly recommended.

In conclusion, the *Guidelines* offer the following recommendations.[9] Create rules or guidelines for transferring a task from one operator to another operator. Clearly document an operator's responsibilities and priorities when workload approaches or surpasses a peak level. Priorities should provide rules or guidance on which tasks are more critical and which tasks can remain incomplete. Ensure that the TMC system supports task transfer. One operator must be able to complete a task received from another operator, which may require the second operator to use the same equipment as the first operator. An approach to ensuring task transfer is to standardize the capabilities and interfaces of the equipment (e.g., operation consoles). Another approach to facilitating task transfer is to provide cross training for different positions. Cross training enables employees in different positions to offer assistance during peak workload conditions. For example, a manager may provide assistance to an operator on duty during an off-peak time period if there is a major incident, or an operator trained in handling the changeable message sign (CMS) system may also receive cross training in special event management to offer assistance during infrequent peaks in workload.

2.5.3. Shared task allocation

Shared task allocation principles apply to teams. Although most of the tasks performed by operators are performed more efficiently by a single operator, teams sometimes outperform individuals.[9] Teams bring together a collection of employees with potentially different KSAO's. Teamwork may be advantageous (1) to simultaneously identify, collect, and process

information (e.g., identify, monitor, and respond to multiple incidents), (2) to complete complex procedures while monitoring system feedback (e.g., troubleshooting), and (3) to solve problems (e.g., system failures). When teamwork is advantageous the operating procedures, technology, and the workspace must be designed to accommodate and facilitate team interaction. The disadvantage of using a team is the additional time and effort required for coordination. In general, use a team when the advantages of teamwork outweigh the effort required to coordinate and manage the team.

2.6. Service operations

Operations that do not produce tangible outputs are often referred to as services or service operations (e.g., postal service, police service), in contrast to manufacturing operations (e.g., automaker, pharmaceutical company).[7] Service operations have a number of unique qualities in comparison to manufacturing operations. For the most part, outputs cannot be surplused (e.g., haircut at a barber), and there is usually a short lead time for the production of the service. Typically, service outputs are consumed at the same time as they are produced (e.g., food served at a restaurant), and their worth decreases quickly after production.[8,13] As a result, services must be produced concordantly with consumer demand, and transferred directly to the location of the consumer. Creation of the service is often labor intensive, and requires high labor costs (e.g., employee wages and benefits) relative to capital costs. Productivity, quality, and overall performance of a service operation and of the service employees are difficult to measure because there is no tangible product.

In general, service operations with more consumers in the service system for longer periods of time are referred to as high contact systems, which indicates the high degree of contact between the consumers and the service providers.[14] The greater the contact between the service system and the consumer, the more the service provider loses control over the service system. In high contact systems the consumer may determine the time of demand and the nature of the service. To avoid shortages of service or overstaffing, forecasts of demand for services must be computed. Typically, employees are scheduled to accommodate the peak of the demand. The primary method for buffering against higher demand is extra staff, which may be limited by budget allocations, legal requirements, company policies, or employee preferences.[15]

2.6.1. TMC services

The characterization of a TMC as a service operation provides a framework from which to discuss the operation of TMCs and the work performed by their employees. TMCs provide a number of civic and emergency-related services. Similar to the collection of customized, short-duration activities performed by police departments and hospitals,[7] TMCs respond to consumer demands for services that may help maintain the safety of the general public (e.g., emergency management, incident management). Services that require more customization typically require more training and capital investment in equipment. The services provided by a TMC are often delivered to a large number of people simultaneously. In contrast to most services (e.g., hair salon, marriage counselor), TMC employees interact very little with individual consumers directly.

The transportation infrastructure is typically a service provided by another government agency (e.g., state department of transportation) that the TMC may be a part of. The main role of the

TMC is to manage aspects of consumers' interaction with the transportation system. That is, the TMC provides management services for an existing service provided by another government agency. Although a TMC interacts little with consumers, consumers have very high contact with the transportation system, and a TMC utilizes a variety of unidirectional direct and indirect methods to contact consumers (e.g., CMSs, Web pages, ramp meters, third parties [news and radio stations]). All points of contact are designed to facilitate consumer interaction with the transportation system.

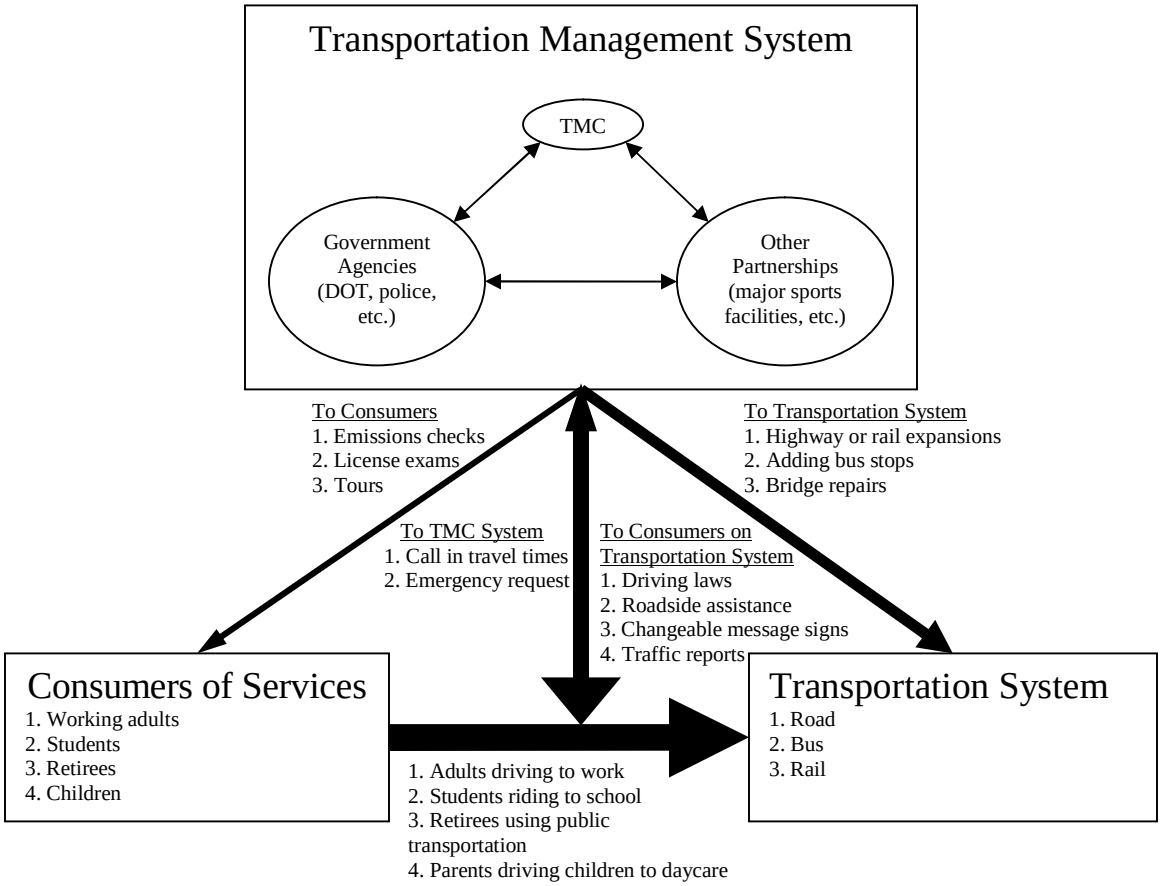

Figure 2.4. TMC Service Operation System

Figure 2.4 was designed to help untangle TMCs' service operations. Each box represents a different entity or system connected with transportation. The transportation management system includes the TMC, affiliated government agencies (e.g., police), and partnerships with nongovernment agencies (e.g., special event facilities, wrecker services). The bottom two boxes represent the consumers of the services and the transportation system. There are a variety of consumers to account for, from those who use motorized transportation (e.g., motorcycles, automobiles, trucks, light and heavy rail systems, buses) to those who use non-motorized transportation (e.g., walking, rollerblading, bicycling).[16] All of them desire safe, reliable, and predictable trips. In addition, decision makers (e.g., elected officials) represent the consumers and determine how public moneys and resources are allocated. The transportation system includes roadways, bus routes and stops, railways, and more. The arrow connecting consumers with the transportation system is the thickest to represent that the greatest amount of interaction

between any of the entities represented by the three boxes occurs between consumers and the transportation system.

The transportation management system manages aspects of the interaction between consumers and the transportation system (represented by the three arrows pointing down). The arrow on the left represents the interaction between the transportation management system and consumers before or outside of their interaction with the transportation system. For example, state laws require adults who would like to operate a car to pass a licensing exam that demonstrates some minimal level of driving competence. The middle arrow represents the reciprocal interaction between the transportation management system and how the consumers interact with the transportation system. TMCs interact with consumers to the greatest extent in this capacity. Consumers and TMCs may be viewed as co-participants in using the transportation system. Consumers and TMCs attempt to determine the best routes to take. In addition, services may be performed directly for a consumer, such as when a highway emergency response operator aids a motorist with a flat tire. The middle arrow is reciprocal because consumers interact with the TMC, for example, by calling in with trip times or emergency response requests. Finally, the arrow on the right represents the role of the transportation management system in designing, building, maintaining, and repairing the transportation system.

2.6.2. Service objectives

Often service operations, especially in the public sector, must reconcile conflicting objectives.[17,18] TMCs attempt to minimize a number of factors including congestion on major roadways, the number of incidents experienced by consumers, etc. At the same time, TMCs attempt to minimize costs and satisfy employee preferences. Problems arise because of conflicting objectives from consumer demand, budgetary constraints, laws and regulations, TMC policies, and employee preferences. For example, more equipment or more employees could be used to reduce congestion and the number of incidents experienced by consumers, yet the budget limits equipment expenditures and employee wages. The objectives of TMCs must be met within the constraints of other objectives.

2.7. Demand analysis

For most service operations, a major portion of the budget is used to pay employees. Effective scheduling practices help to control costs.[18] However, effectively managing schedules is difficult because of varying consumer demand, differences in employee performance levels and preferences, government regulations, and company policies. At times a TMC may have too few employees or employees without the necessary training, causing poor service, frustrated consumers, overworked employees, and low morale. Too many employees, on the other hand, causes financial losses and may also reduce morale if employees are not assigned enough work. **Demand analysis** is a technique used to translate an anticipated pattern of work (e.g., level of congestion, volume of calls) into work demands. The work demands are used to determine employee scheduling requirements. A job analysis, as discussed earlier, can be used to determine the necessary employee attributes to perform a work shift. A demand analysis yields the number of employees required during each hour (other time units [e.g., fifteen minute intervals] may be used) of operation for each job. Both of these employee requirements (i.e., the necessary employee attributes and the number of employees required) can be used to generate a schedule. As discussed above, employees who are responsible for scheduling decisions (e.g.,

supervisors, managers), acting as subject matter experts, may be able to determine the employee requirements based on their judgment and past experience on the job. The remainder of this section describes the principles behind demand analysis and offers several methods for conducting a demand analysis.

Several steps are required to conduct a demand analysis. The first step involves identifying and tracking key variables that drive the demand for services. Second, levels of demand are equated with employee requirements. Certain standards may be set to help translate demand estimates into employee requirements. Third, historic patterns of demand that are anticipated to continue into the future and related variables (e.g., population of eligible drivers in coverage area) may be used to predict future demand. Finally, the predicted future demand may be compared to the actual demand to determine the level of accuracy of the predictions.

2.7.1. Demand

2.7.1.1. Identification of labor drivers

The first step in conducting a demand analysis is to identify the **labor drivers** or what drives the workload for a group of employees.[18,19] Identifying labor drivers requires knowledge of the work process. For a group of employees (e.g., field equipment inspectors, junior-level operators), labor drivers are the events that affect which actions an employee performs (e.g., a camera needs repair, a car crash requires emergency services) and how long an employee performs those actions. Section 2.4.1 on the workload of TMCs provides a list of potential labor drivers.

Labor drivers that require immediate action are more important than labor drivers that have a longer window of opportunity for completion. Determine the length of time from the initial occurrence of the labor driver to the completion of all associated work tasks. Often there is a lag between the occurrence of a labor driver and the performance of an associated task. For example, a time lag will occur between the occurrence of a damaged camera or car crash and its detection. A convenient time interval to measure the length of work events should be chosen. The time interval should coincide with scheduling processes (five minutes to an hour is common). For example, an hour interval may be convenient for setting up shift changes, and fifteen minutes may be useful for arranging breaks during shifts.

The number of employees and employee attributes (e.g., KSAO's) required to perform the work should be associated with each labor driver. This information can be determined by observation and measurement (e.g., actual time to complete a task that results from a labor driver) or by any of the subjective methods (see Table 2.2). Choose labor drivers that are not related to each other to avoid an overlap in the prediction of future demand. Multiple regression and correlation analyses can be used to determine the effect of labor drivers on work, and the relationship between similar labor drivers.

Table 2.3. Georgia Incident Levels

Active Incidents	
Level 1	On shoulder, no lanes blocked
Level 2	One lane blocked
Level 3	Two or more (but not all) lanes blocked
Level 4	All lanes blocked

From http://www.georgia-navigator.com/incidents/georgia

If labor drivers are too complex, consider segmenting them into different levels or categories.[20] For example, the Georgia Department of Transportation's Intelligent Transportation System (NAVIGATOR) reports incidents (e.g., accident, stall) and includes a rating of each incident on a scale created by the Georgia Department of Transportation to indicate the impact of the incident on the roadway (see Table 2.3).[21] Clean-up times are estimated based on the severity of the incident. The determination of the employee scheduling requirements needed to handle an incident may be easier and more precise if an incident is categorized in one of four levels instead of lumping all incidents together.

A database should be created to track the labor drivers over time.[19] This data will be used to predict the demand for services in the future to derive employee schedules. Past record tracking efforts used for other purposes can be used to assess past demand, but may be missing key documentation such as unusual or special events that affected the demand, the accuracy of the variables, and the service level provided.

2.7.1.2. Variation of demand

Higher variations in demand cause higher uncertainty in predicting future demand, which leads to either less reliable service or lower utilization of staff during lulls in demand.[19] Higher staffing levels are generally used to meet peak levels of demand if there is a lot of variation, but when the demand drops the need for employees also drops. A number of staffing strategies may be adopted to handle high variation in demand (see Section 3.3 for alternate staffing arrangements). For example, Nashville's TMC hires part-time operators to cover morning and evening peak hours that typically occur from 6:30 am to 9:30 am and 4:00 pm to 7:00 pm on weekdays.[22]

2.7.2. Translating demands into employee requirements

Translating demand into employee requirements requires two considerations.[19,23] First, the employees or combination of employees who have the qualifications to handle the demand (i.e., work a shift) must be determined. Second, the number of employees required to handle the demand must be determined. The objective is to determine the employees' workload capacity for performing the labor drivers over time. That is, at what capacity of workload can an employee perform the work without experiencing an overload and accommodate the demands for services. A common method for deriving appropriate staffing levels is to establish a standard based on the level of predicted demand. Three standards are discussed below productivity standards, service standards, and economic standards.

2.7.2.1. Productivity standards

Productivity standards establish performance standards for employees to complete tasks consistently and in a certain amount of time.[23] For example, an operator should handle an incident of a certain level of severity in a certain amount of time, or a field maintenance employee should repair a broken CMS in a certain amount of time. Productivity standards are

the simplest of the three standards, and work best for tasks with a window of opportunity for completion or tasks that can be performed uninterrupted. If the tasks must be performed immediately then idle time needs to be built into the projections. As the work situation becomes more complicated, productivity standards become more difficult to use.

2.7.2.2. Service standards

Whereas productivity standards focus on consistent performance by employees, **service standards** focus on assuring consumers consistent service.[23] For example, a service standard may include a maximum wait time for an incident of a certain level of severity, or a certain update frequency of CMSs during peak traffic conditions. The idle times of employees during periods of low workload are implicit in this approach. The challenge is to develop the service standard. Methods for developing service standards include consumer surveys and focus groups, direct observation, analyzing historical data, and experimentation with different service levels.

2.7.2.3. Economic standards

Economic standards focus on delivering services in the most economical way feasible.[23] Typically, economic standards translate into assigning more people during higher demand conditions and fewer people during the lulls in demand. An example of a decision under this approach would be that it may be more economical to automate TMC services during the night shift and hire more employees during peak traffic times to help handle the spike in demand. This approach may be the most difficult for a TMC to implement, as the benefit of TMC operations is difficult to measure in dollars.

2.7.3. Demand prediction methods

The objective of the demand prediction methods is to use the labor drivers as a measure of past demand to predict future demand. After translating the demand for services into employee requirements, an appropriate number of employees with the necessary attributes can be scheduled to accommodate the demand forecast.

Several decisions go into determining which forecasting method to use.[6,8,24] In general, there is a trade-off between cost and accuracy, because higher accuracy in prediction can often be achieved at greater expense. High accuracy methods (e.g., Delphi method, complex statistical models, consumer research) often require more data and time, and are more complicated to design, implement, and use continuously. In some cases, lower cost methods (e.g., less complex statistical models, jury of executives) may provide results that are as accurate as high cost methods. The appropriate demand prediction method will depend on the data available for analysis. In general, choose a technique that makes full use of the available data. Also consider the time span to be predicted, and how much time there is to formulate the predictions. Avoid collecting additional data at great cost to improve prediction if available data exists.

The subjective methods listed in Table 2.2 can be applied to demand predictions. Subjective methods are commonly used when there is no quantitative data available, such as when a TMC first opens.[6] Two quantitative methods will be discussed. First, time series models will be discussed in detail, and several relatively simple methods for computing time series analyses are presented. Second, there is a brief discussion of regression methods. Due to the technical nature of implementing regression methods, only a conceptual description of regression is provided.

2.7.3.1. Time series models

A **time series** is a set of data that was recorded over equally spaced intervals and ordered by occurrence (e.g., daily average number of incidents occurring each month). Time series models are useful if consistent patterns of demand exist over time and the patterns are expected to continue into the future.[7] In other words, past time series can be used to extrapolate the demand for services into the future. A time series may include four components:

1. Trend component – either a general upward or downward movement over time. From week to week there is little movement in the average demand for TMC services outside of the other time series components.

2. Seasonal component – a consistent, recurring movement upward or downward from the trend component over an interval of time. Demand for services at most TMCs varies with a recurrent weekly cycle. Rain storms, school holidays, and other similar events, which affect the demand for services, are also considered seasonal components. Prediction of future demand for TMC services can capitalize on the relatively consistent seasonal component.

3. Cyclical component – a recurrent upward or downward movement with a cycle lasting one year or longer. For example, since the inception of most TMCs, the demand for transportation management services has increased with the growing populations of cities. The cyclical component will cause a gradual need for more employees in certain cities with population growth.

4. Random component – erratic changes without a pattern. Random changes are unpredictable. To some extent, for example, car accidents are random events.

Figure 2.5 depicts hypothetical levels of demand for services from Monday through Thursday measured at fifteen-minute intervals. Converting measures of demand into numerical or graphical presentations aids in the identification of patterns.[19] The objective of Figure 2.5 is to demonstrate how to use the seasonal component of a time series to predict levels of demand in the future.

To use past levels of demand for prediction, average together past time series that include the most similar seasonal components to predict the demand occurring for similar seasonal components. Prediction will improve with the inclusion of more time series in the average to the extent that the past time series include similar seasonal components and do not deviate from the future time series based on other time series components. If the demand for services increases over a five year period with more residents moving into a city (i.e., a cyclical component), then time series more than several years old may no longer reflect future demand.

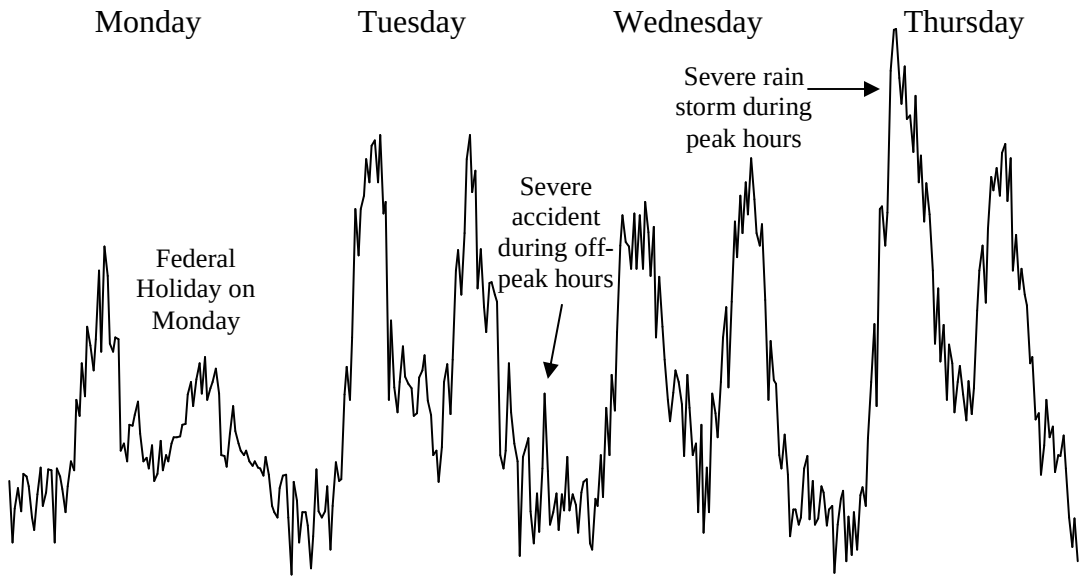

Figure 2.5. Demand Time Series Model

Dates with similar attributes (e.g., Monday, holiday) can be used to predict similar future demand patterns. Although the average demand from similar periods of time could be used to predict future demand, high peaks in demand may necessitate the need to schedule for peaks in demand rather than just average demand (see Section 2.7.3.2.4 on scheduling for shifts). Although Mondays that occur during a holiday, a special event, or during the summer may be excluded from predicting a typical Monday during non-summer months, they may be used to predict Mondays with those seasonal components. That is, Mondays with a Federal holiday can be used to predict future Mondays with Federal holidays. The prediction of an increase in the demand for services resulting from a severe rainstorm can be used to predict future days with similar seasonal components and severe rainstorms. However, there will be more error in predicting weather patterns, as the reliability of their occurrences and effects on the transportation system is lower than, for example, a Federal holiday.

Demand arising from predictable special events (e.g., an annual parade) should be included in demand predictions and employee schedules. Severe accidents during off peak hours occur to a great extent randomly and cannot be predicted. Although random events cannot be predicted, their occurrence can be anticipated with advanced planning or emergency operating procedures (see Section 7.3.2 on emergency management planning). In terms of scheduling, the question during an unanticipated event becomes "at what point does an incident become so severe, or demand for TMC services increase to such an extent that a real-time change in employee scheduling is necessary?" [see Section 3.9 on real-time scheduling changes]).

2.7.3.2. Demand smoothing

Demand smoothing is a set of statistical techniques used to remove steep variations in demand, and is predicated on the assumption that the peaks and valleys in the data are caused by random

fluctuations that would not be so pronounced in larger data sets.[18] Demand smoothing is most useful when there is little data from which to base future predictions. Averaging together a large amount of data will also provide a smoothing effect. The danger in using demand smoothing techniques is the removal of peaks or valleys that are caused by predictable, nonrandom labor drivers. For example, a fast moving rainstorm or a severe accident may cause a spike in trip times. As both of these events may be difficult to predict, their removal from the model may not represent a problem. However, a spike in demand for TMC services occurring immediately following a sporting event would represent a predictable event that could be recorded and tracked for future predictions. The Atlanta TMC monitors several Web sites to ensure awareness of upcoming events in the area that could affect traffic conditions.[11]

2.7.3.2.1. Simple moving average (SMA)

The **simple moving average** (SMA) smoothes data by imputing a measure of past demand with the mean of the data centered over the specific time point and several adjacent time points.[7] For example, the raw data used in Figure 2.5 was recorded in 15 minute intervals. The SMA was computed by averaging the time point (a 15 minute interval) with the two closest time points on either side (a total of five 15 minute time periods were averaged). The SMA is a simple method for smoothing the random fluctuations that occur in the data and provides stability to the prediction of future demand. The more time periods included in the SMA, the more stable the prediction. Greater stability becomes undesirable when nonrandom fluctuations are no longer apparent in the data. Figure 2.6 depicts how the demand resulting from the severe car accident decreases after using the SMA technique. Table 2.4 demonstrates how to use the SMA presented in Equation 2.1.

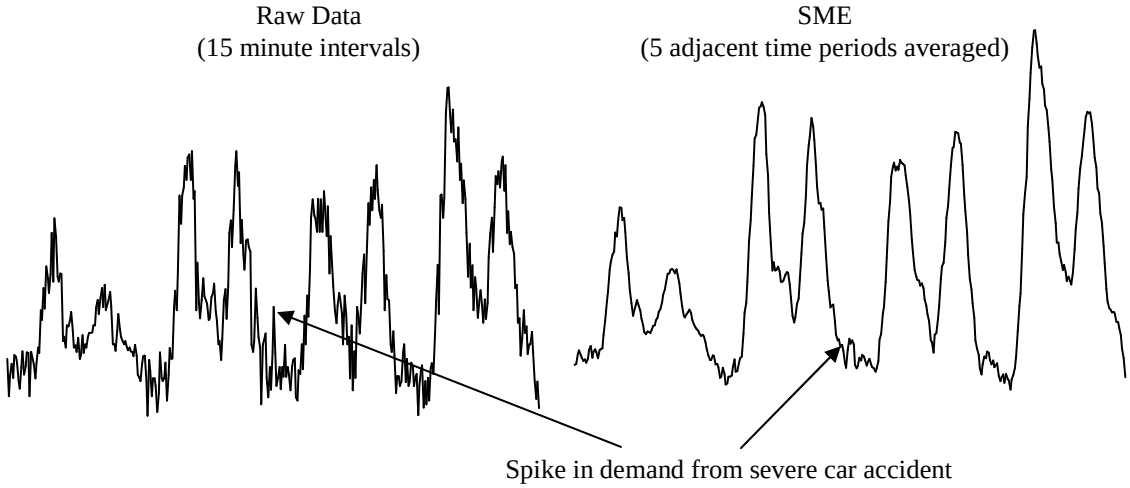

Figure 2.6. Raw Data vs. SME Time Series Model

$$SMA_{t+1} = \left(\frac{1}{n}\right)\sum_{i=t+1-n}^{t} A_i \qquad \text{(Equation 2.1)}$$

where: SMA_{t+1} = simple moving average at the end of period t

A_i = actual demand in period i

n = number of periods included in each average

Σ = summation sign

Table 2.4. SMA for Tuesday Morning Demand

Time Period	Demand	Total Demand (5 time periods)	Average Demand (5 time periods)
6:00	3.32		
6:15	3.82		
6:30	3.23	21.36	÷ 5 = 4.27
6:45	4.34	23.86	4.77
7:00	6.65	26.69	5.34
7:15	5.82	30.35	6.07
7:30	6.65		
7:45	6.89		

(Adapted from reference 7)[7]

2.7.3.2.2. Weighted moving average (WMA)

A variation of the SMA is the **weighted moving average** (WMA), in which weights are assigned to the demand estimates in the center and adjacent time points.[7] In the SMA, all raw data points are weighted equally. The rationale for weighting is to provide greater weight to more recent time points. Table 2.5 demonstrates how to compute a weighted moving average. All of the weights add up to 1.0, providing an average on the same scale as the original data and the average computed using the SMA.

Table 2.5. Weighted Moving Average for Tuesday Morning Demand

Time Period	Demand	Weights for 6:30	Average Demand (5 time periods)
6:00	3.32	× 0.10	
6:15	3.82	× 0.20	
6:30	3.23	× 0.40	3.92
6:45	4.34	× 0.20	4.68
7:00	6.65	× 0.10	5.68
7:15	5.82		6.11
7:30	6.65		
7:45	6.89		

(Adapted from reference 7)[7]

2.7.3.2.3. Trend identification

Visual inspection of plotted time series data is often helpful in determining patterns in the data. A line graph of the raw data suggested that there were daily differences in demand. One method for summarizing the daily totals is to compute the mean for each day and use the values to create a bar chart. Figure 2.7 reveals that the least amount of demand occurred on Monday. Tuesday and Wednesday had similar levels of demand, and Thursday had the most demand. This pattern of demand would be expected if a holiday occurred on Monday and a major rainstorm occurred on Thursday.

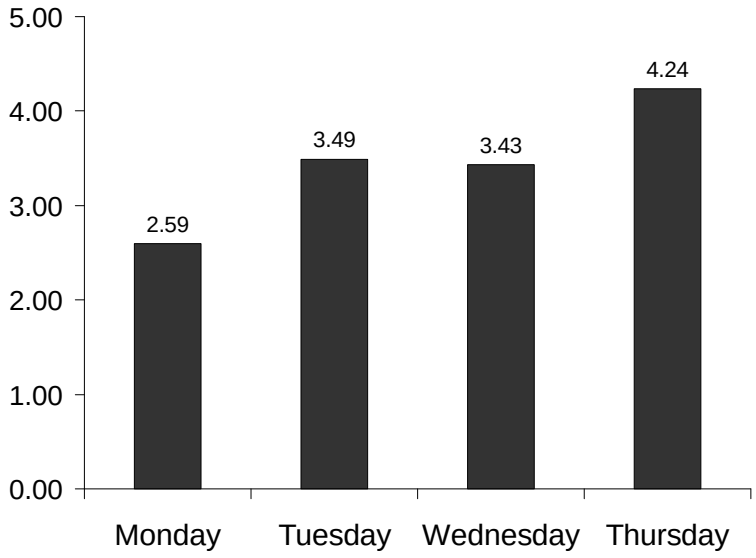

Figure 2.7. Daily Demand Bar Chart

A more useful way to represent the data for scheduling purposes may be to compute averages by shifts. The raw data was broken down into morning (6 am to 2 pm), afternoon (2 pm to 10 pm), and evening (10 pm to 6 am) shifts (see Figure 2.8). Several differences (or patterns) are evident among the shifts. The most demand for TMC services appears to occur in the morning, followed by a small decrease in the afternoon, and a large decrease in the evening.

2.7.3.2.4. Scheduling to meet different levels of demand

Three staffing levels need to be considered depending on the variability of demand and the possibility of random events: (1) the staffing level required to meet peaks in demand, (2) the staffing level required to meet typical levels of demand, and (3) minimum staffing level requirements. Section 2.7.2 discuses several strategies for determining employee requirements based on establishing a standard (e.g., a standard of service). The purpose of this section is to further discuss how to determine what level of demand to translate into employee requirements. To calculate the distribution of the variability for demand during a time period, determine the average level of demand, the highest level of demand, and the lowest level of demand. An alternative to the range (i.e., the highest and lowest levels of demand) is to use the standard deviation.

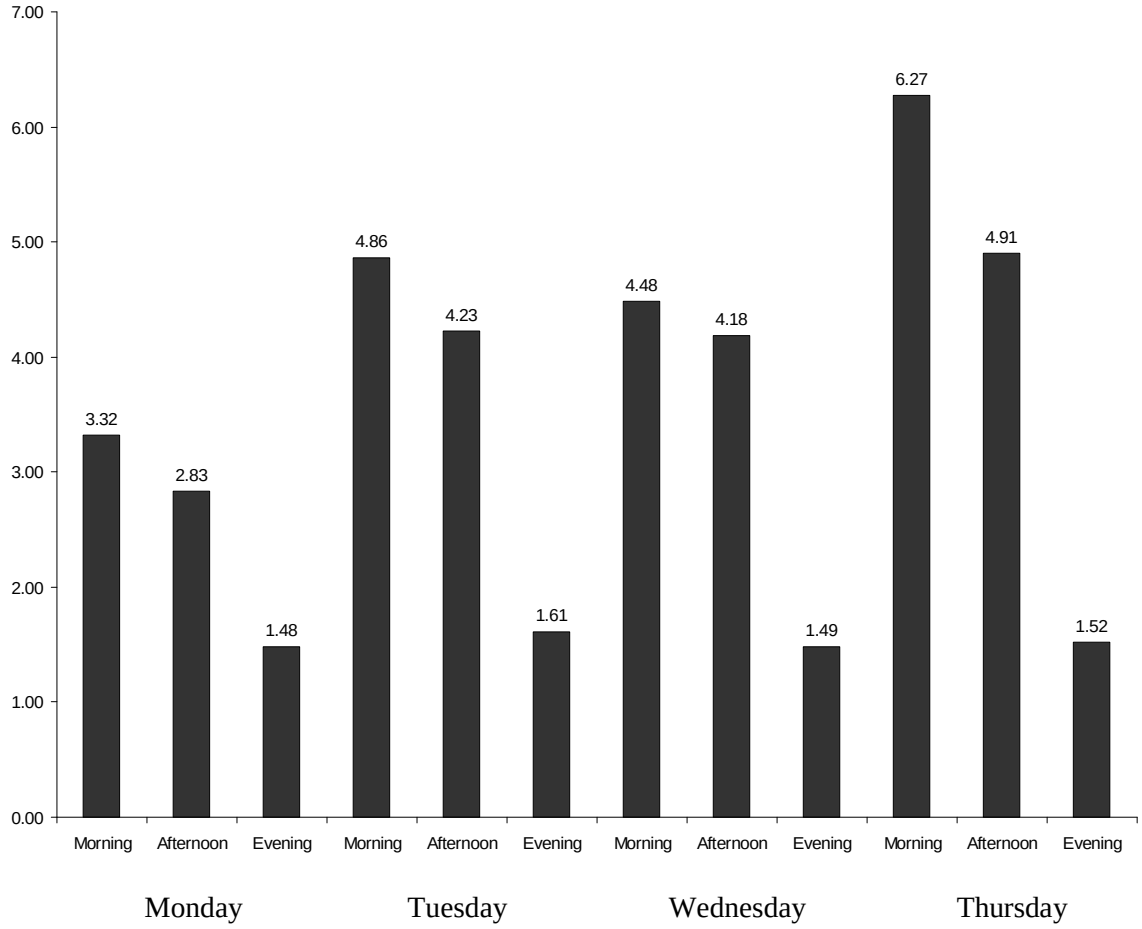

Figure 2.8. Shift Demand Bar Chart

Translating the average level of demand into employee requirements results in the number of employees needed to handle the typical amount of workload during a specific time period. However, during periods of high variability in demand, employees may frequently experience changes in workload that require more or fewer employees than were scheduled. For example, during peak traffic conditions workload may overwhelm the number of operators on duty. As discussed above, the primary way to buffer against extra demand is with extra staff. Under such circumstances, a determination will need to be made as to what level of demand to schedule for. Although employee schedules will not always meet demand 100 percent of the time, public safety concerns may dictate scheduling more employees to meet peaks in demand rather than average levels of demand, which is a common scheduling practice for 911 operators. To schedule for peaks in demand, select a level of demand between the average level and the highest level to translate into employee requirements. Scheduling for peaks in demand will result in overstaffing most of the time unless alternative staffing arrangements are used, such as cross training employees or hiring part-time workers (see Section 3.3 on staffing arrangements).

During periods of time with little variability, using the average demand level may be appropriate. In addition, the level of demand may drop below what is required, on average, for a single employee during the night shift. A determination needs to be made regarding the minimum

staffing level desired. The minimum staffing level should include a judgment of how to handle an unforeseen event (e.g., a major incident). Alternative staffing arrangements include hiring a low level employee to monitor TMC systems and to contact an operator or manager should something occur. Or, TMC systems may be able to monitor the transportation system and contact an employee should something happen. On the other hand, the TMC may need to rely on other agencies (e.g., police, private towing companies) to handle off-hour incidents due to budget restrictions or because such incidents are rare.

2.7.3.3. Regression models

Due to the technical nature of the statistics used to compute a regression model, the statistics should only be calculated by a professional with statistical training. Therefore, only a brief description of regression is provided. **Regression analysis** is a set of statistical techniques that uses one or more predictor variables (e.g., number of cars registered in area of coverage, weather conditions) to predict an outcome variable (e.g., number of incidents, volume of traffic, speed of traffic).[7,8] Similar to time series models, regression models use past demand to predict future demand (e.g., number of incidents on a typical Monday since a construction project started). In contrast to time series models, regression models may also use other predictor variables (e.g., estimated population of an area) that forecast changes in service demands not captured by using past demand in a time series model. The advantage of using regression is that these other variables may predict changes in demand before they are evident through the time series models described above. The best predictor variables are unrelated to each other (avoids overlap in prediction), and are highly related to the outcome variable. For example, the number of cars registered in a TMC's coverage area and the number of driver's licenses issued in the coverage area overlap too much to be useful. In this case, either standardize both variables and average them or use only one of the variables.

2.7.3.4. Measures of accuracy

As demand forecasts are formulated before the actual demand is known, the accuracy of the prediction is only evident when the demand prediction is compared to the actual demand.[8] The expectation of exact predictions is unrealistic.[7,18] Calculating measures of accuracy is important to determine whether to continue using a forecasting method or if the error is too great and a new forecasting method is needed.

2.7.3.4.1. Mean absolute deviation (MAD)

The **mean absolute deviation** (MAD), also known as the **mean absolute error** (MAE), is the average difference between the predicted demand and the actual demand.[7] To calculate MAD, subtract the forecasted demand from the actual demand in each period. Any negative values should be multiplied by -1 to yield a positive value. Sum all of the resulting values, and divide the total by the number of periods.

$$MAD = \frac{\sum_{t=1}^{n} |A_t - F_t|}{n} \qquad \text{(Equation 2.2)}$$

Where: A_t = actual demand in period t

F_t = forecasted demand in period t

n = number of periods

| | = the absolute value of

Σ = summation sign

2.7.3.4.2. Mean square error (MSE)

By squaring the deviation of the forecasted demand from the actual demand, the **mean square error** (MSE) weights larger errors more and smaller errors less than the MAD. Use the MSE if large errors are critical and extremely difficult or impossible to correct. The square root of the MSE will provide a value approximately on the same scale as the MAD.

$$MSE = \frac{\sum_{t=1}^{n} (A_t - F_t)^2}{n} \qquad \text{(Equation 2.3)}$$

Where: A_t = actual demand in period t

F_t = forecasted demand in period t

n = number of periods

Σ = summation sign

2.7.3.4.3. Mean forecast error (MFE)

The **mean forecast error** (MFE) is used to diagnose whether a model is biased.[7] A biased model will consistently either over predict or under predict actual demand. If the error in prediction is random and unbiased, then the average difference between the actual and forecasted demand will approximate zero. That is, sometimes the forecasted demand will be above the actual demand and sometimes below. The further the MFE value is from zero, the greater the bias in prediction. The sum of the difference between the actual and forecasted demand is called the **running sum of forecast errors** (RSFE). The MFE is obtained by dividing the RSFE by the number of time periods included in the calculation.

$$MFE = \frac{\sum_{t=1}^{n} (A_t - F_t)}{n} = \frac{RSFE}{n} \qquad \text{(Equation 2.4)}$$

Where: A_t = actual demand in period t

F_t = forecasted demand in period t

n = number of periods

Σ = summation sign

2.7.4. Demand modification

Demand modification is a strategy that is used to influence the level of demand from the consumer.[19] The goal of demand modification is to make demand less variable and more predictable. For example, dentist offices typically schedule appointments rather than relying on a walk-in policy. Consumers benefit by an assurance of service, and service operators benefit from more accurate employee schedules. Other examples of demand modification include offering more favorable prices during off-peak hours (e.g., off-peak prices for cell phone use), developing nonpeak demand (e.g., dinner restaurant adds breakfast menu), and developing complementary services (e.g., bar or lounge used to content customers as they wait for a table at a restaurant).[13]

Many of the functions performed by TMCs are designed to modify the demand of travelers. Traveler information is provided to offer better routes and travel times through a variety of sources (e.g., CMS [see Figure 2.9], television and radio reports, Web sites). The timings of traffic signals at intersections and at on-ramps are often controlled to provide a more uniform travel pace. HOV lanes were created to reduce volume by encouraging carpooling. Not only do demand modification strategies affect the transportation system by reducing congestion and the number of incidents, but these strategies also lower employee requirements.

Figure 2.9. CMS on I-75/85 Northbound in Atlanta

2.7.5. Additional demand modification resources

The Transportation Management program office under the Federal Highway Administration's Office of Operations (http://www.ops.fhwa.dot.gov/index.asp) addresses the area of travel demand management. The travel demand management strategies are the same types of strategies referred to above as demand modification. Under travel demand management, the Office of Operations has posted a variety of reference materials, tools, and links to related Web sites (see http://www.ops.fhwa.dot.gov/tdm/index.htm).

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Chapter 3. Scheduling Practices

3.1. Overview of TMC scheduling needs

TMCs vary widely in a number of aspects, including the functions offered, the administrative structure of the TMC, and the number of employees required for operation. The differences among TMCs necessitate different scheduling practices, which may include staffing typical hours of operation (e.g., 9 to 5 Monday through Friday) or advanced schedule designs (e.g., shift schedule with variable start times). TMCs that operate 24 hours a day/seven days a week typically use a three shift system.[1] Full- and part-time operators cover morning and afternoon shifts during peak travel conditions. Operators report to shift supervisors. Weekday shift supervisors are typically full-time employees who monitor TMC operations, complete administrative duties, and train lower level employees. During the night shift or "off-peak" hours, part-time employees, maintenance staff, or computer systems may monitor TMC operations and contact an on-call shift supervisor if there is an emergency.

There are several general approaches to scheduling employees.[2,3] With a **fixed schedule**, an employee's schedule remains fixed or the pattern of the shift assignments remains fixed over a long or indefinite period of time. A fixed schedule may include either dedicated shifts or schedules that rotate in a repetitive, cyclic pattern with employees working morning, afternoon, and evening shifts in a predetermined sequence. Because the number of employees assigned to each shift is fixed, a fixed schedule is only successful at meeting consistent patterns of demand. Many TMCs use dedicated shifts in which employees only work morning, afternoon, or evening shifts, and part-time employees are used to handle excess demand during periods of peak congestion and for weekend work. A **flexible** or **acyclic schedule** requires the generation of a new schedule each planning horizon (e.g., every month). Employees work different shifts to meet varying patterns of demand and other scheduling constraints (e.g., budgetary constraints).

3.2. Administration of scheduling

Responsibility for schedule administration varies across organizations.[2] **Department scheduling** involves an appointed manager overseeing schedule generation and implementation for a group of employees. **Team scheduling** involves dividing a group of employees into a set of teams, and electing a team leader who oversees the generation of schedules after consultation with team members and other team leaders. For example, employees working dedicated shifts could be divided into morning, afternoon, and evening scheduling teams to ensure weekend coverage. Typically, a manager will authorize the final schedules generated by the team leaders before implementation. **Self-scheduling** involves giving an entire group of employees responsibility for generating their own schedule. Typically, a manager will authorize the final schedule.

Department scheduling is the most common approach.[2,4] Often a centralized department handles the scheduling duties for an entire organization, or a manager within each unit is given responsibility for employee scheduling. With department scheduling, managers usually have greater control over the final scheduling decisions. In addition, managers typically have more access to scheduling resources (e.g., software, historical data) than their employees. A number of advantages are associated with schedules generated by managers in contrast to schedules generated by employees. In general, schedules generated by managers are created more quickly and within a defined time frame, problems are resolved more efficiently, schedules are more balanced with predicted levels of demand, new schedules are more easily compared to old schedules, and trends across schedules are more easily tracked. Successful department scheduling requires an employee who can handle the complexities of scheduling, and who can communicate with other employees and handle their scheduling problems. Department scheduling is more vulnerable to challenges regarding fairness and favoritism. New employees are more susceptible to a loss of confidence in the scheduler as they typically lack an understanding of the complexities involved in resolving scheduling decisions and judge the success of the scheduler based on how well their needs are met. Failures may lead to resentment and counterproductive work behaviors (e.g., absences, lateness).

Self-scheduling transfers the scheduling responsibility to employees, often an unpopular activity for managers.[2,5] Empowering employees to make their own scheduling decisions often leads to increases in satisfaction with the schedule as well as improved motivation, morale, and overall

job satisfaction. As employees are more likely to cater to each other's preferences, there is a greater chance that a schedule will be unbalanced (i.e., over- and under-staffing). Self-scheduling requires employees who can work together to make the scheduling decisions. Employees may require training to fully communicate the implications of scheduling decisions and an adjustment period to transition the responsibility. In practice, junior-level employees are frequently slighted in favor of senior-level staff preferences, which may lead to less positive outcomes for junior-level employees.

Team scheduling is similar to self-scheduling (with similar advantages and disadvantages), except that the employees are divided into groups or teams.[2] Team scheduling may also lead to improved teamwork, which may increase the willingness of team members to cover unpopular shifts. Of the three methods, team scheduling may require the most employee time and effort. The complexity of resolving problems and conflicts in scheduling increases dramatically with the number of teams. Employees may also become loyal to their own teams at the expense of the rest of the staff. For example, an employee may refuse to swap shifts with employees from other teams.

An examination of the schedule administration practices of 50 hospital wards revealed the importance of aligning the method of schedule administration with the number of employees, the demand variability, the demand predictability, and the variety of KSAO's and performance levels of the employees (see Figure 3.1).[2] Department scheduling is recommended for large groups of employees with complex situations (i.e., high demand variability, low demand predictability, and greater variety of KSAO's and performance levels). Self-scheduling is only

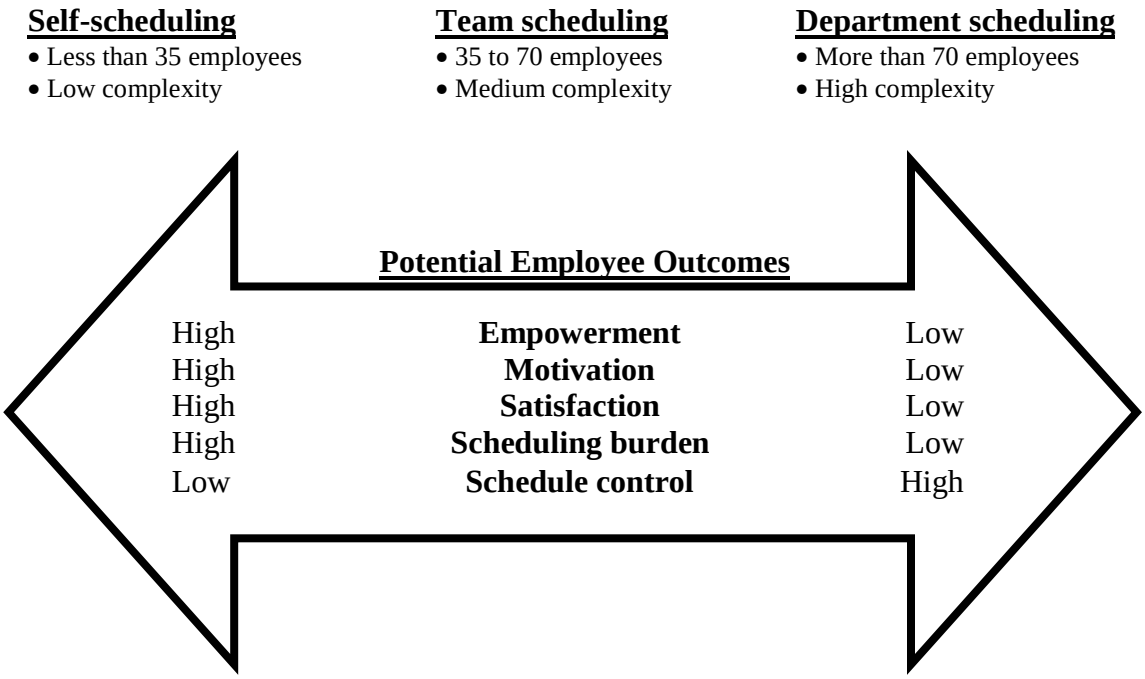

Figure 3.1. Schedule Administration
(Adapted from reference 2)

feasible with smaller groups of employees with simpler scheduling requirements, and should not be attempted with more complex arrangements. Team scheduling may be an appropriate alternative to department scheduling when self-scheduling is not feasible.

3.3. Staffing arrangements

Different staffing arrangements may be used to meet various scheduling demands.[6,7] Common staffing arrangements include full-time employment, part-time employment, temporary employment, and contract positions (see Table 3.1 for typical full- and part-time positions at TMCs). In addition, overtime, promotion, and redeployment can be used to meet scheduling demands. Typically, alternative staffing arrangements are used to increase the flexibility of using human resources to meet scheduling demands. For example, part-time employees may be used to meet the excess demand for services during anticipated periods of peak congestion.

Table 3.1. Common TMC Positions

Full-Time Positions	Part-Time Positions
• TMC manager/director • Supervisors (e.g., operations, engineering, maintenance, systems, law enforcement) • Equipment (field or central) engineer/maintenance coordinator • Transportation engineers • Electrical engineers • Computer programmers • Workstation operators/analysts • System administrators (e.g., computer hardware, software, networks) • Inspectors (e.g., field equipment) • Inspecting supervisor • Law enforcement personnel • Radio dispatchers • Administrative staff • Maintenance staff	• Additional workstation operators/analysts • Desk operators • HAR broadcasters • Dispatchers • Emergency planners • Maintenance technicians • Task-oriented trainees • Public information/media relations personnel • Interns

(Adapted from reference 1)

Part-timers are typically cheaper for a TMC because they are paid less and have fewer benefits (e.g., no paid vacation, no health insurance) than permanent employees.[6] Generally, part-timers work between 16 and 32 hours per week.[8] Although some part-time employees desire the reduction in hours per week, others accept part-time positions because of a lack of full-time positions. Part-timers may be considered involuntary part-timers if they would prefer to work in a full-time position but were not able to obtain one. On the other hand, voluntary part-timers accept part-time work for other reasons, such as the need to care for a child or ailing relative. Part-time employees often require as much supervision and administrative support as full-time employees. A segment of part-time employees do not consider themselves temporary employees and are referred to as permanent part-time.[9] Although permanent part-time employees typically

receive prorated benefits (e.g., pension and vacation accrual at a slower rate), often health insurance benefits are at the same rate as full-time employees.

Job sharing is defined as two or more part-time employees covering the duties of one full-time position.[8] Job sharers are typically at the same performance level (i.e., similar levels of experience). Job sharing does not require that each employee works half time or that the number of hours add up to 40 per week. Often the decision to increase the number of hours beyond 40 per week will be made based on the preferences of the personnel at a TMC and budget allowances. By converting one full-time position into two or more part-time positions, employers gain flexibility in scheduling and a greater pool of KSAO's. Job sharers often are able to cover each other's absences and are more productive than a single employee. Job sharers can work extra hours without overtime when unexpected workload surges occur. To succeed, job sharers must be willing to work as a team and able to perform the job as efficiently as one employee, which requires communication and cooperation. They must also have complimentary KSAO's and work styles, or else splitting the job may be difficult and conflict might arise.

Although temporary employees hired from another agency usually cost more per hour, there are a number of benefits associated with hiring temporary employees.[7] Temporary employees are not paid when there's no work for them to perform, are not provided benefits, and cannot file claims for unemployment compensation upon termination. Using temporary employees provides a layer of flexibility. TMCs may also choose to contract work to outside vendors. Typically, contractors are used on a project basis, or for the maintenance of field equipment.[7] Because temporary employees and contractors are not employees of the TMC, the TMC is not responsible for hiring, disciplining, paying, or terminating them.[10] TMCs require less human resources support for temporary or contracted employees.

Although many alternative staffing arrangements may be used to add flexibility to accommodating scheduling demands and meeting budgetary constraints, the staffing implications of the arrangements should be considered. For example, although voluntary part-time employees and job sharers may be satisfied with their working arrangements, involuntary part-time employees may resign as soon as they can find a full-time position. And as contractors are not employees of the TMC, they may not show the same commitment to their jobs as TMC employees.

Several internal human resource decisions, such as promotions, redeployment, and overtime allocation, may also be used to satisfy scheduling needs. Internal actions are often a more efficient option that maintains cost levels through the flexible utilization of existing employees. Redeployment may be permanent or temporary, and may become necessary during an unexpected peak in demand or when an employee takes an extended vacation or sick leave.[7] Overtime also enables employers to meet more demand without hiring additional employees. Employees are more willing to work overtime the more satisfied they are with their jobs.[11] However, overtime reduces job satisfaction and morale. If overtime is necessary, the amount of overtime should be minimized and the number of hours should be limited to no more than 48 hours per week when possible.

3.4. Equipment and TMC size

Equipment availability and the size of a TMC limit the number of employees who can work a shift. For example, the number of operators who can work one shift is limited to the number of workstations available. The number of workstations available may be limited by space or by financial costs. The consideration of equipment must also include contingencies if a piece of equipment fails and needs to be repaired or replaced. Maintenance personnel are critical to the successful operation of a TMC.[1] Maintenance personnel ensure that TMCs control the repair of critical equipment. However, contracting maintenance employees, hardware/software support, and operators is a common practice.

In general, the original size of a TMC was determined by its original coverage area.[1] With the continual increase in the demand for TMC services, a TMC may outgrow the original space allocation. Typically, an expansion of consumer demand warrants additional operators, dispatchers, and other personnel, which require additional equipment and space. The reallocation of space can be costly and operationally disruptive. TMCs with highly complex equipment or integrated systems (with regional TMCs or other transportation agencies) may find it more difficult to expand existing systems. Room for expansion should be considered during the initial design of a TMC.

3.5. Scheduling systems

All places of work include methods for ensuring that the work is completed.[3] A common method that is used to ensure the completion of work is a schedule that dictates when employees must perform their jobs. This section provides an initial introduction to scheduling practices, common scheduling terminology, different types of schedules related to the hours of operation of an organization, and examples of schedules.

A **shift** comprises of the hours in a single day that an employee is scheduled to work, and is the basic unit of a scheduling system.[3] All employees who have a schedule work a shift, whether they work the 9 am to 5 pm shift Monday through Friday or the night shift from 10 pm to 6 am Tuesday through Saturday. Both examples contain employees who work dedicated shifts. That is, they work the same hours each day. There are several advantages to implementing dedicated shifts. Employees can select a shift to fit their lifestyles.[5] For example, students can continue their education. Employees who work together on a regular basis may form a cohesive work group.[5] However, hiring for dedicated shifts assumes that enough staff can be recruited to fill all of the shifts, even unpopular shifts.[2,12] Another type of fixed schedule is a cyclic, rotating shift; an employee's schedule rotates following a predetermined, repetitive pattern. As shifts rotate, unpopular shifts are spread out among all employees. Cyclic schedules often include a number of advantages over acyclic designs.[4] Employees know their schedules in advance and healthy scheduling designs are more easily implemented (e.g., includes forward rotation). Using fixed schedules assumes that demand remains relatively consistent for each shift. With acyclic schedules, employees work in nonrepetitive patterns based on updated projections of demand for services.[12] Typically, acyclic schedules include a planning horizon of 4 to 6 weeks, which means that employees do not know their schedules far in advance.[2] The advantage of acyclic schedules is greater flexibility.[4] Acyclic schedules are appropriate when the pattern of demand fluctuates over time and an accurate prediction of demand is not possible until some point in time such as a month in advance.

Three-shift systems and two-shift systems are the most common shift systems for 24/7 operations.[3] Three-shift systems typically include 8-hour shifts plus a 30 minute carry-over period for a total of 8 and a half hours. The 30 minute carry-over period is used by the current shift of employees to brief the on-coming shift as to the status of any incidents being logged or maintained. Most likely, a TMC that monitors busy roadways will avoid scheduling shift changeovers during peak congestion periods and will schedule an overlap long enough to avoid any loss of information between shifts. The two-shift system typically includes shift lengths of 10 hours or more per day. Other shift classifications include a split shift, which includes two shifts less than 7 hours in duration separated by an hour or more on the same day, and irregular shifts that include variable start times and possibly varying shift lengths.

Scheduling systems are designed to match the hours of operation of an organization.[3] Four categories of operations may be distinguished, each with its own unique characteristics. **Discontinuous operations** do not require operation either 24 hours a day or 7 days a week. Typically, discontinuous operations close at night and on the weekends. **Continuous operations** function 24 hours a day and 7 days a week. **Compressed operations**, a special case of discontinuous or continuous operations, includes employee schedules with shifts that are longer than 8 hours a day and a reduced workweek less than 5 full days per week. A "4/40" (10 hours per day/four days per week) and one day off every fortnight (9 hours per day with one day off every other week) are common. A continuous operation that allows for shifts longer than 12 hours in length is typically referred to as a **sustained operation**. Sustained operations allow workers to remain on the job for as long as they can work to create a "nonstop" work rate.

3.5.1. Discontinuous operations

Table 3.2 displays a typical Monday through Friday operation with one shift over 84 days (or three 28-day periods). The S1M1 represents one work system (S1) and the first 28 days, about one month, of the schedule (M1).[3] The S1M2 represents the next 28 days (days 29 to 56) of the same work system. Every employee working this schedule starts work in the morning and works about 8 hours.

Table 3.2. Discontinuous Operation with One Dedicated Schedule

	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su
S1M1	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0
S1M2	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0
S1M3	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0

M = morning shift, A = afternoon shift, N = night shift, O = off day. (Adapted from reference 3)

Table 3.3 displays three work systems over a four-week period. Each work system includes a dedicated shift (e.g., morning, afternoon, and night) and could be used to cover a 24-hour operation from Monday through Friday. Part-time employees could be used to cover periods of peak workload and weekend work.

Table 3.3. Discontinuous Operation with Three Dedicated Schedules

	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su
S1M1	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0	M	M	M	M	M	0	0
S2M1	A	A	A	A	A	0	0	A	A	A	A	A	0	0	A	A	A	A	A	0	0	A	A	A	A	A	0	0
S3M1	N	N	N	N	N	0	0	N	N	N	N	N	0	0	N	N	N	N	N	0	0	N	N	N	N	N	0	0

M = morning shift, A = afternoon shift, N = night shift, 0 = off day. (Adapted from reference 3)

Table 3.4 displays three work systems that represent three rotating shifts. The direction of rotation is forward. In other words, the shifts move forward through time from morning to afternoon to night. Alternatively, the shifts could rotate backwards, or the speed that the shifts rotate could increase by changing within the same week rather than changing from week to week. On the other hand, the speed of rotation could decrease to every four weeks, or one year with employees bidding for their preferred shifts each year.

Table 3.4. Discontinuous Operation with Three Rotating Schedules

	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su	M	T	W	R	F	S	Su
S1M1	M	M	M	M	M	0	0	A	A	A	A	A	0	0	N	N	N	N	N	0	0	M	M	M	M	M	0	0
S2M1	A	A	A	A	A	0	0	N	N	N	N	N	0	0	M	M	M	M	M	0	0	A	A	A	A	A	0	0
S3M1	N	N	N	N	N	0	0	M	M	M	M	M	0	0	A	A	A	A	A	0	0	N	N	N	N	N	0	0

M = morning shift, A = afternoon shift, N = night shift, 0 = off day. (Adapted from reference 3)

3.5.2. Continuous operations

Continuous operations include more hours of operation than discontinuous operations and as a result often require more complicated scheduling systems.[3] Usually there are more than three scheduling systems in a schedule and the shifts often rotate in cyclic or acyclic patterns. Although dedicated shifts are feasible for a continuous operation, more scheduling systems will be required to cover all of the hours of operation or alternative scheduling arrangement will be required (e.g., part-time employees, contract employees). Examples of several common cyclic, rotating schedules are presented. Although a cyclic schedule could be constructed to meet a pattern of demand, the cyclic schedules below assume that the amount of demand is the same for each shift. Section 3.7 on manual scheduling discusses a method for generating acyclic schedules to meet varying patterns of demand. The scheduling notation used to depict schedules in the tables below was modified to facilitate the communication of the schedules. Instead of presenting each scheduling system, only the first system was presented. Other scheduling systems may be abstracted by starting at different weeks (w2 = week two, w4 = week four). The number of scheduling systems and the minimum number of employees (or groups of employees) required to perform the schedule is equal to the number of weeks the schedule covers (i.e., the number of rows in the table). Table 3.5 displays a common schedule in Europe referred to as the

Table 3.5 Continuous Operation with Four Forward Rotating Schedules (2-2-3)

	M	T	W	R	F	S	Su
S1W1	M	M	A	A	N	N	N
S1W2	0	0	M	M	A	A	A
S1W3	N	N	0	0	M	M	M
S1W4	A	A	N	N	0	0	0

M = morning shift, A = afternoon shift, N = night shift,
0 = off day. (Adapted from reference 3)

continental rota or the 2-2-3, which indicates the on/off days. The 3-shift system repeats every four weeks with a rapid forward rotation, and employees average 42 hours a week when working an 8-hour shift.

The schedule in Table 3.6 is referred to as the French continuous system. The 3-shift system repeats every five weeks with a rapid forward rotation. Employees average 33.6 hours per week when working 8-hour shifts. The average number of hours per week may be increased to 34.65 hours by including a fifteen minute overlap during shift changeovers and to 35.7 hours with a 30 minute overlap.[13] In addition, the average number of hours per week may increase when accounting for public holidays, training time, and absence coverage.[14]

Table 3.6 Continuous Operation with Five Forward Rotating Schedules (French)

	M	T	W	R	F	S	Su
S1W1	M	M	M	0	0	A	A
S1W2	A	A	0	0	N	N	N
S1W3	0	0	0	M	M	M	M
S1W4	0	0	A	A	A	0	0
S1W5	N	N	N	N	0	0	0

M = morning shift, A = afternoon shift, N = night shift, 0 = off day. (Adapted from reference 15)

Table 3.7 depicts a schedule similar to the French continuous system. The average number of work hours per week is 33.6, and the schedule rotates every ten weeks instead of every five weeks.

Table 3.7 Continuous Operation with Ten Forward Rotating Schedules (2-2-2-4)

	M	T	W	R	F	S	Su
S1W1	M	M	A	A	N	N	0
S1W2	0	0	0	M	M	A	A
S1W3	N	N	0	0	0	0	M
S1W4	M	A	A	N	N	0	0
S1W5	0	0	M	M	A	A	N
S1W6	N	0	0	0	0	M	M
S1W7	A	A	N	N	0	0	0
S1W8	0	M	M	A	A	N	N
S1W9	0	0	0	0	M	M	A
S1W10	A	N	N	0	0	0	0

M = morning shift, A = afternoon shift, N = night shift, 0 = off day. (Adapted from reference 14)

The next two work systems depict schedules with 12-hour shifts and 4 week cycles. A 12-hour shift schedule includes a number of benefits over an 8-hour shift.[15] There are fewer afternoon and night shifts and more days and weekends off. There is a reduction in the number of commutes to and from work. Of course, the downside is the long work day and correspondingly

shorter off time between consecutive work days. The work system known as EOWEO, or every other weekend off, includes an equal number of free weekends for each employee and two 3-day weekends every month (see Table 3.8).[3,15] There is a maximum of three nights per week. The schedule rotates quickly. The average number of hours per week is 42.

Table 3.8 Continuous Operation with Four Rotating Schedules (EOWEO)

	M	T	W	R	F	S	Su
S1W1	D	D	0	0	N	N	N
S1W2	0	0	D	D	0	0	0
S1W3	N	N	0	0	D	D	D
S1W4	0	0	N	N	0	0	0

D = day shift, N = night shift, 0 = off day.
(Adapted from reference 3)

Another schedule with a 12-hour shift is the DuPont schedule (see Table 3.9). A fifth (relief) week of four 8-hour day shifts followed by three off-days may be added. The relief week may be used as an opportunity for employees to catch up on paperwork or to complete training. The fifth week brings the average work week length from 42 hours down to 40 hours.

Table 3.9. Continuous Operation with Four Rotating Schedules (DuPont Schedule)

	M	T	W	R	F	S	Su
S1W1	N	N	N	N	0	0	0
S1W2	D	D	D	0	N	N	N
S1W3	0	0	0	D	D	D	D
S1W4	0	0	0	0	0	0	0

D = day shift, N = night shift, 0 = off day.

3.6. Schedule design

The design of a schedule depends on a number of factors. Policies establish the work rules that are applied in the context of employee availability and preferences, work demands, and financial constraints, all of which create scheduling constraints.[16] Conflicting constraints often cause problems that must be resolved by the schedule administrator to generate the most desirable schedule.

Generating a schedule increases in complexity as the number of constraints increase. One method to help alleviate the complexity of scheduling problems is to prioritize the constraints.[12] A common method used to prioritize constraints in software is to classify each constraint as a hard constraint or a soft constraint. **Hard constraints** (e.g., laws, contractual obligations) must be satisfied. **Soft constraints** (e.g., employee preferences) may be violated to resolve scheduling conflicts.

A number of common scheduling policies (or constraints) that should be considered before designing a schedule are listed below.[12,13,16,17,18]

- The start times and duration of the shifts
- The number of hours and days worked per week
- The maximum/minimum number of consecutive work days (e.g., maximum of 7 days, minimum of 2 days)
- The maximum/minimum number of consecutive off days (e.g., maximum of 6 days, minimum of 2 days)
- The minimum number of weekends (e.g., 2 weekends per month)
- Off days over the weekend should be equally spaced throughout the schedule
- Shift rotation policies (e.g., rotation can only occur after at least two off days)
- Permissible shift sequences (e.g., three consecutive day shifts allowed, but an afternoon shift may not follow a night shift)
- Shift changeover procedures
- Alternative, reserve, and contingency scheduling and staffing policies
- The method of shift assignment
- The staffing levels of the shifts
- The start times and duration of breaks
- Overtime and shift differential policies
- Days-off policies for vacation, sick leave, personal time, jury duty, maternity/paternity leave, etc.
- Groups or teams of employees that should remain intact throughout the schedule

Although many of the constraints listed above may seem reasonable, including too many of them as hard constraints may create too many scheduling conflicts. Often, constraints may need to be amended to accommodate other constraints. For example, employee preferences may run counter to organizational policies. Violating some of the constraints may enable more desirable schedules. In addition, the importance of the soft constraints may be ranked to help determine which soft constraints may be violated before others. Employee preferences are an important consideration, and several methods may be used to accommodate them.[12] Employee preferences may be implemented into the schedule during the design phase, or employees could bid for shifts in order of seniority or in a lottery system.

3.7. Manual scheduling

Although computer programs use algorithms to generate "optimal" schedules, most schedules are developed by hand. Schedules developed manually often offer more flexibility, but take a lot of time to complete. The purpose of this section is to discuss aspects of developing schedules by hand to meet the needs of the scheduler and to reduce the amount of time required to create the schedule.

The first step to generate a schedule is to determine the number of employees who will be subject to the schedule.[19] Employees should be scheduled in groups that perform the same job (e.g., operators, maintenance personnel) or who work together. For example, if in a 3-shift system one senior-level operator is required during the morning and afternoon shifts, and at least two operators (senior or junior level) are required during each shift, because the senior-level operators are more constrained, schedule them first. Next, fill in the remaining openings with

senior- or junior-level operators. In general, assign employees to the schedule to meet the strictest constraints first.

Although no single scheduling algorithm will satisfy the needs of all TMCs, two flexible algorithms are discussed below that address a variety of scheduling needs. Although only manual methods for using the algorithms are discussed below, both algorithms can also be implemented on a computer. The scheduling methods described below include a number of constraints that may not hold at some TMCs. As a result, the algorithms may need to be adapted to the specific scheduling needs of a TMC. For example, one of the algorithms assumes that the work week is seven days long. TMCs with a six day work week may proceed by setting the demand for the off day to zero. Alternatively, the schedule may be changed after implementing the algorithms to more closely match the needs of a TMC.

Although some modifications are possible, the following assumptions are part of the scheduling algorithms presented below.[16,18,20]

- The length of the work week includes seven working days.
- An employee's work week consists of 5 consecutive days of 8 hour shifts and two consecutive off days.
- A preference is given for days off that overlap with the weekend.
- The demand, or number of employees needed, has been predetermined (see Chapter 2 on work analysis).
- Every employee included in the schedule works full time.
- Employees are interchangeable.
- The objective of the algorithm is to provide the minimum number of employees that meet the demand.
- Adjacent planning periods are not considered.

The scheduling algorithms are relatively simple procedures that are accessible to most schedule administrators who do not have access to advanced, computer-based operations research scheduling methods (e.g., integer programming).[18,20,21] The algorithms generate very good to optimal solutions in many cases.

3.7.1. Scheduling efficiency

As the scheduling algorithms must satisfy all demand requirements, under-scheduling is not possible. However, over-scheduling may occur. The **scheduling efficiency** equation helps to determine the amount of slack time, if any, employees will experience (see Equation 3.1).[16]

$$\text{Scheduling Efficiency} = \frac{\text{The Total Number of Employees Required each Day over the Week}}{\text{The Total Number of Employee Days Scheduled}}$$

(Equation 3.1)

When the sum of the total number of employees required each day over the work week equals the total number of employee days scheduled, scheduling efficiency equals 1.0, which indicates that a scheduling solution with no over-scheduling is theoretically possible. Two conditions

determine the scheduling efficiency, and must be satisfied to achieve peak efficiency (i.e., no over-scheduling).[16]

Condition 1. The sum of the total number of employees required each day over the work week divided by the number of days on per week (typically 5) must equal an integer.

Condition 2. The minimum number of employees required to meet the amount of weekly demand must be equal to or greater than the number of employees required to meet the demand for employees on each work day.

The three examples below demonstrate the application of the scheduling efficiency formula and the two conditions.

In Table 3.10, the sum of the total number of employees required each day over the week is 9 + 9 + 7 + 8 + 10 + 4 + 3 = 50 and each employee works 5 consecutive days each week. The first condition is satisfied as the total number of employees required each day over the work week divided by the number of days on per week is an integer (50/5 = 10). Ten employees would be required to cover 50 employee days if each employee worked 5 days per week. The second condition is also satisfied. The minimum number of employees required for the week (10 employees) is equal to or greater than the number of employees required on any single day during the week (e.g., 10 employees [the most on any single day] required on Friday). As both conditions are satisfied, a slack free solution is theoretically possible. The scheduling efficiency is equal to 1 as the total number of employees required each day over the week divided by the total number of employee days scheduled equals 50/50 = 1.

Table 3.10. Daily Demand with Peak Efficiency Possible

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Employees Required	**9**	**9**	**7**	**8**	**10**	**4**	**3**

(Adapted from reference 16)

In Table 3.11, the total number of employees required for the week equals 47. If a 5 day work week is used then the first condition fails (47/5 = 9.4). Although 9.4 is greater than the highest daily demand of 9 employees on Monday and Friday (satisfying condition 2) a slack free solution is not possible. The number of employees required to meet the weekly demand is rounded up to the next highest integer (i.e., 10). As a result, the total number of employee days scheduled becomes (10 × 5 = 50). The theoretical scheduling efficiency does not equal 1 (47/50 = .940). The need to increase the number of employees required to meet the weekly pattern of demand over a week is common when days off have to be consecutive.[16]

Table 3.11. Daily Demand When Condition One Fails

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Employees Required	**9**	**8**	**8**	**7**	**9**	**4**	**2**

(Adapted from reference 16)

In Table 3.12, the total number of employees required for the week equals 50, and if each employee works 5 days per week then the first condition is satisfied (50/5 = 10). However, condition 2 fails because the number of employees required on Monday is 11, which is greater than the number of employees required to cover the amount of weekly demand. A total of 11 employees would cover 55 employee days, which is five more than the 50 employee days required by the total weekly demand. As a result, the total number of employee days scheduled becomes (11 × 5 = 55). The theoretical scheduling efficiency does not equal 1 (50/55 = .909).

Table 3.12. Daily Demand When Condition Two Fails

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Employees Required	**11**	**9**	**7**	**8**	**10**	**3**	**2**

(Adapted from reference 16)

3.7.2. Shift-scheduling algorithm

The **shift-scheduling algorithm** assigns employees to shifts with variable start times within a work day. The number of employees required across the course of a day (i.e., the demand) provides the basis for the assignments. The manual shift-scheduling algorithm includes four steps.[18,20]

Step 1. Allocate to the earliest possible shift the number of employees required to work the first hour of operation.

Step 2. Allocate to the latest possible shift the number of employees required to work the last hour of operation.

Step 3. If all of the demand requirements have been met, stop. Otherwise, continue to step 4.

Step 4. Identify the segments of time with the highest demand. Allocate employees to the earliest or latest possible shift that meets the greatest amount of demand. Choose the most desirable shift for ties. Return to step 3 when step 4 is completed.

The shift-scheduling algorithm accommodates the constraints of the schedule first by meeting the demand of the earliest and latest hours. The example in Table 3.13 uses hypothetical demand for each hour in a 24-hour period (starting at 6 am and ending at 6 am the next day) to demonstrate the shift-scheduling algorithm. Each assignment row represents at least one employee's shift assignment, with values in the row indicating the number of employees working the shift. The

amount of demand is then reduced by the number of employees included in the assignment. The example assumes a single 8-hour shift with variable start times and without breaks. Alternatively, employees could be restricted to working either a morning shift (6 am to 2 pm), an afternoon shift (2 pm to 10 pm), or an evening shift (10 pm to 6 am). Overlap during shift changeovers might be included by extending shifts beyond 8 hours or including breaks for employees in the schedule.

Table 3.13. Shift-Scheduling Algorithm Example

Hours	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
Demand	**4**	7	8	7	4	4	3	3	2	4	6	7	5	5	3	2	2	1	2	1	2	1	1	2
Assignment (4)	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*																
Demand	0	3	4	3	0	0	0	0	2	4	6	7	5	5	3	2	2	1	2	1	2	1	1	**2**
Assignment (6)																	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
Demand	0	3	4	3	0	0	0	0	2	4	6	7	5	5	3	2	0	0	0	0	0	0	0	0
Assignment (7)									*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*								
Demand	0	3	4	3	0	0	0	0	1	3	5	6	4	4	2	1	0	0	0	0	0	0	0	0
Assignment (8)									*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*								
Demand	0	3	4	3	0	0	0	0	0	2	4	5	3	3	1	0	0	0	0	0	0	0	0	0
Assignment (9)								*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*									
Demand	0	3	4	3	0	0	0	0	0	1	3	4	2	2	0	0	0	0	0	0	0	0	0	0
Assignment (10)							*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*										
Demand	0	3	4	3	0	0	0	0	0	0	2	3	1	1	0	0	0	0	0	0	0	0	0	0
Assignment (11)							*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*										
Demand	0	3	4	3	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Assignment (12)		*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*															
Demand	0	2	3	2	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Assignment (13)		*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*															
Demand	0	1	2	1	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Assignment (14)		*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*															
Demand	0	0	1	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Assignment (15)					*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*												
Demand	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Assignment (16)			*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*														
Demand	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Assignment (17)					*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*												
Demand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	4	7	8	8	10	10	12	13	11	8	7	7	5	5	3	2	2	2	2	2	2	2	2	2
Overage	*0*	*0*	*0*	*1*	*6*	*6*	*9*	*10*	*9*	*4*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*1*	*0*	*1*	*1*	*0*

(Adapted from reference 18)

The staffing needs generated by the shift scheduling algorithm require 17 employees. As the algorithm continues to schedule shifts until all of the demand is met, there were substantial overages during the middle of the day. The amount of over-scheduling was especially high because the hours of operation covered a 24-hour period and there were steep changes in the amount of demand in the morning and afternoon. A number of strategies may be used to reduce the amount of over-scheduling. For purposes of the example, shifts were scheduled in an attempt to accommodate the closest occurrences of demand. For example, when the 15th assignment was scheduled, the shift was extended toward the early morning demand. The shift could have easily been scheduled toward the evening instead of the morning to even out the amount of over-scheduling. The shift-scheduling algorithm may be terminated before all demand is met for a variety of reasons. For example, the schedule administrator may feel that the amount of employee coverage is sufficient, budget constraints may restrict the number of employees, the design of the TMC may restrict the number of employees, etc. Alternative staffing arrangements (e.g., part-time employment, overtime, split shifts) may be used to accommodate the peaks in

demand. Finally, including breaks (e.g., 1-hour lunch break, 15-minute rest break) in employees' schedules may enable a greater range of coverage for each employee.

3.7.3. Days-off scheduling algorithm

The **days-off scheduling algorithm** assigns employees to a weekly schedule based on the number of employees required each day. The number of employees needed to fulfill the shift-scheduling algorithm each day may be used as the daily staffing requirement for the days-off scheduling algorithm. The days-off scheduling algorithm consists of three steps.[16,18,20]

Step 1. When possible, select the pair of days that include the lowest daily employee demands and the lowest average daily demand. For example, select a pair of days that require 6 employees on each day before selecting a pair of days that require 5 employees on the first and 7 employees on the second. If there is a tie, select days that overlap with the weekend first; otherwise select the most desirable off days.

Step 2. Increase the days-on schedule by one employee and decrease the demand requirements by one employee.

Step 3. If all of the demand requirements have been met, stop. Otherwise, return to step 1.

The days-off scheduling algorithm assumes that employees receive two consecutive off days per week. The algorithm schedules to the constraints of the system by assigning employee off days during the days with the least demand. An example with peak efficiency was used to demonstrate how to use the days-off scheduling algorithm (see Table 3.14). The numbers that are in bold and underlined represent the assignment of the off days. All of the other days are

Table 3.14. Days-Off Algorithm Example

Days-off algorithm							Days-on tally						
Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
9	9	7	8	10	**4**	**3**	0	0	0	0	0	0	0
8	8	6	7	9	**4**	**3**	1	1	1	1	1	0	0
7	7	5	6	8	**4**	**3**	2	2	2	2	2	0	0
6	6	4	5	7	**4**	**3**	3	3	3	3	3	0	0
5	5	3	4	6	**4**	**3**	4	4	4	4	4	0	0
4	4	**2**	**3**	5	4	3	5	5	5	5	5	0	0
3	3	2	3	4	**3**	**2**	6	6	5	5	6	1	1
2	2	**1**	**2**	3	3	2	7	7	6	6	7	1	1
1	1	1	2	2	2	**1**	8	8	6	6	8	2	2
1	**0**	**0**	1	1	1	1	8	9	7	7	9	3	2
0	0	0	0	0	0	0	9	9	7	8	10	4	3

(Adapted from reference 16)

reduced by one representing an employee's work week on the left hand side of the table under the days-off algorithm. On the right side of the table under days-on tally, the number of employees required to work each day is enumerated. Because both conditions for peak efficiency are met, a schedule with no over-scheduling is theoretically possible. Peak efficiency was achieved, and the sum of the days-on tally equaled the amount of initial demand.

If peak efficiency were not possible, the days-off algorithm would continue until all demand was accommodated. Similar to the shift-scheduling algorithm, schedule administrators may choose to deviate from the algorithm or implement alternative staffing arrangements (e.g., part-time employment, compressed work week) to avoid excessive over-staffing.

3.8. Scheduling software

Scheduling software offers automated and, in some cases, improved scheduling decisions. If generating a schedule requires a lot of time and staffing costs represent a high percentage of the budget, then the potential benefits of scheduling software may sound appealing. However, to realize the full benefits of scheduling software requires planning to determine the software requirements and if the software requirements can be met within a given budget. Manual methods remain prevalent because they are more flexible in terms of generating and modifying a complex schedule. On the other hand, scheduling software can efficiently process more variables simultaneously than a human scheduler.[22]

Selection of scheduling software should depend on the needs and situation of the TMC.[23] As vendors of scheduling software most likely are not familiar with TMC operations, the determination of software requirements is imperative.[24] Never accept software that is less than satisfactory. Once the product is accepted, the TMC loses leverage to request modifications to resolve existing and future problems.

3.8.1. Organizational goals

The organizational goals for the scheduling software may range from a request by an employee for a simple scheduling aid to an initiative to implement an extensive human resource management system with a sophisticated scheduling application.[23] More specific goals may include the creation of a schedule that requires less time and effort, a reduction in staffing expenses, or better consumer satisfaction with service output. Most likely, planning efforts will be proportional to projected expenses and the time and effort required for implementation. The organizational goals should clarify the intended impact of the software. A determination of the organizational goals and objectives will also help determine the software requirements. If many of the software features seem appealing, consider ranking the most important features. Assign a projected budget to each aspect of the software and/or software development. Advanced planning helps ensure that the final product meets the needs of the TMC, and that each step of the process can be evaluated to ensure that the implementation of the software moves toward meeting the organizational goals.

3.8.2. Software features

Before selecting a scheduling program, consider the features the software should include. In general, four classes of features should be considered: (1) how it works, (2) ease of use, (3) flexibility, and (4) tracking features.[22,23] Schedules that are developed holistically are preferred. Although later modifications may be necessary, the initial schedule should consider all variables and constraints, such as employee availability and preferences, simultaneously. The best scheduling system will exploit differences in employees' preferences to meet time constraints. Alternatively, scheduling may progress in stages until a final schedule is achieved. For example, an initial schedule may be generated based upon employees available and in a second iteration

employee preferences are taken into account. The worst case scenario requires a number of manual adjustments after the final schedule is generated. A second important consideration is how the software treats adjacent planning periods. If adjacent planning periods are not taken into account in the generation of a schedule, violations may occur across planning periods. For example, an employee may be scheduled to work five out of seven days in two adjacent planning periods. If the adjacent planning periods are not monitored, then the schedules could result in ten consecutive work days. Third, how far in advance does the scheduling program operate? That is, consider how long each planning period is, and whether the length of the planning period coincides with TMC scheduling practices. Finally, determine whether the scheduling software includes soft and hard constraints, and how conflicting constraints are handled.

The scheduling software should be easy to use.[22] The interface should be intuitive. A graphical user interface would be ideal for this purpose. Less sophisticated applications may simply use a spreadsheet-based front end. More complex systems may require more extensive training, which is important to ensure adoption of the software by employees. The flexibility of the software will also determine the ease of use. For example, can the software handle multiple shift lengths (e.g., 8-hour and 10-hour shifts), employees in different jobs and at different performance levels, and changes made to existing schedules?[22] Although the additional flexibility may increase the complexity of using the software, more problems will arise if greater flexibility is needed, but not available.

Finally, how are past schedules recorded?[23] If planning periods remain the same or similar, the generation of a new schedule may be unnecessary. The software may allow a past schedule to be used or slightly modified. Also, determine which aspects of the scheduling software are recorded (e.g., whether modifications to existing schedules are tracked). As discussed in the next section, other human resource management information could be stored in a database as part of the software package.

3.8.3. Other human resource management functions

The functionality of the software does not need to be limited to scheduling applications.[23] Other human resource management functions could be included as applications of the software. Either the software could include additional human resource management functions, or the software could be designed to connect with existing systems. Consider how extensive the software capabilities should be. Also monitor the extent to which the software reduces or creates redundancies.

The most obvious additional function concordant with scheduling software is a database that stores a variety of human resource management information.[23] As a database, the system could store information such as demographic information, vacation requests and accrual, attendance records, lateness, timecard stamps, performance evaluations, and wage and salary information. If other human resource management functions are included, the report generation capabilities of the software will need to be considered.

3.8.4. Legal requirements

The software should meet the legal requirements and the policies of the TMC.[23] In general, there are two requirements. First, if sensitive data is stored in a database through the software,

the security of the information will need to be ensured. Second, the scheduling decisions made by the software should follow legal guidelines and rules of the TMC.

3.8.5. Final cost/benefit analysis

Simple programs that operate through spreadsheets or Windows-based software can be purchased over the Internet for several hundred dollars.[22] Alternatively, consultants can develop several schedules to the specification of a TMC or they can develop programs that are customized to a TMC's needs. The final decision of what to purchase will come down to a cost/benefit analysis. Be aware that a common problem with scheduling services is that the promotional materials may promise more than the service can deliver or may make entirely erroneous claims.[22]

3.8.5.1. Costs

As TMCs operate within a strict budget, the scheduling software will be purchased within some financial constraints. In addition to a consideration of the project and final price for the scheduling software, a number of additional costs should be factored in.[22,23] For example, how much training is necessary before the software can be implemented and used? The software will have a certain shelf-life after which time it may not be usable. A longer shelf-life is preferable, and a number of factors may cause the scheduling software to become obsolete. For example, the staffing structure of the TMC may change or later technological advancements may not be compatible with the scheduling software. Not only should the shelf-life of the software be considered, but also determine how expensive upgrades or additions to the software will be. Finally, determine the costs for technical support, and what happens if the system fails or needs to be fixed.

3.8.5.2. Benefits

Most likely the benefits of the new system will be compared to an older system that may have been a simple manual scheduling process.[22,23] How long does it take for the program to generate the schedule? Does the system include all of the desired features? For example, the scheduling software may not be worth the cost if the time required to modify the schedule is equal to or greater than the time required to generate the schedule by hand. Improvements in scheduling decisions may be considered on several dimensions. Lower staff costs may occur from more efficient schedules that require less overtime coverage. Or employee schedules may satisfy service demands more accurately, leading to higher consumer satisfaction. The final question should be, "Do the benefits outweigh the costs?"

3.8.6. Software evaluation

Evaluate scheduling software to the extent possible before making a purchase, and continue to do so afterwards. More extensive evaluation is warranted the greater the final price of the software or the more time and effort that is required to implement and use the software. A number of methods may be used to evaluate the software.[23] Solicit opinions and insight from managers or other schedule administrators, or from employees who work under the scheduling system of interest. Demonstrations and tradeshows provide on-site presentations of how the software works. Feedback from other TMCs provides valuable information about experiences with scheduling software. Visit and interview TMCs that use scheduling software. The Internet is another useful source of information. Trial versions of the software may be available. Often,

trial versions will only work for a limited duration, or will only have a subset of the features of the full version of the software. After purchasing the software, continue to evaluate it. If there is a chance to use the software with a trial version or during a demonstration, attempt to generate some schedules with typical scenarios that the TMC commonly faces.[22]

3.8.7. Shift scheduling resource

Dispatch Monthly is a magazine that provides news and information primarily for public safety dispatchers (http://www.911dispatch.com/). The Dispatch Monthly Web site hosts a page with information on staffing and shifts (http://www.911dispatch.com/shifts/). The staffing and shifts Web page includes sections on different shift configurations, shift and staffing resources, and shift and scheduling software.

3.9. Real-time scheduling changes

3.9.1. Predicting demand

Schedules are generated based on predictions of demand. Actual demand may deviate widely from predicted demand, necessitating real-time changes to the schedule. To maintain the appropriate level of service output with consumer demand, the difference between predictions of demand made in the past and actual demand that occurs in real time should be monitored.[25] Based on actual demand and a revised prediction of future demand, certain real-time changes to an existing schedule may be warranted. Judgment is required to decide whether to make a real-time change to an existing schedule, and to determine what change to make. Higher variability and greater uncertainty contribute to the need to make more real-time changes. Real-time changes can be classified as either short-lived actions or long-lived actions.[25] **Short-lived actions** include small adjustments that have a small effect on service output (e.g., recalling an employee from a break). **Long-lived actions** include larger adjustments that have a greater impact on service output and are more difficult to undo (e.g., sending an employee home early).

3.9.2. Short-lived actions

Short-lived actions only affect a small period of time (i.e., a few minutes to an hour).[25] Examples of short-lived actions include recalling, extending, or canceling an employee's break, extending the length of an employee's shift (including overtime) by a small amount, and asking an employee to perform different tasks for a small part of a shift. Short-lived actions are typically easy to reverse and require little time and effort to implement, but tend to have a small impact on meeting changes in service demands. Short-lived actions are appropriate for meeting small deviations from demand forecasts. In addition, if a high degree of uncertainty regarding future demand remains, a short-lived action may be more appropriate as the decision will be easier to modify.

3.9.3. Long-lived actions

Long-lived actions affect a period of time longer than an hour and may entail a greater commitment of time and effort by employees.[25] Examples of long-lived actions include calling in additional employees to work, reassigning employees to different jobs for a substantial portion of their shifts, and sending an employee home early. Long-lived actions are typically difficult to reverse and require time and effort to implement, but tend to have a sizeable impact on meeting extreme changes in service demands. Long-lived actions are appropriate for extreme deviations

in predicted demand from actual demand when there is a high degree of confidence that the level of demand will remain consistent or continue to change in the predicted direction.

A hurricane, for example, may necessitate a long-lived action to the extent that the impact of the hurricane can be predicted. Because long-lived actions are based on a prediction of the near future, there is always the possibility of error. Depending on the severity of an incorrect prediction, managers tend to err on the safe side in favor of overstaffing. For example, ensuring the safety of motorists during a hurricane may outweigh the costs of overstaffing the TMC. One strategy for mitigating the need to use long-lived actions is to cross train employees in multiple jobs. Redeployment of employees from one job to another is preferable to calling in an employee who is not on duty. For example, a supervisor could perform the role of one of their subordinates.

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Chapter 4. Shiftwork

4.1. Introduction to shiftwork

The purpose of this chapter is to provide an introduction to shiftwork and how different aspects of a work schedule affect employees. This introduction supports the next two chapters, which offer strategies employees and employers can implement to facilitate an employee's adjustment to a work schedule.

4.1.1. Shiftwork

A shift schedule enables an organization to continue operation beyond the length of a single employee's shift by scheduling successive shifts to cover all hours of operation.[1] **Shiftwork** may be defined as any type of employment that includes hours of work that are scheduled outside of typical day work hours from about 7 am to 10 pm. Shift schedules were designed to accommodate the needs of the organization.[2] As TMCs provide a public service, shiftwork has most likely spread across TMCs for economic reasons having to do with the demand for services from consumers. TMCs provide important civic and emergency-related services that help ensure

safety and cost savings (e.g., less gas consumption). Research on shiftwork may be used not only to design better shift schedules that meet organizational needs, but also to help shiftworkers adjust to their schedules.

The problems encountered by shiftworkers depend on the design of their schedules. As discussed below, the most critical aspect of a schedule is the amount of exposure to night work.[3] Although the schedule of night workers does not rotate, they often adopt a day schedule during their off days to interact with family and friends. As a result, many night workers assume a rotating schedule between work and off days. Problems associated with exposure to night work will abate to the extent that night workers are able to adjust to their schedules. Although adapting to an evening shift is less difficult than adapting to a night shift, evening workers may also experience some problems associated with their schedules. As most evenings are commonly considered family time or used for leisure, evening workers often encounter social conflicts. Typically, employees who work the morning shift suffer from the fewest problems associated with their schedules. Although less potent, day work may also cause problems for employees that result from their schedules (e.g., overtime, early morning report times), in addition to the general stress associated with working a job.

The diversity of shift systems does not allow for a description of each type of system (see Section 3.5 on scheduling systems for some examples of shift schedules).[2] However, several crucial aspects of shiftwork differentiate many shift systems. The most critical aspect is whether a shift system requires work outside traditional hours of work (i.e., outside of 7 am to 10 pm). Other key features that differentiate among shift systems include the speed and direction of rotation, the amount of coverage (e.g., 24-hour coverage), and the amount of weekend work. Other features that also differentiate shift systems include the average daily and weekly working hours, the start and end times, the number of hours of work before a break and the length of the break(s), the percentage of weekends off, the number of consecutive work days, the number of consecutive days off, the amount of annual leave, employee control over the schedule, the amount of advance notice of the finalized schedule and scheduling changes, the number of hours on call, and the amount of overtime.[4]

4.1.2. Shiftworkers

4.1.2.1. Overview of how shiftwork affects shiftworkers

As a result of working nontraditional hours, shiftworkers are more likely to report sleep disturbances, physical problems (e.g., gastrointestinal problems), and disruptions to their social lives.[2] A better understanding of shiftwork effects on employees enables the use of preventative and reactive solutions to problems. Typically, employees prefer the morning shift the most, the afternoon shift second, and the night shift least.[5] A sample of female nurses reported that the night shift, when compared with the day and afternoon shifts, caused more sleep disturbances and gastrointestinal problems, was less interesting, and caused greater feelings of loneliness.[5] On the other hand, the night shift was also reported to be more peaceful, less demanding, and to require more independence and responsibility.

4.1.2.2. Prevalence of shiftwork

The statistics reported below related to the prevalence of shiftwork came from the May 2004 Current Population Survey (CPS), which was conducted by the Census Bureau of the U.S. Department of Labor.[6] The CPS surveys typically sample about 60,000 households each month. Service operations employ the most shiftworkers with just under a third working an alternate shift (i.e., a shift other than the typical morning/day shift). Although shiftwork was less common in the public sector (11.9% on average), one prominent exception is services that help ensure public safety. The schedule for about 14.5 million full-time wage and salary workers frequently included an alternate shift (about 15%), which is less than the percentage of shiftworkers reported in 1991 (18%). Of the 15 percent of shiftworkers, the evening shift was the most common alternate shift (4.7%), followed by the night shift (3.2%), irregular shift schedules (3.1%), and rotating shifts (2.5%). Of those with any type of flexible work schedule, men (16.7%) were more prone to shiftwork than women (12.4%). Shiftworkers responded that the main reason that they worked a shift schedule was because it was the "nature of the job" (54.6%). Other reasons for working a shift schedule included personal preference (11.5%), family or child care arrangements (8.2%), inability to find another job (8.1%), higher pay (6.8%), and educational arrangements (3.2%).

4.2. Biological factors and the circadian system

Understanding the biological factors of shiftwork is important for understanding how different shift designs affect shiftworkers. People have evolved in a world with a 24-hour cycle.[7] The 24-hour cycle includes variations in light and dark and variations in temperature. Modern society has constructed a typical social rhythm with work during the day, leisure in the evening, and sleep at night. Not only have social systems been adopted that follow a 24-hour cycle, but biological systems with a 24-hour cycle are also common. For example, although body temperature, heart rate, and blood pressure typically remain within a narrow range of values, all three vary in predictable patterns over the course of a day. A 24-hour cycle exhibited by a biological system is known as a **circadian rhythm**.

The word "circadian" comes from the Latin words "circa," meaning "about," and "dies," meaning "a day."[7] Body temperature, heart rate, blood pressure, and hormone levels are all higher during the daytime, fall at night, and reach their lowest point after midnight. The rhythms are not solely the result of the sleep/wake cycle. Body temperature typically begins to rise before waking occurs. Furthermore, circadian rhythms continue to vary in predictable patterns during periods of sustained wakefulness, even if external influences are removed (e.g., changing levels of light and noise).

Free-running studies isolate people from any cues that convey the passage of time.[7] Participants may take meals and sleep at any time. The purpose of these studies is to observe the circadian rhythms of the participants in the absence of any time cues. Studies often demonstrate that the participants, on average, adapt to a circadian rhythm slightly longer than 24 hours, which demonstrates a propensity toward a longer day.[8,9] Under normal conditions, however, the circadian rhythm follows a cycle of exactly 24 hours.[7] The adjustment of the circadian rhythm to time cues in the environment is referred to as **synchronization**.[7,9] Daylight and social contact are two examples of strong time cues. Time cues have different levels of effect. For example, comforting a crying baby (a social time cue) may become more important than

adhering to the day/night wake/sleep cycle. Although circadian rhythms will synchronize to changes in time cues, synchronization is not instantaneous. The sleep/wake cycle may take several days or longer to adapt to a change in a time cue (e.g., a change in an employee's work schedule). In addition, the speed of synchronization will vary by rhythm (e.g., sleep/wake cycle will synchronize faster than deep body temperature fluctuations) and by person.

Various relationships exist between circadian rhythms and performance.[10] The plainest performance relationship is with simple or routine tasks. Interesting tasks may increase arousal and performance levels, whereas stressful activities may increase or decrease performance depending on the activity and the stressor. Stress may motivate employees to higher levels of performance. And in some cases, employees who are aware of their own impairment (e.g., exhaustion from sustained wakefulness) will implement strategies (e.g., working slowly and deliberately) to compensate for the loss in performance. Regardless of interest level, the accumulation of stress tends to intensify negative outcomes associated with shiftwork, which may overcome higher levels of motivation and strategy use. Individuals will vary on how their circadian system functions, their levels of performance on different tasks, and how their circadian rhythms affect their performance.

4.3. Individual differences and shiftwork

Some believe that individuals with the right mix of characteristics and attributes (e.g., age, personality) will be well suited for shiftwork.[11] That is, an organization should be able to select employees who are suited for shiftwork, and weed out the applicants who will not adjust to the schedule. This belief may result from the recognition that certain individuals are more tolerant of certain shift schedules where others fail.[10] Although certain relationships exist between individual differences and shiftwork outcomes, it is doubtful that a method will be developed to distinguish between those suited for shiftwork and those who fail.[12] An individual may be suited for one shift schedule and perform poorly under another. Although methods for selecting employees who can work well in a shiftwork system are not available, important relationships do exist between individual difference variables and certain workplace outcomes.[11]

4.3.1. Human resource decisions, individual differences, and the law

Although the following discussion covers group differences supported by psychological research, it should be understood that many of these groups have been given certain protections in the workplace. For example, Title VII of the Civil Rights Act of 1964 restricts the use of race, gender, religion, color, and national origin for a variety of human resource decisions including personnel selection, training selection, promotion, and retention.[13,14] The legal status of these protections comes from ever changing and evolving Federal and state laws (e.g., protection from age discrimination, protection for those with mental or physical disabilities), case law (e.g., Supreme Court decisions), executive orders, etc. Consultation with a human resources expert may be necessary to avoid legal problems. In general, human resource decisions should be job related. Instead of asking for a job applicant's (e.g., for a dispatcher position) country of origin to verify if the person understands English, ask if the job applicant would be able to handle a telephone call from a distressed motorist and to coordinate an emergency response.

4.3.2. Age

There may be an expectation that older employees, by virtue of their experience, have adjusted and developed strategies to cope with their shift schedules, and employees who could not adjust to shiftwork would not last long.[10,12] In addition, domestic responsibilities (e.g., raising children) decrease with age. For the most part, however, research evidence indicates that between the late forties and the early fifties an individual's ability to cope with shiftwork weakens. No clear explanation exists for this decline in adjustment, and most likely multiple factors are involved. One hypothesis suggests that the loss in sleep efficiency results from a change in older adults' sleep patterns. Sleep becomes shorter and more uneven in older adults, which causes more awakenings. In addition, older adults adopt a schedule with an earlier wake time and an earlier bed time. Age is also associated with a flattening of circadian rhythms, which attenuates coping and adjustment with shift schedules. Another hypothesis suggests that the cumulative affects of shiftwork may start to have a noticeable impact on older adults (age and shiftwork experience are usually related). In addition, dissatisfaction with shiftwork has been found to grow with an increase in age and shiftwork experience.[15]

4.3.3. Sex differences

In the past, women in some countries were prohibited from working night shifts (except for nurses) based on a fear that women could not cope with the nontraditional working hours.[10] The prohibition against women shiftworkers seemed to be supported by psychological research. In a typical sex differences study, men and women shiftworkers were asked to report any health complaints. On average, women shiftworkers reported more complaints than men. However, women tend to report more health problems, especially mental health symptoms, than men in general. Scientific evidence does not support physiological differences between the circadian systems of men and women. More recent research suggests that although there are differences between men and women in shiftwork, women adjust to schedule changes better than men in some cases.

More recent research has focused on differences between men and women in terms of social obligations and attitudinal differences.[10] Often, women must tend to a variety of domestic obligations above and beyond their workload and have less leisure time as a result. One study found that women over the age of 50 became more tolerant of shiftwork than their younger female counterparts and men of the same age, which is a reversal of the age trends found with men.[16] Although several studies have found evidence favoring the adjustment of women, the question of who adjusts better to shiftwork remains open to debate.

The main area of concern that remains for women is reproductive health.[10,12] Although not conclusive, evidence of erratic menstrual cycles have been reported.[10,12,17] Several studies have suggested that premenstrual and menstrual pain are more severe during night work. In addition, several studies have reported lower pregnancy and delivery rates, greater numbers of babies born prematurely or with a low birth weight, and a higher risk of miscarriage among women working rotating shifts or nontraditional hours. It has been recommended that pregnant women should be rescheduled to a day schedule.[18] Keep in mind however, that the data is correlational, which does not provide causal evidence. The reproductive problems may have arisen from factors that are not biological in origin, such as personal choices or social factors.

4.3.4. Personality

Two types of circadian rhythms in the sleep/wake cycle have been recognized by both psychological researchers and lay people.[10,19,20,21,22] The first type describes people high on morningness, who prefer to go to bed early, awaken early in the morning, and perform activities during the day. The second type describes people high on eveningness, who prefer to stay awake late into the night, sleep in, and perform activities in the evening or during the night. Questionnaires typically ask about preferred times of physical and mental activity and sleep, and studies typically focus on those who respond as either extreme morning types or extreme evening types. Some evidence suggests that matching people's circadian rhythms to their schedules (i.e., morning people should work early shifts and evening people should work late shifts) facilitates adjustment to shiftwork. In addition, morningness has been associated with poorer adjustment to shiftwork. One hypothesis suggests that morning types find it hard to remain awake at night, which is what is required of a night worker. Another hypothesis suggests that evening types are less susceptible to physical and social time cues. Or evening types may have a different free-running circadian rhythm that is more in tune with the requirements of shiftwork. For example, a longer free-running circadian rhythm would facilitate adjustment to a schedule that rotated forward. As the evidence for using personality questionnaires is still being established, the results should be interpreted with caution. In addition, people will most likely fall closer to the middle rather than at the extreme ends of the two types.

Rather than focusing on morning versus evening types, a more meaningful approach may be to focus on individual differences in sleep pattern adaptability.[10,19,20] Three findings have been reported. Individuals who keep more rigid sleep patterns and who maintain fixed sleep, wake, and work times regardless of other factors are less likely to adapt to shiftwork. Those who report better sleep habits in general (e.g., less waking during the night) most likely adjust better to shiftwork. Finally, those who require more sleep (i.e., nine hours or more) will most likely have problems adapting to shiftwork, whereas those who need 5 hours or less will find it easy to adjust.[20]

4.3.5. Shiftwork commitment

Organizational commitment denotes the extent to which employees feel and demonstrate a sense of allegiance or loyalty to their employer.[13] An employee's attachment to an organization may operate through three connections: (1) an emotional connection, (2) a feeling of obligation to remain with the employer, or (3) an assessment of the costs and benefits associated with staying versus leaving. Higher commitment is associated with higher job satisfaction, higher job performance, and lower turnover intentions.

Employees may also be committed to various aspects of their jobs; for example, employees may vary in the level of commitment to their schedules. An employee's commitment to a work schedule may compete with a number of other priorities.[12] An employee who holds a second job by moonlighting (or "daylighting" in the case of a night worker), may face competing demands from the other job. Domestic responsibilities, such as caring for a child or ailing relative, may also present conflicting priorities (e.g., less sleep during optimal times). Differences in commitment to one's shift schedule are associated with differences in circadian rhythms. Lower commitment is related to both poorer sleep quality and poorer synchronization.

4.3.6. Job type

Jobs high in fatigue or high in stress may exacerbate the negative consequences associated with shiftwork.[10] Jobs high in fatigue include activities that require extensive manual labor, are performed in a harsh environment (e.g., high level of heat), or are monotonous. Stressful jobs include activities with lots of contact with people, lots of demands with low control over the work system, monotonous tasks, time pressure, high responsibility, potentially dangerous activities (e.g., firefighter), and the potential of witnessing trauma. As jobs within a TMC may include one or more fatiguing or stressful elements listed above in combination with a shiftwork schedule, special attention should be directed to the safety and health of these employees and the performance of their responsibilities.

4.4. Social factors

As discussed in the last section, there are many biological reasons why individuals prefer to be active during the day and to sleep at night.[20] Society appears to have evolved around these preferences, forcing shiftworkers to overcome many social challenges because they are out of phase with society and their families. The findings of the study presented in Note 4.1 portray how social factors may overwhelm biological influences and cause undesirable performance and safety outcomes.[23]

Note 4.1. Social Disruptions Can Overpower Biological Factors

Miners at the U.S. Lake Superior iron ore region worked a rotating shift with seven night shifts in a row. The night shift started at 11 pm or 12 am and lasted for 8 hours. By law, all accidents had to be reported to the Mine Safety and Health Administration. The series of night shifts started on a Thursday after 56 hours of rest and ran through Wednesday. Biological factors suggested that more accidents should occur on Thursday, when there is the largest circadian misalignment, and decrease thereafter as the workers adjusted to the night duty. However, most accidents occurred on Sunday nights in the middle of the seven night shift series, and decreased slightly thereafter until the last day on Wednesday. After considering reports from the community, it was hypothesized that shiftworkers interrupted their post-shift sleep on Sunday morning to attend church services and church-related events, which caused a peak in accidents on the Sunday night shift.[23]

4.4.1. Society

Society maintains a double standard when handling those who work nontraditional hours, and are forced to sleep at nontraditional times.[20] For example, although social taboos protect the night sleep of day workers, members of society often feel justified calling night workers during the day and blame them for choosing to work nontraditional hours. A 4 am call is only considered appropriate in the case of an emergency, but an 11 am call to a sleeping night worker is not considered improper. As discussed below, shiftworkers are neglected by many aspects of society, which may lead to feelings of alienation and loneliness.[20]

Although shiftworkers may experience some advantages from their schedules, most often they pay a price for working when others are sleeping and sleeping when others are working.[1,24] There is less opportunity for group activities with friends and family. Often shiftworkers report a lack of time for participation in social organizations, cultural events, and hobbies. Entertainment is scheduled to accommodate the day worker's schedule.[20] For example, restaurants serve specific meals at specific times, prime time television programs are scheduled for the evening, and sporting events occur in the evening or on the weekend.

Depending on a shiftworker's schedule, access to a business may be facilitated or hindered.[20] For example, a shiftworker's schedule may include free, nonsleep time between 9 am and 5 pm when banks are open, whereas a nine-to-five worker may find it difficult to visit a bank. With the continual expansion of services outside of traditional hours of operation (e.g., ATMs, 24-hour shopping, late night dining), shiftworkers may continue to find access more convenient.

Some shiftwork schedules facilitate double jobbing, which may be regarded as a perk or liability of the job by the employer.[20] In fact, double jobbing or moonlighting is more common among shiftworkers than day workers. A double jobber may resist a change in the schedule if the changes conflict with the schedule of the second job.

4.4.2. Family

Adverse consequences of shiftwork related to family life may be considered in terms of the three roles of a spouse: the caregiver, the social companion, and the sexual partner.[20] The caregiver cooks, cleans, maintains the house, etc. The consequences of neglecting caregiver duties generally include a failure to meet the expectations of society and other family members. Women usually have a greater amount of the work associated with the caregiver role, which at times results in unreasonable expectations in combination with their work schedules. Men may also fall behind in more stereotypical masculine tasks (e.g., fixing a part of the house, car maintenance). In addition, a shiftworker may maintain the roles as caregiver at the detriment of the other roles of the spouse. The social companion attends social events with his or her partner. Society expects couples to appear at social events together. The absence of a spouse may cripple the social life of both the shiftworker and the spouse, and lead to feelings of loneliness. Finally, the sexual partner spends intimate time with his or her spouse. Sexual inactivity may lead to martial problems. Shiftwork and loss of sleep may become only two reasons among others (e.g., children, daytime interruptions) for why lovemaking is hindered or neglected.

An employee may find that quality time spent with children is hindered by schedule conflicts.[20] Shiftworkers' schedules may cause them to go for an entire week without interacting with their children. An evening shiftworker most likely experiences the most problems in this area. On the other hand, parents who are shiftworkers may be able to care for their children for more hours of the day than a typical family.[20]

4.5. Health factors

Many shiftworkers have fears that aspects of their schedules may have long-term medical consequences or shorten their lifespans.[20] Although many shiftworkers are willing to bear short-term problems (e.g., sleep problems, temporary discomforts), they worry about the long-term health impact. Simulation studies with animals (e.g., insects, mice) have been contradictory. Past studies with humans have severe methodological problems. One common problem is that field studies that investigate shiftworkers do not sample an appropriate cross section of working adults. In general, employees who cannot cope with shiftwork transfer to jobs with day hours. The sample of employees, especially older adults, represents employees who have adjusted to a shiftwork schedule. Unfortunately, there are no good answers to questions about long-term health outcomes. However, health problems are more likely to occur for those who fail to adjust. Furthermore, shiftworkers may adopt poor coping mechanisms (e.g.,

smoking, alcohol abuse) that exacerbate health problems related to shiftwork.[10] As discussed in Chapter 7, employers can implement intervention strategies (e.g., educational programs) to help employees adjust and cope.

4.5.1. Stress and strain model

The stress and strain model provides a way of conceptualizing the connection between aspects of a shift schedule and what employees experience (see Figure 4.1).[20,25] Stress arises from aspects of the shift system (e.g., night work). Strain is the experience that results from the shiftworker attempting to adjust, successfully or not, to the shift system. Strain results from three general sources: circadian rhythm factors, sleep factors, and social factors. For example, although an employee's circadian rhythm may adapt to night work over time and sleep efficiency improves as a result, a death in the family may cause severe strain (a social factor). Variables (e.g., adjustment ability) intervene between the stress from the shift system and the strain experienced by the shiftworker. The stress and strain model facilitates the consideration of aspects of the shift system, outcomes (e.g., health) experienced by the shiftworker, and variables that may improve or exacerbate strain that is caused by stress.

A number of intervening variables may alleviate or exacerbate the connection between the stress and the strain experienced by a shiftworker. Strain may be reduced by improving the shift system or by an intervention (e.g., an educational program).[20] The model suggests that negative outcomes associated with high levels of strain (e.g., indigestion) may result from a lack of social support to the same extent as a difficult shift schedule.

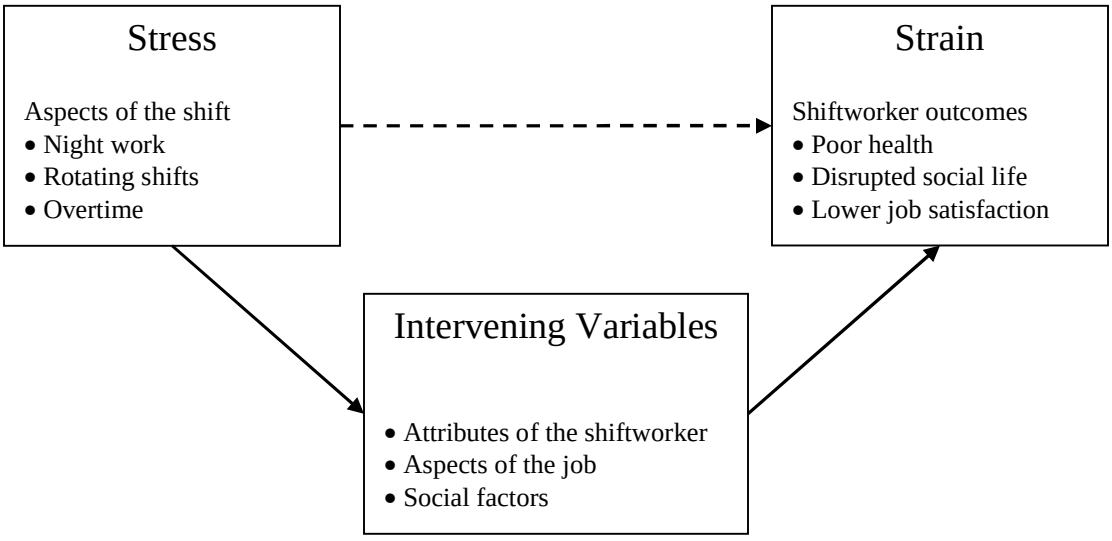

Figure 4.1. Stress and Strain Model
(Adapted from reference 20)

4.5.2. Schedule impact on health

Although shiftworkers complain about and suffer from sleep problems, as many people do, the occurrence of a sleep problem is affected by multiple factors and not just shiftwork.[26] Healthy employees do not manifest health-related problems, requiring medical attention, immediately upon starting a shift schedule. And as discussed above, shift adjustment and health-related problems may be affected by social factors as well. A consideration of acute and chronic exposure to aspects of shift schedules helps to evaluate possible health risks.[26] Acute exposure occurs in the short term and chronic effects occur over the long term. Although both acute and chronic effects may cause greater error proneness, safety problems, and decrements in performance and health, their causes and effects differ. The sources of acute exposure (e.g., long work shifts, traumatic events) act more quickly and are typically more severe. The effects of chronic exposure (e.g., permanent night work) accumulate over time and have an effect over the long term. In general, more attention is given to problems associated with acute (short-term) exposure than problems that arise from chronic (long-term) exposure. Identification of an acute or chronic hazard enables an appropriate response, such as a scheduling change, an educational program, or some other organizational intervention.

Scientific research supports the conclusion that adverse health problems associated with shiftwork occur for employees who fail to adjust or cope.[20] As suggested by the stress and strain model, intervening variables such as coping strategies, education, and health care provision may ameliorate the adverse consequences of shiftwork.

4.5.2.1. Sleep problems

According to a poll conducted by the National Sleep Foundation, 65 percent of respondents reported that they did not get enough sleep at night.[27] Although most adults require 8 hours of sleep, on average, most adults sleep from 6 hours and 45 minutes to 7 hours.[27,28] On-the-job sleep deprivation causes people to move and think more slowly, to make more mistakes and errors, and to have difficulty recalling information, which leads to lower job

Note 4.2. What is acute sleep loss like?

Decrements in performance caused by acute sleep loss are similar to performance loss caused by alcohol intoxication. In a study, fourteen healthy volunteers between the ages of 18 and 27 consumed a 40 percent vodka mixer each hour until their blood alcohol concentration (BAC) reached 0.10 percent during the day and at another time completed seven continuous 8-hour night shifts (11 pm to 7 am). After each night shift, the volunteers were taken outside and exposed to natural light for twenty minutes to further simulate a shiftworker's drive home. During both conditions, participants completed a vigilance task (i.e., sustained attention) that required them to respond to an infrequent event for ten minutes. Performance decrements (i.e., decrease in response time and misses) were greatest on the first night shift, and participants' performance near the end of the shift was similar to their performance at a BAC of 0.10 percent. During the second and third nights, impairment was similar to a BAC of 0.05 percent near the end of both shifts. During the final four shifts, impairment did not exceed performance observed for a BAC of 0.05 percent.[30]

The results compare the effects of acute sleep loss to the effects of alcohol consumption. Performance was lowest on the initial night shift when sleep loss and circadian misalignment are most likely at their peaks. Performance improves after the first night shift as adjustment to the night shift occurs and sleep loss subsides.[30]

performance and an increased risk of accidents (see Note 4.2). Outside of the job, sleep deprivation may cause rocky relationships with family and friends and ruin social outings. The most common shift-related complaints come from problems with sleep.[12]

Two physiological factors account for 85 to 90 percent of what is referred to as fatigue – sleep and the circadian system.[28] Sleep needs appear to be genetically determined and unalterable by training. Sleep loss accumulates over time. As discussed in section 4.3.2, sleep efficiency degrades with age around 50 years. The aging process causes a reduction in deep sleep, more awakenings, less restful periods of sleep, and an increase in the number of sleep disorders. Unfortunately, the most common sleeping aid in the United States is alcohol, which disrupts the quantity and quality of sleep during the second half of sleep.

In general, the circadian rhythm is at its lowest and the desire for sleep is at its highest from about 3 am to 5 am. [28,29] The 10 to 20 percent of night workers who fall asleep on the job report doing so during the second half of their shift. This period of time also includes the lowest levels of many other functions, including temperature, mood, and performance. A second period of sleepiness occurs between 3 pm and 5 pm. Peaks in alertness occur between 9 am and 11 am and 9 pm and 11 pm. During peaks in alertness, an individual may find it difficult to fall asleep.

4.5.2.2. Gastrointestinal problems

There is little question that shiftwork causes gastrointestinal problems.[20] Gastrointestinal problems are the second most common set of problems reported after sleep problems. One review found that 20 to 75 percent of shiftworkers with night shifts complained about a digestive problem (e.g., heartburn, abdominal pains) compared to 10 to 25 percent of day workers and shiftworkers without a night shift.[17] Another study found that shiftworkers with three rotating shifts (5 years) or night work (5.6 years) developed peptic ulcers, on average, more quickly than day workers (12.2 years) or 2-shift workers with no nights (14.4 years). Most shiftworkers will complain about a gastrointestinal problem at some point during their tenure.[20] Problems may include increased appetite, decreased appetite, indigestion, constipation, diarrhea, or something more serious (e.g., ulcer). Gastrointestinal problems are most likely caused by the confluence of a variety of factors. The circadian system eliminates the need to eat and use the bathroom during the night to facilitate sleep. A disruption of the circadian system leads to disruptions in appetite, digestion, and elimination.

A number of factors contribute to poor diets.[17,20] As discussed above, restaurants cater to day workers. Poor canteen facilities and vending machines may contribute to an employee's poor diet. As a result, employees often eat cold, poor quality food in a hurry and in an uncomfortable environment. Due to the strong connection between shiftwork and gastrointestinal problems, employers are strongly advised to educate their employees about healthy eating habits, related adjustment strategies, and potential gastrointestinal problems.

4.5.2.3. Cardiovascular problems

With advances in the detection of cardiovascular abnormalities (e.g., heart attacks, hypertension) the connection between shiftwork and cardiovascular disease is becoming more evident.[17,20] Stress from shiftwork appears to provide the causal link to cardiovascular problems. As shiftwork may be a risk factor, employees should also avoid or attend to other risk factors

including smoking, inactivity or lack of exercise, poor diets high in fat, eating and sleeping problems, and psychological problems. Those with a history of cardiovascular problems in their families may be at an increased level of risk. Monitoring shiftworkers' health is important; the effects of heart disease, for example, can be minimized by an early diagnosis.

4.5.2.4. Mental illness

It is not unexpected that sleep loss, martial problems, and little time spent with friends and family causes periods of anxiety, irritability, and impatience.[20] However, bouts of anxiety, irritability, and impatience do not indicate the presence of mental illness. Depression has been found to cause problems with the circadian system, and there is some tenuous evidence that disruptions to the circadian system may lead to depression. As risk factors for mental illness, alcohol, and drug use should be avoided.

4.6. Performance and safety

Multiple factors affect shiftworkers' performance, including task demands, type of shift system, and individual differences. The importance of job performance takes on greater significance than increasing worker efficiency and productivity by one or two percent when errors may affect public safety. When the number of employees is accounted for, more accidents occur between midnight and 6 am, which highlights the importance of considering the circadian system (see Note 4.3).[10] How to determine a shiftworker's performance and safety risk is one of the most complex questions that confronts shiftwork researchers.[35]

4.6.1. Performance

Decrements in job performance are determined by a number of factors, including the demands and characteristics of work tasks, the time of day, the number of hours awake and the amount of sleep loss, the circadian system, individual differences (e.g., age), health, and motivation.[20] All of these factors may either directly affect performance, or affect performance depending on how well the employee adjusts to shiftwork. A number of studies have shown that performance drops during the night and decreases slightly after lunch.[35] Drops in performance are thought to be more significant as the amount of stress associated with the job increases. Although sleep loss and factors related to the circadian system most likely contribute to drops in performance, other factors such as motivation may also contribute to the effect. Boring, machine paced tasks have a negative influence on motivation and compound sleep loss. Interesting tasks, on the other hand, boost motivation and have been found to counteract severe levels of sleep deprivation.

4.6.2. Safety

Although environmental risk factors (e.g., night and temperature changes) are associated with night work, a greater risk comes from human error rather than environmental factors.[20,35,36] Risk of an accident may increase not only because of fatigue, but also because of mood changes (e.g., anger, depression) arising from biological (e.g., circadian dysfunction) or social reasons (e.g., marital conflict). Humans are able to adapt their level of performance to their state of functioning, such as driving slower when sleepy. Employees may slow down their work pace to match their performance level, which may prevent accidents from occurring during vulnerable time periods. If other factors are not a problem (e.g., motivation), simply telling employees to work at a pace that is concordant with their state of functioning may help eliminate accidents.

An often neglected safety risk is accidents occurring during nonwork times. For example, most traffic accidents caused by commuters involve shiftworkers driving home after a night shift.

A number of trends regarding safety risks are apparent.[34] The risk of an accident occurring increases by 18 percent during the afternoon shift and 30 percent during the night shift relative to the morning shift. As permanent afternoon workers sleep more than those on the morning shift, the number of hours an employee sleeps does not entirely account for level of performance or safety. The risk of an accident also increases across successive work days. The risk of an accident was 6 percent higher on the second night shift, 17 percent higher on the third night, and 36 percent higher on the fourth night. A similar trend was found for the day shift, although at a decreasing rate. Risk increased by 2 percent on the second morning shift, 7 percent on the third day, and 17 percent on the fourth day. Finally, the risk of an accident occurring increases dramatically the longer the shift. For example, relative to an 8-hour shift the risk of an accident occurring during a 10-hour shift is 13 percent greater, and during a 12-hour shift is 27 percent greater. Breaks from working during the shift decrease the likelihood of an accident.

Note 4.3. Infamous Accidents and Shiftwork

On March 24, 1989, the Exxon Valdez ran aground on Bligh Reef, Alaska, and 10.8 million gallons of crude oil poured into Prince William Sound. Third Mate Gregory Cousins was the only officer at the helm, in violation of an Exxon Shipping Company protocol requiring at least two officers on the bridge at all times. He had the opportunity to sleep from 1:00 am to 7:20 am the previous morning and again from 1:30 pm to 5 pm that afternoon, affording approximately 10 hours of sleep. Instead, testimony of the accident indicates that Cousins "pounded the deck" by completing paperwork in his cabin during the afternoon and ate dinner at 4:30 pm before going on duty at 5 pm. Second Mate Lloyd LeCain was scheduled to relieve Cousins for the 12 to 4 pm shift. As LeCain had worked long hours loading the ship, Cousins had offered to remain on duty for the second shift. Cousins may have been awake and mostly working for 18 hours when the crash occurred at 12:04 am due to human error in navigation.[31]

The accident that occurred at Three Mile Island on March 28, 1979 is considered the most serious nuclear power plant accident in the history of U.S. commercial operations. The first failure occurred at 4 am with a breakdown in the main feedwater pumps. The President's Commission on the Accident at Three Mile Island cited a number of problems including a combination of human errors, system failures, and design inadequacies. Related to shiftwork, the commission noted problems with a loss of critical information during a shift changeover.[32,33]

A number of experts have noted that both accidents occurred during a circadian low point.[10,20,34]

4.7. Additional shiftwork resources

The National Institute for Occupational Safety and Health (NIOSH) is a Federal agency that was created by the Occupational Safety and Health Act of 1970 (http://www.cdc.gov/niosh/). NIOSH was formed as part of the Centers for Disease Control and Prevention (CDC) in the Department of Health and Human Services (DHHS). The mission of NIOSH is to advance safety and health practices in the workplace (e.g., illness, injury, and mortality prevention) by conducting original research, making recommendations, writing reports, etc. *Plain Language about Shiftwork* is a report that provides

an easy-to-read source covering topics related to shiftwork in fulfillment of NIOSH's mission (http://www.cdc.gov/niosh/pdfs/97-145.pdf or contact NIOSH at 1-800-356-4674).

The Office of Technology Assessment (OTA) was established by the Technology Assessment Act of 1972 as a Congressional agency designed to analyze public policy issues for Congress on the advancement of science and technology (http://www.wws.princeton.edu/~ota/). The OTA was cut from the budget in 1995. *Biological Rhythms: Implications for the Worker* provides a more technical treatment of circadian rhythms and working time arrangements, shiftwork in particular, in terms of public policy issues and potential Congressional actions (http://www.wws.princeton.edu/~ota/disk1/1991/9108_n.html).

The International Labor Organization (ILO) is a United Nations agency that was initially created through the Treaty of Versailles that was adopted by the Peace Conference in 1919 at the end of World War I (http://www.ilo.org/). The ILO offers international labor standards, and fulfills its mandates through three bodies: member states debate and adopt labor standards at international conferences, a governing body oversees administrative duties and ILO policy, and the International Labour Office coordinates a variety of activities such as conducting research and printing publications. *Working Time: Its Impact on Safety and Health* reports how working time arrangements (e.g., night work, compressed workweeks) affect workers (http://www.ilo.org/public/english/protection/condtrav/publ/wtwo-as-03.htm). The target audience includes researchers and policy makers. The provisions of C171 Night Work Convention (1990) and C89 Night Work (Women) Convention (1948, Revised 1990) represent the most recent ILO conventions on night work (http://www.ilo.org/ilolex/cgi-lex/convde.pl?C171, http://www.ilo.org/ilolex/cgi-lex/convde.pl?C089).

The European Foundation for the Improvement of Living and Working Conditions is a European Union agency that was established by Council Regulation (EEC) No. 1365/75 in 1975 (http://www.eurofound.ie/). The foundation conducts research and advances social policy related to living and work conditions. The Bulletin of European Studies on Time (BEST) series disseminates information related to working time arrangements for policy makers, employers, and employees. *Continuous Shift Systems: Bulletin of European Studies on Time (BEST 11)* and *Shiftwork and Health: Bulletin of European Studies on Time (BEST 1/2000)* discuss shift systems and their affects on employees (http://www.eurofound.eu.int/publications/EF9802.htm, http://www.eurofound.eu.int/publications/EF0009.htm).

Making Shiftwork Tolerable is an easy-to-read book with sections on the problems associated with shiftwork and strategies that employees and employers can adopt to mollify shiftwork problems. The authors, Timothy Monk and Simon Folkard, have been conducting research on the circadian system and its influence on sleep and performance since the early seventies. The book is available for purchase.

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Chapter 5. Strategies for the Employee

The previous chapter focused on shiftwork and potential problems reported by employees who work shift schedules. The purpose of this chapter is to offer strategies that employees in a shift system can implement to help alleviate problems associated with their schedules and to facilitate adjustment to the shift system. The next chapter focuses on strategies that employers can implement to minimize shiftwork problems and facilitate the adjustment of their employees. Although no one should attempt to implement all of the strategies at once, the authors hope that shiftworkers find some of the strategies useful in addressing specific questions or issues.

5.1. Circadian system adjustment

The circadian system is responsible for maintaining synchrony between important physiological processes and the outside world.[1] The circadian system depresses certain bodily functions (e.g., body temperature, heart rate, blood pressure) to prepare the body for sleep. The circadian system protects sleep by enabling people to go for about 7 to 8 hours without eating, drinking, using the toilet, or even moving. When a shiftworker is active during this 7 to 8 hour period, irritability,

feelings of sleepiness, and digestive problems are common consequences. The circadian system also prepares the body for waking. Body temperature increases before waking occurs, and appropriate hormones are released and suppressed. As a result, shiftworkers may find it difficult to go to sleep at times when they are normally awake. When shiftwork alters the typical schedule of sleep and work, the shiftworker can adjust by managing time cues (e.g., meal times, daylight) of the circadian system and by adopting sleep strategies based on the design of the shift schedule.

5.1.1. Basic adjustment strategies

The first step in adjusting to a work schedule is to adopt an appropriate sleep schedule.[1] Recommendations vary based on the rate at which the schedule rotates. For rapidly rotating schedules, when shift times change several times within a week, the worker should maintain a regular day schedule to the extent possible. Schedules that rotate weekly or longer are best matched with a rotating sleep schedule. Schedules with an intermediate rate of one shift change per week tend to be the most problematic, as they require the greatest frequency of adjustment. Most adjustment problems (e.g., sleepiness) occur when the work schedule rotates or changes. The strategies described below are also appropriate for shiftworkers on permanent or dedicated shift schedules (e.g., only works nights).

The second step is to make use of time cues that favor adjustment and to avoid time cues that inhibit adjustment.[1] For example, daylight inhibits the production of **melatonin**, a hormone that promotes sleep. Day workers can use morning daylight as a cue to inhibit sleep; those on the night shift should avoid daylight in the morning and while asleep to improve sleep quality. Other important time cues include eating, sleeping, social interaction, noise, room temperature, and physical activity.

5.1.2. Day work and rapid rotation strategies

Those who work rapidly rotating schedules should attempt to maintain a day schedule.[1] Maintaining or adopting a day schedule is easier than adopting night or evening schedules because the naturally occurring time cues point toward the day. The night shift is the period of work that is the most out of phase with a day schedule. Strategies for working nights while trying to maintain a day schedule include experiencing daylight as much as possible prior to work, avoiding heavy meals during the night, and attempting to take a nap during the night (on a break or during lunch) if possible. Keep in mind that by attempting to maintain a day phase, feelings of sleepiness and fatigue during the night shift will be worse than if night time cues were embraced. Strategies for maintaining alertness during night work should be used (see Section 5.3 on alertness management).

5.1.3. Strategies for adapting to night work

Strategies for working intermediate or slowly rotating schedules are more complicated, as they require ongoing periodic adjustment of the sleep/wake cycle.[1,2] Two important factors affect how readily schedule adjustment occurs. First, the amount of adjustment required increases as the amount of time between the original bedtime and the new bedtime increases. Second, the circadian system adjusts more readily when the change represents a delay in bedtime rather than an advance.[1,2] For example, if a shiftworker was going to sleep at midnight and the new schedule starts at midnight and ends at 8 am, then a 9 am bedtime would represent a delay of

nine hours. Some hypothesize that adjustment is easier with a delay because (as discussed in the previous chapter) circadian rhythms in free run studies adapt to a day slightly longer than 24 hours.[1,3] On average, night workers adjust to a delay of 9 to 10 hours.

In adapting to a new schedule, the shiftworker should synchronize the circadian system as quickly as possible to the new shift. The current discussion focuses on adopting a night schedule, the shift that presents the greatest difficulty. Ideally, a shiftworker who gets to bed by 9 am would be able to sleep for eight hours until 5 pm. However, many shiftworkers report that day sleep is more difficult to achieve and not as restful as night sleep. Several strategies can be employed to ease the transition to a night schedule, and increase the quality of sleep during the day.[1,4,5] As stated above, adjustment to the new schedule is quickest when the delay between the original bedtime and the new bedtime is minimized. After completing the night shift, the shiftworker should immediately go home, have a light meal if needed, and go to bed as soon as possible. The shorter delay minimizes how far the circadian system needs to adapt, and often results in more restful sleep. Time cues, such as avoiding exposure to daylight, are also important for adjustment. Daylight is a powerful time cue that causes the release of **cortisol**, a hormone that promotes waking activity and inhibits the production of melatonin.[1,3] Strategies for minimizing the impact of daylight include wearing dark sunglasses and using thick drapes to prevent outside light from entering the bedroom and bathroom.

Naps in the evening should only be used as a topping-off process to help ensure 8 hours of sleep.[1] Anchor sleep in the evening is not recommended. As a phase advance, evening sleep will create more adjustment problems. Adopting a regular pattern of sleep will promote better sleep habits and quicker synchronization of the circadian system. In addition, adopting regular meal times will also contribute to quicker and stronger synchronization.

Days off may present a problem for those on a night shift, especially for shiftworkers who are married to day workers, have children, or have other daytime commitments.[1] Often, those on the night shift adopt a rotating schedule between work days and off days. Compromises with the family should be made. The objective, in terms of the circadian system, is to avoid desynchronization. Attempts should be made to maintain a night schedule during off days. Sleep as late into the day as possible and go to sleep as late as possible without sacrificing the amount of sleep obtained. Also continue to maintain meal times, and continue to avoid daylight by wearing dark sunglasses and staying indoors in the morning.

5.1.4. Strategies for adapting to evening work

On average, evening workers adopt a phase delay of 2 to 3 hours.[2] The circadian system adapts easily, and generally there are no physiological problems. In fact, evening workers, on average, sleep more than day workers. However, domestic and social problems might arise for shiftworkers who are married and/or have children. An evening schedule hinders the shiftworker's ability to spend quality time with the family and leisure time with friends during work days. Evening workers should focus on ensuring quality time spent with family and friends (see Section 5.4 on social support).

5.2. Sleep strategies

On average, adults only get 6 hours and 54 minutes of sleep during the workweek, which is more than an hour less than the 8 hours of sleep that are recommended.[6] A number of scheduling factors may contribute to sleep loss and the accumulation of sleep debt.[7]

- Early report times
- Long work shifts
- Extended overtime
- Short recovery periods between shifts
- The number of consecutive work days
- Night work
- Rapid rotation
- On-call status
- Frequent schedule changes
- Unplanned schedule changes

The following list of questions provides a quick way to diagnose sleeping problems that are addressed in this chapter.[8]

- Do I go to bed at different times each night? (see Section 5.1. Circadian system)
- Am I napping during the day? (see Section 5.1. Circadian system)
- Is it too bright? (see Section 5.2.1. Light)
- Is my bed comfortable? (see Section 5.2.2. The bed)
- Do I work in bed or just before going to bed? (see Section 5.2.2. The bed)
- Is it too noisy? (see Section 5.2.3. Sound)
- Is my bedroom too hot or too cold? (see Section 5.2.4. Temperature)
- Do I exercise within three hours of going to bed? (see Section 5.2.5. Exercise)
- Am I experiencing any physical problems or discomfort associated with what I am eating (e.g., heartburn)? (see Section 5.3.4. Diets)
- Do I take any medications that may cause sleeping problems as a side effect? (see Section 5.3.5. Drugs and medication)
- Do I drink caffeinated beverages before going to sleep? (see Section 5.3.5.1. Caffeine)
- Do I smoke before going to sleep? (see Section 5.2.7.2. Nicotine)
- Do I have any severe problems with my family? (see Section 5.4. Social support system)

5.2.1. Light

Artificial, bright light can have a powerful effect on circadian rhythms and accelerate synchronization to a new daily phase of waking and sleeping.[2,3,9] Bright light activates the release and suppression of hormones that regulate sleep.[2,3,9] Studies of shiftworkers on nights have found that short exposure to bright light reduces tiredness, improves performance on tests of ability, improves sleeping patterns, and has no effect on other physiological systems (e.g., body temperature).[2,3,9]

Although the support for bright light exposure is promising, the research remains experimental.[3] For example, the relationship between the amount of exposure (e.g., duration, intensity) and the effect on the circadian system is unknown and requires further research. The research findings appear to suggest that the worker must receive both an intensity level equal to that of daylight during the night and no daylight exposure during the day.

Although the manipulation of light exposure outside the laboratory is impractical, the results do have immediate implications for the shiftworker. Eliminating light in the bedroom will help promote sleep quality and quantity during the day. Consider installing heavy blinds in the bedroom and bathroom to block out sunlight.

5.2.2. The bed

The bed is vital to achieving a good night's rest.[4] Ensure that the bed is comfortable, so that it does not become the source of a sleep problem. Mattresses and pillows wear out, and should be replaced periodically. To help facilitate sleep, use the bed only for sleep and sex. If the bed is comfortable, but it is easier to fall asleep in a chair or sofa, then the bed may be associated with other activities. Do not do work or watch television in bed. Only get into bed when tired, leave if not asleep in fifteen minutes, and go back when tired. Try to avoid thinking about not sleeping (e.g., do not check the clock). Instead, picture something relaxing like a warm bath or try to relax every muscle in the body.

5.2.3. Sound

Noise may have an alerting effect or may induce sleepiness.[10] High frequency sounds (e.g., from a radio, from a television) tend to have an alerting effect. Low frequency noises and monotonous noises tend to induce sleep. The objective with sound and sleep is to block out the sounds that hinder sleep and/or to generate sounds that promote sleep (e.g., use a white noise generator). For example, consider installing sound absorbing carpeting and drapes or noise proofing the walls of the bedroom. Telephones and the doorbell should be installed with ringers that can be switched off. Earphones can be used by family members when watching the television or listening to the radio. Noise from individuals in the house should be kept to a minimum when others are sleeping. The house should be designed to facilitate day sleep and prevent interruptions. A sign can be used to indicate when people are trying to sleep.

5.2.4. Temperature

On average, a comfortable temperature for working is about 77º F (25º C).[10] Cooler or warmer temperatures may cause an increase in fatigue or sleepiness.

In the bedroom, the temperature should be at a comfortable level that facilitates sleep onset and maintenance.[4] In general, a cooler temperature improves sleep quality.

5.2.5. Exercise

Exercise can help counter stress, illness, and fatigue.[9] In addition, exercise may improve sleep quality by decreasing the amount of time it takes to fall asleep and deepening the level of sleep.[4] The timing of when an individual engages in exercise is important.[9] Exercise within three hours of bedtime should be avoided, as the alerting affect may hinder the ability to fall asleep.

Depending on an employee's job, an appropriate level of exercise before work may help synchronize circadian rhythms and increase the employee's level of alertness on the job. Individuals who perform physically intensive labor should avoid strenuous exercise before work. Light exercise, such as a bike ride or short jog, not only keeps the heart in shape, but also helps employees wake-up for work.

5.2.6. Food and drinks

There are a number of items to avoid consuming before going to sleep.[4] In general, avoid drinking too much before bed to decrease the number of awakenings from a need to use the bathroom. Also avoid eating too much food before bed or going to bed hungry. The resulting discomfort may disrupt sleep. Avoid eating foods (e.g., spicy foods, tomatoes) that cause heartburn before going to sleep. Heartburn increases in severity when lying down. Not only can heartburn make it more difficult to fall sleep, but the discomfort may awaken the sleeper.

5.2.7. Drugs and medication

5.2.7.1. Sleeping pills and melatonin

A common countermeasure used by shiftworkers is sleeping pills.[1,9] Although shiftworkers typically need sleep relief from their schedules, sleeping pills are only recommended for short-term use. The long-term use of sleeping pills builds up a tolerance to the effects of the drug, and may produce undesirable side effects (e.g., mood changes). Sleeping pills may have carry-over effects after the sleep period has ended when a shiftworker needs to be alert at work. Although more advanced drugs have overcome the carry-over effects, sleeping pills are not recommended without consulting with a doctor.

Melatonin is a hormone released naturally by the body that promotes sleep. Achieving the same quality of sleep during the day is often difficult because sunlight inhibits the natural production of melatonin. Melatonin is the only hormone that is available without a prescription in the United States.[1,9] It can be sold as a dietary supplement without approval from the Food and Drug Administration (FDA) because it is a natural part of several foods. As melatonin is not monitored by the FDA, the label on a box of melatonin pills may be inaccurate, and a single dose (1 to 3 mg) may elevate melatonin levels in the blood up to 20 times the normal level. Side effects, such as fatigue and depression, do not have to be listed on the package.

5.2.7.2. Nicotine

Many people do not realize that nicotine, like caffeine, is a stimulant that can disrupt sleep.[4] Smoking before going to sleep should be avoided. The determination of when to smoke one last cigarette before bedtime is a balance between avoiding the alerting affects of nicotine and avoiding the uncomfortableness of craving another cigarette. Similar to caffeine, avoid nicotine in the last 4 to 6 hours before bed; however, a shorter timeframe may be warranted to avoid craving a cigarette at the same time as trying to go to sleep.

Not only do smokers experience more problems falling asleep than nonsmokers, but they also experience nicotine withdrawal when asleep and sometimes have difficulty waking up.[4] Smoking has also been linked to a greater frequency of nightmares. Although giving up nicotine

will cause some sleep problems initially, the long-term health and sleep benefits outweigh the short-term problems.

5.2.8. Sleep tips

Table 5.1 presents a condensed list of sleep tips distilled from this chapter. The table also includes a section on pre-sleep rituals. As alluded to earlier, establishing a pattern encourages synchronization of the circadian system. Pre-sleep rituals can be used to establish a time cue for your body that signals the approach of sleep onset.

Table 5.1. Sleep Tips

Light
Darken the bedroom and bathroom
Install light blocking curtains or shades
Wear sunglasses (e.g., wraparounds)
Expose yourself to sunlight or bright artificial light when awake
Environment
Find and maintain a comfortable room temperature
Find and maintain a comfortable humidity level in the bedroom
Inspect the bed (Is the mattress comfortable?)
Sound
Wear ear plugs
Block other noises (e.g., white noise generator, fan, play relaxing music with automatic shutoff timer)
Install carpeting and drapes that absorb sound
Install double-pane windows
Lower or disconnect telephone ringers, answering machines, and door bells
Exercise
Maintain a program of regular exercise
Don't exercise within three hours of bedtime
Exercise after sleeping
Pre-Sleep Rituals
Avoid activity that requires a lot of thought (e.g., balancing a checkbook, watching a thriller on TV)
Engage in a relaxing activity (e.g., warm bath, light reading)
Establish regular bedtime and wake time schedules
Avoid using the bed for work-related activities or to watch TV
Get out of bed if not falling asleep, go back when tired
Don't dwell on not sleeping
Think relaxing thoughts (e.g., imagine something relaxing like receiving a massage)
Food and Drinks
Reduce the amount of caffeine in the diet
Avoid caffeine less than five hours before sleeping
Avoid alcohol (alcohol disrupts sleep)
Don't go to bed too full or too hungry (eat a light snack if hungry)
Restrict fluid intake before bedtime (to prevent waking in the middle of the sleep cycle)
Avoid foods that upset your stomach or give you heartburn (e.g., spicy foods, tomato products)
Smoking
Don't smoke in the last four to six hours before bedtime (like caffeine, nicotine is a stimulant)
Quit smoking to increase sleep quality over the long term

(Adapted from references 3 and 4)

5.2.9. Speaking to a doctor

Adopting a sleep strategy may not be enough to help alleviate all sleep problems.[8] Severe problems may warrant a visit to a general practitioner or a sleep specialist. A sleep specialist is

trained in sleep medicine and can diagnose sleep-related disorders. Sleep specialists may work at a hospital or a free-standing facility. Overnight observation of sleep patterns may be conducted at a sleep center.

5.2.10. Additional sleep resource

The National Sleep Foundation (NSF) is an independent nonprofit organization (http://www.sleepfoundation.org/). Formed in 1990 by a grant from the American Academy of Sleep Medicine, the NSF seeks to improve public health and safety by increasing awareness and understanding of sleep and sleep-related disorders. The NSF supports sleep-related education, research, and advocacy. The NSF Web site includes an assortment of information in the form of polls, tools, quizzes, articles, etc. Topics on sleep range from work and shiftwork to sleep apnea and restless legs syndrome.

5.3. Alertness management

Shiftworkers can adopt several strategies before, during, and after work to cope with fatigue. Alertness management strategies are designed to combat the effects of sleep loss and circadian disruption.[11] Rather than focusing on the elimination of fatigue or sleepiness, these strategies focus on promoting alertness. Alertness strategies rely on an understanding of the physiological principles of sleep and the circadian system and the alertness and performance requirements of work. Before attempting an alertness strategy at work, test the strategy at home.[7] The object of alertness management is to take deliberate action to prevent problems or maintain a certain level of functioning rather than reacting after a problem occurs.[11]

5.3.1. Evening shift

In general, evening shiftworkers tend to maintain their circadian rhythms and have fewer problems compared to the night workers.[1] In fact, employees who work the evening shift tend to sleep longer than those on the day shift. Nevertheless, evening workers are advised to follow several recommendations for maintaining their late schedules.[1] Fatigue is greatest during the last hour or two of the shift and on the drive home when the circadian system is preparing for sleep. Strategies for remaining awake include remaining active by moving around and talking to others. Monotonous work should be scheduled earlier in the shift. Stopping off for a drink or nightcap after work is not recommended. More time spent awake further misaligns circadian rhythms and alcohol hinders sleep later in the night. Consuming caffeine late in the shift is also not advised. Although caffeine will provide a short-term gain in alertness, going to sleep after the shift will be more difficult. If safety is a concern either at the end of the job or on the drive home, a judgment call will need to be made weighing the subsequent difficulty in falling asleep against the need to remain alert when at work or driving home. Also consider decaffeinated and non-caffeinated alternatives (e.g., fruit juice).

5.3.2. Night shift

In general, shiftworkers on the night shift encounter the most sleep problems.[1] The most difficult hours will be between 4 and 6 am, which represent a circadian low point for a typical circadian system. A little caffeine may help, but it should be consumed during the first half of the shift. Caffeine consumed in the second half of the shift may remain in the bloodstream and inhibit sleep after the shift is over. Also consider how much caffeine to consume. For example, soft drinks (e.g., Coke, Pepsi) typically have about one-third of the amount of caffeine in coffee.

Breaks and meal times should be used strategically. Long periods of constant work should be avoided in favor of work punctuated with consistent, regular breaks. Breaks should be used to walk around, get something to eat or drink, or use the bathroom about every two hours if possible. The lunch break should be taken at the same time each day. A hearty, healthy, warm meal is best. Social activities during lunch will also help combat fatigue. Unless on a quickly rotating shift, naps should be avoided. Naps during the night signal a day schedule and cause feelings of sleepiness throughout the rest of the shift, especially during the 4 to 6 am dip. Critical and monotonous work should be scheduled well before 4 am.

5.3.3. Breaks

Breaks can be used to offset the effects of fatigue that result from working.[3,10] Without breaks, the effects of fatigue continue to influence a worker's state of functioning at an increasing rate.[3] A break is more effective if it occurs before the part of the body (e.g., brain, cardiovascular system) that requires rest is too fatigued. The most recovery from a break occurs at first, and then the value of the break diminishes at an increasing rate. Different parts of the body require different types of breaks of different lengths. Manual labor, such as lifting heavy objects, requires regular short passive breaks. Routine or monotonous work, such as data entry or filing, requires regular short mentally or physically active breaks. Work that causes high mental strain, such as interaction with the public or press, requires passive or physically active breaks. Work with environmental stressors (e.g., hot room, high noise level) requires an alternate place for breaks without the stressors present.

5.3.4. Diets

Diets that attempt to combat sleepiness with elaborate feasting and fasting schedules show little benefit in research studies.[1] Rather than focusing on a diet that recommends certain foods (e.g., carbohydrates versus meats) for inducing alertness or sleep, focus on a healthy diet with exercise that ensures a physically fit body.[9]

5.3.5. Drugs and medication

5.3.5.1. Caffeine

Caffeine is the most common drug used to stimulate the central nervous system, and is often used by shiftworkers to maintain a certain level of on-the-job performance.[12] Caffeine improves subjective alertness, mood, and physical and cognitive performance. Caffeine is absorbed rapidly by the body, usually within 30 minutes to 2 hours, and has an almost immediate effect on self-reported fatigue.[4,10] The stimulant effect of caffeine lasts about 5 to 7 hours.

Caffeine's effectiveness varies depending on the level of fatigue and the frequency of use.[4,10] The greater the level of sleep deprivation, the higher the dose of caffeine required to counteract fatigue. Through continued use, individuals develop a tolerance to caffeine and require higher doses to achieve the same effect. With higher doses, side effects (e.g., jitteriness) begin to counteract the alerting benefits. In addition, the body may build up a dependence for caffeine. A common effect from a dependence on caffeine is a headache on off days when workers do not consume any caffeine.

5.3.5.2. Amphetamines

Amphetamines, diet pills, or "uppers" are extremely strong stimulants that boost alertness.[9] In some cases, the need for sleep can be eliminated altogether. They are too strong for conventional use and should be avoided unless recommended by a doctor. Many of these drugs are illegal or require a prescription and may cause addiction. Frequent use builds up a tolerance, which requires higher doses to achieve the same effect. Side effects include mood changes, nervousness, and decreases in performance.

5.4. Social support system

Family (or an individual's social support system) fulfills a critical role in the adjustment and coping of a shiftworker.[1,13] Without social support, shiftworkers may fail to adjust to their schedules even if their circadian systems have adapted to the changes. In the best case scenario, the family will be involved in reading and acquiring information with the shiftworker. Many of the strategies that the shiftworker can implement require the understanding and involvement of family members. Communication within the family is critical. In turn, successful adjustment and coping may improve family life. For example, a shiftworker may be less irritable at home after sleeping uninterrupted for 8 hours.

The family should protect the day sleep of the night worker to the same extent that the night sleep of the rest of the family is valued and respected. The family should adopt the attitude that the sleeping shiftworker is not at home when asleep, except in cases of an emergency. Priorities should be set. A calendar can be used to note work and sleep times. Family time may also be included in the schedule. Family or domestic obligations should be scheduled around everyone's hours of sleep as much as possible. For example, deliveries, dentist appointments, and shopping should be scheduled around sleep needs. Other family and friends should be informed of appropriate hours for making calls and visits.

The social support system should also include friends. Relationships forged with families of other shiftworkers offer friends who share similar challenges, and who can provide understanding, empathy, and support. Talking to a friend about the stress of work may help to reduce stress and increase satisfaction.[14] In addition, consider visiting a self-help group. Self-help groups can also fulfill many of the roles a friend would in a more structured environment.

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Chapter 6. Strategies for the Employer

Although there are many strategies (e.g., attention to diet, sleep routines) that employees can adopt depending on their specific schedules as discussed in the previous chapter, there are also a number of things supervisors and managers oversee that are outside the purview of their subordinates.[1] Supervisors and managers are responsible for employee selection and compensation, job and schedule design, and environmental conditions. Unless required by law, employers often ignore their responsibilities to facilitate the adjustment of their employees to demanding work schedules. In fact, employees are often blamed for failing to adjust although they are not equipped with the necessary tools (e.g., information, environmental factors) to adapt to their schedules. Refusing to implement employee-friendly policies is similar to denying a welder at a construction company protective goggles and a hard hat. Existing strategies are often in place as a reaction to some past problems and have continued to exist because of habit or tradition. Not only will employees benefit, but employers will also benefit if an active role is taken to implement strategies to ensure that shiftworkers have adapted to their work schedules.

6.1. Management education

For an organization to implement employee-friendly scheduling strategies, the decision makers must be convinced that the changes will benefit the organization and educated to ensure that appropriate and effective strategies are employed.[1] Adopting effective shiftwork strategies benefits both employees and employers. By increasing employee performance, the efficiency and productivity of the organization will improve. By improving employee safety, the number of

costly accidents will decrease. By increasing employee health and general well-being, the number of sick days, the amount of turnover, and both the number and amount of insurance payouts will decrease. Reducing turnover is critical for positions with high recruiting, selection, hiring, and training costs. In addition, the possibility of litigation from sick or injured employees may be reduced. As described below, the adoption of scheduling strategies may not require costly or time consuming interventions. Moreover, intermediate steps (e.g., employee education) may be possible on the way to implementing grander changes.

6.2. Worker-oriented approach

The purpose of this chapter is to provide employers with strategies to help improve the safety, health, and general well-being of their employees. Interventions in the worker-oriented approach focus on employee outcomes rather than organizational outcomes (see Figure 6.1).[2] An intervention designed to improve an employee outcome may have a greater impact on the productivity and efficiency of the organization than an intervention that solely focuses on organizational outcomes. For example, an improvement in safety will reduce the number of accidents, and the cost of a single accident often outweighs the benefits from an increase of a couple of percentage points in productivity. In addition, the workforce is more likely to accept and support worker-oriented strategies. Although an intervention may require some upfront costs, the long-term benefits often outweigh the short-term expenses.

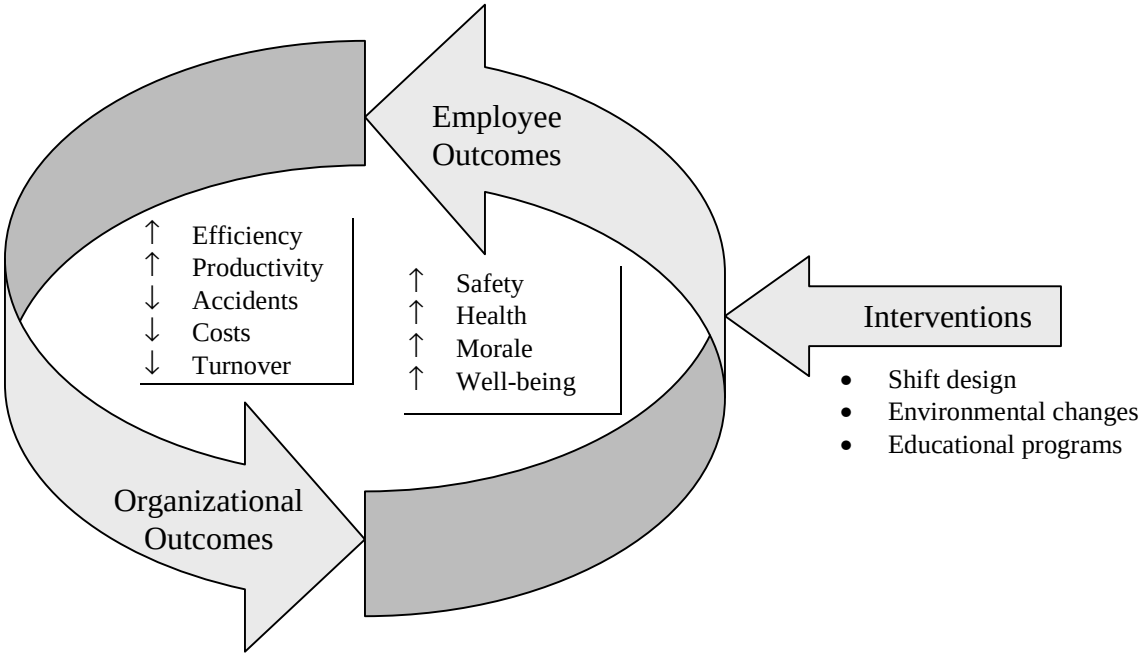

Figure 6.1. Worker-Oriented Approach

6.3. Counterweight versus countervalue strategies

The purpose of the counterweight versus countervalue model is to provide a way of predicting the effect of a potential strategy (see Figure 6.2).[3] Counterweight strategies attempt to compensate for the negative consequences of some aspect of a shift system (e.g., exposure to night work) by providing some general benefit (e.g., higher pay for night workers). That is, the

discomfort and negative consequences on one side are reduced by a single solution, often with an easy to calculate dollar value, on the other side. In addition to the general benefit, the impact of the counterweight strategy will depend on the income level of the employee, the motivational level of the employee, and the negative aspects or costs associated with the shift system.

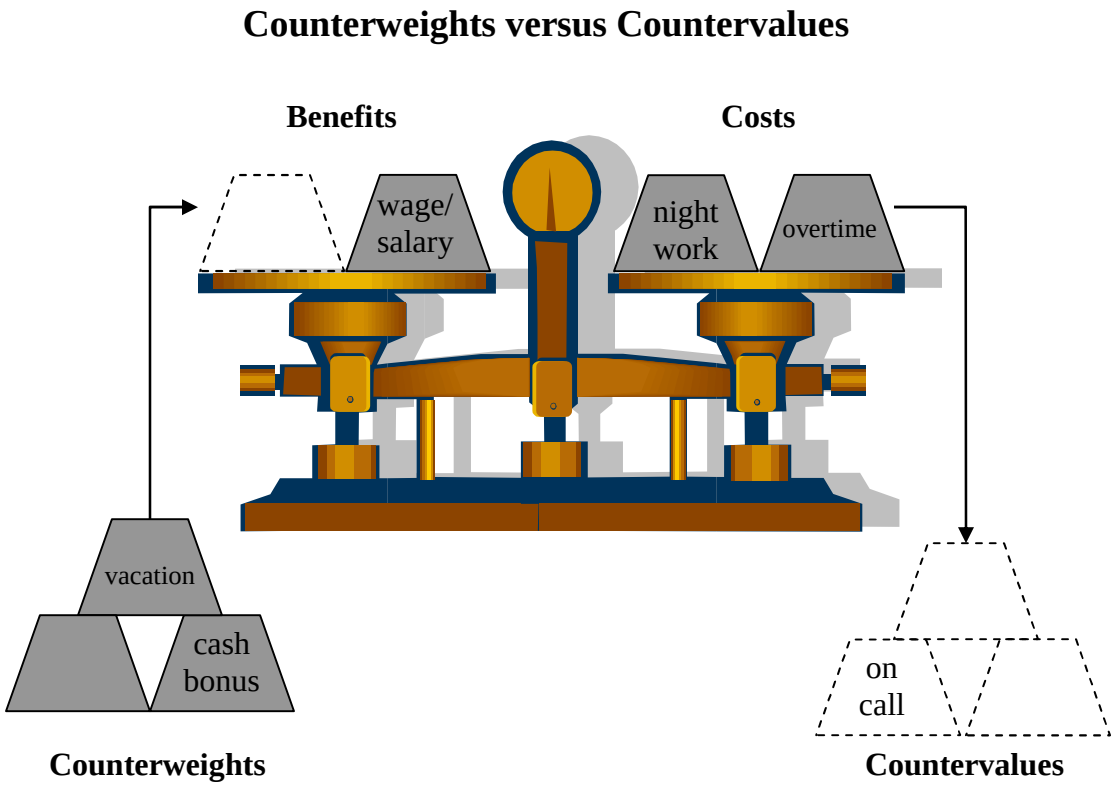

Figure 6.2. Counterweight versus Countervalue Model

Counterweight strategies operate by adding more weight to the benefits, which may lessen the dissatisfaction associated with the costs of the shift system.[3] The costs of the shift system remain unchanged. Counterweight strategies provide simple and easy solutions that do not affect the cause of the dissatisfaction. In fact, the benefit afforded to the shiftworker may conceal the real problem and promote the status quo when a strategy that focuses on reducing the costs is needed. Counterweight strategies are only recommended when countervalue strategies are not feasible.

Countervalue strategies attempt to achieve balance through a reduction in the weight of costs, either by removing a cost (e.g., change in shift design) or treating the negative outcomes resulting from the cost.[3] Countervalue strategies require extensive analysis and careful planning to ensure that the intervention has the desired effect and that other aspects of the work system are not adversely affected. The three levels of countervalue strategies denote the directness with which the strategy affects the cause or inconvenience, the potential power of the effect, and the recommended order in which they should be considered. As the most direct and potentially most powerful change, Type I interventions should be considered first, followed by Type II, and then Type III. If no countervalue strategy is feasible then consider a counterweight strategy. Type I interventions focus on eliminating or reducing an undesirable aspect of the shift

system (e.g., reducing the amount of night work, reducing the length of a shift). Type II interventions focus on eliminating or reducing the consequences of the inconveniences. For example, if a group of employees is not able to attend a holiday party during the day, it may be necessary to either extend the hours of the party or to have multiple parties. Although the shift schedule was not altered to accommodate the party, the consequences of the schedule have been addressed. Type III interventions act upon the psychological meaning of the inconvenience caused by the shift system. For example, evening workers may not be able to attend an early morning meeting with the night and morning shifts. The evening workers may feel a loss of status (i.e., the psychological meaning) as a result. The evening workers may be given the task of reviewing the meeting notes and the right to challenge a decision to give them more status in the decision-making process. Although the shift schedule was not changed to accommodate the meeting (i.e., the cause) and the schedule of the meeting was not changed (i.e., the effect), the psychological meaning of the cost was addressed.

6.4. Shift design

Although there is no one "best" shift schedule, scientific research offers several insights regarding elements of various shift designs.[1,4,5,6] There are advantages and disadvantages to all shift systems. The following list features the aspects of shift systems that are often more favorable or better for shiftworkers. Because shift schedules are created to accommodate the needs of the organization or service demands, some of the recommendations listed below may not be feasible. In addition, employees may prefer undesirable features of a shift system that provide other desirable features in the balance. For example, a greater number of consecutive work days may result in a greater number of consecutive off days.

- Night work should be eliminated or reduced to the extent possible.[4,5,6]

- The direction of rotation should be forward (i.e., clockwise) rather than backward: morning à evening à night.[1,4,5,7,8] Humans adapt to a longer day, prolonging sleep, more easily than they adapt to a shorter day with an earlier bed time. For example, if an individual normally goes to bed at 11 pm, it will be easier for that person to go to sleep at 1 am than 9 pm. However, partly from tradition, backwards rotation appears to be more common in the United States.[9] In addition, shiftworkers like the "long change" that occurs when going from an evening shift to a night shift the next day.

- Due to the long amount of time the body takes to synchronize to a new shift, the rate of rotation should not be intermediate (1 week per rotation).[1,7,9] By the time the shiftworker has adapted, the schedule will rotate again. It is unclear whether a quick rotation speed (1 to 2 days per rotation), slow rotation speed (about 3 or more weeks per rotation), or no rotation at all is more advantageous for the employees and the organization. For example, rotation systems spread out the exposure to night work among all of the employees, whereas although a permanent night shift does not require synchronization to new work schedules, recruitment is often more difficult.

- The number of consecutive work days should be limited to no more than six days, and occasionally seven days if the scheduling arrangement is highly beneficial.[6]

- The schedule with the greater number of days off and the greater number of days off during the weekend is preferable.[6] In addition, consecutive days off are preferred until the number of days reaches 3 or 4 days in a row. With more than four days off, the time off is often used to work a second job rather than for leisure or family time. On average, workers prefer the following days off (in order of preference): Saturday, Sunday, Friday, all other days. Most workers prefer the traditional schedule of Saturday and Sunday off.

- Very early start times (earlier than 7 am) in the morning should be avoided.[1,4,5,6,7,8,10] However, operational requirements (e.g., morning rush hour traffic) may require early start times.

- Overtime or long shifts should be limited, especially for physically demanding jobs or jobs that expose employees to additional risks or hazards (e.g., exposure to toxic fumes), to one day per week and five days per six months.[4,5,6,7] Additional hours of work in a work day are recommended before adding additional days of work. Overtime should be rotated among employees and not restricted to a few employees.

- Quick shift changes (i.e., ten hours or less between shifts) should be avoided to ensure that employees are able to rest before returning to work.[4,6,8,9]

- Shift changeovers (e.g., the afternoon shift replaces the morning shift) should be scheduled for periods of lower workload (e.g., periods of less traffic congestion, periods when incidents are less frequent).[1]

- Tasks that are more dangerous when performed during the night shift should be transferred to the day shift if possible.[11] Safer and less fatiguing work methods should be used at night. Avoid work tasks that isolate employees at night.

- Within a shift, schedule work activities when employees are most alert, and avoid windows of time when employees experience circadian low points, including early in the morning shift, late in the evening shift, and late in the night shift.[1,9] For example, avoid work that is critical, error prone, or dangerous and work that is monotonous or repetitive (see Section 4.3.6 on the characteristics of stressful and fatiguing jobs).

- Rest breaks are a necessary part of a schedule that offset fatigue. The length, frequency, and provision of break activities should depend on the work performed by the employee (see the discussion on breaks in Section 5.3.3).[7,12]

6.5. Maintaining employee morale and job satisfaction

Maintaining high employee morale and job satisfaction is important, not only for the benefit of employees, but also for the operation of the organization. Employees who experience more negative aspects of a shift schedule are more susceptible to drops in morale and job satisfaction. Morale and job satisfaction are similar concepts.[13,14] The greatest difference between the two

concepts is most often attributed to the level of analysis (i.e., individual level versus group level). Job satisfaction is the positive or negative evaluation of one's work position. The evaluation is influenced by cognitive (e.g., beliefs, reasoning), emotional (e.g., feelings, moods), and situational (e.g., the work environment) factors. Because job satisfaction operates at the level of the individual, the level of job satisfaction among a group of employees varies widely and each employee is affected by different combinations of factors.

Morale is the emotional response of a group of employees to their employers.[14,15] Morale includes the confidence and optimism employees experience when solving a problem or completing a task, and operates at both the individual and group level. The emotions may arise from an individual employee or from the interaction of a group of employees. For example, factors that influence morale may become amplified through the interaction of a group and affect each group member in a similar way. Studies on morale often focus on the cohesiveness of a group, group identity, group membership, and job satisfaction. Common outcomes associated with high morale include loyalty, regard for the employer, and high employee job performance.[16]

Morale is determined by what individual employees or a group of employees value most at work. In a study on morale in higher education, midlevel administrators ranked the most important morale issues at their universities.[15] Out of 53 items, the professional and institutional issues ranked as the most important, on average, were salary (24.3%), degree of trust from supervisor (19.2%), opportunity for promotions (15.2%), opportunity for career development (14.8%), support for activities (7.0%), sense of teamwork (6.4%), recognition of contribution (6.3%), recognition of expertise (7.6%), communication with supervisor (5.8%), authority to make decisions (5.3%), workload distribution (4.7%), and bureaucratic red tape (2.4%). TMC employees most likely find the same sorts of issues important. Other items (e.g., sexual harassment, parking) are most likely only salient if there is a problem. Research has also found that higher morale is related to a positive and unique organizational culture, greater employee autonomy, a sense of organizational energy or zeal among employees, and a strong employee-employer bond.[16] Lower morale was linked with a poor work environment, lower pay, a lack of job mobility, employee conflict, and a lost sense of community.

If turnover is high and productivity low, then the recognition of low morale and identification of the underlying cause of the problem is past due.[17] The morale of employees must be monitored to ensure that any dips are addressed quickly. Although morale is perhaps best assessed directly using an employee survey, an initial indication of a change in morale can be observed by considering the characteristics of organizations with high and low morale described above. In addition, there are three types of behavior to watch for that may be symptoms of low morale. First, look for a lack of involvement.[17] Do employees appear disconnected from the outcome of important decisions? Are feelings of indifference frequently expressed at staff meetings? Second, look for passive aggressive behavior. The behaviors may be overt (e.g., high absenteeism or lateness) or covert (e.g., an employee failed to complete an assignment because "an e-mail was misplaced" or "a deadline misunderstood"). Covert behaviors typically include some form of malfeasance that is accompanied by a plausible yet unlikely excuse. Third, look for depressed, dejected body language. Signs include crossed arms, negative facial expressions,

a lack of energy, and few expressions of positive emotion (e.g., smiles). If a morale problem is detected, address the problem immediately.

Shiftwork schedules present a number of unique challenges for evening and night workers in comparison to day workers.[18] A common shift-related problem that causes lower morale is a sense of isolation and lack of community atmosphere at work. In general, shiftworkers are out of phase with the community at work and where they live. Shiftworkers are especially vulnerable to feelings of isolation if they live in smaller communities with a small number of shiftworkers and the social needs of shiftworkers are not met. On average, shiftworkers meet with friends less often, belong to fewer social organizations, hold fewer positions of stature in social organizations (e.g., treasurer, president), and engage in more social activities alone. Shiftwork may also strain family life. Employers with shift schedules should consider and assess the shiftwork climates within their organizations. Employers with a poor shiftwork climate should consider creating a greater community climate within their organizations. In addition to considering the characteristics of organizations with high morale discussed above, also consider providing services for employees that may not be available to them because of their schedules (e.g., recreation services, food-related resources). Counseling services may provide shiftworkers with strategies for adjusting to their schedules. Finally, consider an intervention that may be used to increase morale. Increasing morale may also cause employees to become more excited about going to work, strengthen their bonds with their managers, supervisors, and co-workers, and improve their views of their organizations.

There are a number of methods to build morale and camaraderie among employees. Organizational gatherings, hobby clubs, sports, and games (e.g., ITS trivia games, Traffic Management Jeopardy) can lessen feelings of isolation and build group cohesion.[9] Celebrate birthdays on a monthly schedule.[19] If cash is in short supply, then have each employee who wishes to participate pay $2 for cake, snacks, and drinks. Create a secret gift exchange either just before the winter holidays or throughout the year. To initiate a gift exchange, have interested co-workers write down their favorite color (or other favorites), birthday, anniversary, or hobbies on a card, and then have a random drawing. During the winter holiday office party, have the unveiling of the secret gift givers. Also consider brainstorming new ideas and ask other TMCs about activities that they have used in the past. These activities may require creative scheduling; for example, events may need to be scheduled twice or for an extended period of time.

Finally, communication is a key ingredient in a strategy to maintain high morale.[17] Communication includes keeping employees informed, and enabling employees to speak with managers and supervisors. Not only will morale improve, but free communication will also facilitate the detection of a morale problem.

6.6. Environmental changes

Shiftwork, especially night work, can cause severe fatigue, lower performance levels, and an increased risk of accidents. A number of countermeasures can be implemented by employers to ameliorate the negative consequences of shiftwork. TMCs not only control the work performed by their employees and their schedules, but also the physical features of the work environment, including lighting, sound, temperature, ventilation, and any food or recreational resources.

6.6.1. Bright lights

Although the research on using bright light exposure (daylight levels of > 2000 lux) is promising, the technology is not ready for conventional use.[1,7,9] Most studies require a high degree of control over participants' exposure to light for a 24-hour period, which is not practical outside a laboratory, and some lab studies have met with only partial success. Moreover, excessive exposure to bright lights may cause retinal damage.

Although bright light exposure is not ready for conventional use, a number of implications of the research can be applied.[1,7] Work areas should not be dimly lit, especially at night. A bright and stimulating work environment will help diminish fatigue in contrast to a dim workspace. Schedules can be designed to use light as a time cue. For example, morning light can help day workers maintain alertness throughout their shifts. In contrast, night workers may find it easier to fall asleep if they are able to drive home and get in bed before dawn.

6.6.2. Sound

The work environment should be screened for any noises that could disturb employees or cause drowsiness (see Section 5.2.3 in the previous chapter).[11]

6.6.3. Temperature

Although a comfortable office temperature varies by person, on average, the optimal temperature for sedentary work is about 77º F (25º C).[12] A high room temperature begins to degrade performance at 86º F to 95º F (30º C to 35º C).

6.6.4. Ventilation

Poor ventilation systems may contribute to fatigue.[12] Poor ventilation may cause increases in carbon monoxide or carbon dioxide, poor temperature regulation, and high levels of monotonous noise, all of which increase drowsiness.

6.6.5. Food

Employers manage many aspects of what their employees consume by making decisions regarding microwaves, coffee makers, refrigerators, freezers, vending machines with snacks and caffeinated beverages, canteen facilities, and meal benefits. Not only do unhealthy eating patterns lead to medical problems, but circadian dysfunction exacerbates gastrointestinal troubles.[1] Employers should promote healthy eating habits in their employees.

6.7. Sleep at work

Many shiftworkers unofficially take naps either during their lunch breaks or on the job.[8] Just over a quarter of working adults (27%) reported that they felt sleepy at work 2 days per week or more.[20] For shiftworkers, the percentage jumps to just over one-third (34%). Almost one tenth (8%) of working adults said that they occasionally or frequently fell asleep while at work. An official napping policy may be better than uncontrolled, unofficial napping by employees.[8]

The implementation of a napping policy, however, may be difficult for several reasons.[7,11,21] If napping is allowed, then provisions will need to be made to accommodate sleeping, such as a comfortable rest area without disruptions (e.g., noises) and opportunities to use the policy. Safeguards will need to be arranged to ensure that the napping policy promotes and does not

reduce safety and productivity. For example, it is important to allow for a 5 to 15 minute wakening period immediately following a nap.[9,12,21] Alertness is impaired for a short time, often referred to as sleep inertia, immediately after waking. In many organizations in the United States napping at work is prohibited. More generally, American culture associates sleeping with laziness. Only 16 percent of adults reported that their employers allowed napping at work. Of those permitted to nap at work, nearly one half used the policy (46%), and shiftworkers were more likely to make use of the napping policy (57%) than non-shiftworkers.[20] On the other hand, employees may prefer to maximize their time at home with family and may not want a napping policy.

Typically, naps only have value for those on a rotating schedule who want to synchronize to a new schedule.[7] For example, naps would be recommended for those on a quickly rotating schedule, and for some employees who are about to rotate (e.g., from night shift to day shift). Otherwise naps may have more negative consequences than positive outcomes. In addition, naps work best as extra sleep time, and do not work well if used to make up for lost sleep.[9]

6.8. Occupational health services

Providing routine preventative health services helps to maintain the physical and mental health of shiftwork employees. For example, consider providing a directory of physical and mental health services with convenient locations and expanded hours of service, and information about exercise and eating a healthy diet.[9,11] Medical assessments should examine any issues that involve sleep, digestion, or drug consumption.[22] The initial examination should include screening of all workers before they start working a shift schedule. Follow-up examinations should include regular health checks to ensure the continued health of the shiftworker. Contact a human resources expert before using any of the following information to make a human resources decision (e.g., personnel selection).[23] Even advising a job applicant of potential issues related to medical or psychological problems may be construed as having a chilling effect on a group of employees protected under Federal law (see Section 4.3.1 on human resource decisions, individual differences, and the law).

6.8.1. Medical considerations

The conditions listed below may be aggravated by failing to maintain a regular schedule for sleep, meals, and medication.[22,24] Consult with a human resources expert about potential actions that can be taken for employees with a medical condition noted below. For example, employees with one or more of these conditions should be considered for schedules that do not involve night work.

- Severe gastrointestinal problems including cirrhosis or chronic hepatic or pancreatic illness
- Diabetes (particularity if insulin dependent)
- Severe hormonal problems, severe thyroid (thyrotoxicosis or thyroidectomy) problems, or supradrenal pathologies
- Moderate to severe epilepsy or other types of seizures, especially if medication is required
- Brain injury with sequelae, severe nervous disorders, or another mental illness associated with the sleep/wake schedule (e.g., depression, chronic anxiety disorder)

- Chronic sleep problems
- Spasmophilia
- Chronic elimination or renal problems
- Chronic cardiovascular problems, such as chronic heart disease (e.g., a recent heart attack), angina pectoris, hyperkinetic syndromes, or severe hypertension
- Malignant tumors
- Pregnancy

It is further recommended that, in some cases, employees with one or more of the risk factors listed below seek advice from a doctor before accepting an assignment requiring night work.[22,24]

- Less than 25 years old (particularly if living alone) or over 50 years old (especially if without previous shiftwork experience)
- Digestive problems including chronic gastritis, gastroduodentis, or colitis
- Chronic respiratory problems including asthma or chronic obstructive bronchitis
- Excessive alcohol consumption or drug use
- Moderate to severe hemeralopia or visual impairment (the lack of light may create a safety hazard)

6.8.2. Medical assessment

Regular medical assessments are important to ensure that shiftworkers remain healthy.[23,24] The frequency of the assessments should be determined by a physician based on the risk factors of the employee. For example, employees between the ages of 25 and 50 may only need a check-up every five years, employees younger than 25 and between the ages of 50 and 60 every two to three years, and those who are over 60 every one to two years. A check-up after the first year of shiftwork is also recommended.

6.8.3. Counseling

Counseling services are especially important before an employee starts a shift schedule.[22,24] Counseling services should focus on strategies for adjusting to and coping with shiftwork. In the end, although a shiftworker is not alone, adjusting to a shift schedule is an individual task. Important topics include sleep, diet, stress management, physical fitness, risk factors (e.g., smoking), activities outside of the job, and maintaining social contacts (e.g., relatives, friends). In addition, a number of books have been written that discuss potential problems associated with shiftwork and strategies for adjusting to a shift schedule (see Section 4.7 on additional shiftwork resources).

6.9. Educational interventions

Educational interventions are a critical first step in improving the health and safety of shiftworkers.[25] In 2003, only about 22 percent of U.S. facilities with shiftwork schedules offered some form of training, and just under five percent included family members.[26] Although people may feel knowledgeable, in general, they are either unaware or misinformed about sleep and how the circadian system operates.[25] As a result, employees may view themselves as sick or weak, decide that their marriage is failing, and blame others for not understanding them. A simple educational or social support program may help employees understand the causes of the problems that they are having and how to develop strategies to

overcome those problems.[1] Family involvement is often a critical component for a shiftworker's adjustment.[9,26] Not only is it important to incorporate family members, but they will also want to know what the shiftworker is experiencing. It is important to ensure that the programs are accessible to all schedules. Educational interventions require a continuous or semi-continuous effort similar to health or safety interventions that include year-round fitness or smoking cessation campaigns.[8] For example, instead of just having workers track their weight and exercise regimen, they could also keep a sleep journal. Include participatory sections where employees and family members can share problems and compare strategies.[26]

If the educational program is intended to change existing behaviors and not just to disseminate information, then educational methods beyond a lecture are required.[24] Training programs that change behaviors (e.g., smoking cessation) require a high level of motivation and time to work. Recommendations should be specific to the group of employees and to the scheduling systems, and should be realistic and socially acceptable. Recommendations will be rejected or fail if not accepted by the employees or the people in the social support system. Focus on one topic (e.g., diet, health) at a time. Too many recommendations presented at once will overwhelm the audience.

During and after the educational intervention, evaluate the success of the program. Solicit feedback from employees, supervisors, and managers. For example, survey employees immediately following a training session to get feedback when the session is fresh, and then in six months to assess the results and impact of the session. Assess whether employees made any behavioral changes, and if there were any improvements in workplace outcomes.

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Chapter 7. Staff Planning

7.1. TMCs and staff planning

7.1.1. Trends

The number of vehicles in the transportation system and the average number of vehicle miles traveled per day continue to increase at a greater rate than the expansion of the transportation system.[1] Already, many road systems in major cities bear volume greater than their intended capacity. To meet these demands, TMCs are undergoing a number of fundamental changes, including the introduction of more sophisticated technologies (e.g., evolving ITS architectures), a shift to integrated operations (e.g., multiagency, multimodal), and improvements to customer service capabilities.[2] The increased demand for services and changes to TMC operations affects staffing practices. For example, the introduction of ITS has prompted the need to hire (and train) TMC employees with a set of skills that in the past were not necessary.[3] Although the implementation of new technology may add to the automation of TMC functions, often a greater level of skill is required to operate the new technology. In general, increased demand for services will require an increase in the number of services offered by a TMC, an increase in the coverage area, an increase in the number of partnerships, etc. Increasing demand requires more employees and employees with the necessary knowledge, skills, abilities, and other

characteristics (KSAO's) to handle the demand. Although advances in technology that automate certain aspects of the TMC may reduce the number of employees required to manage TMC operations, employees with higher level KSAO's will be required.

Another major difference with a large impact on staff planning is whether a TMC is a new center or a legacy center.[1] Legacy centers are generally older centers that were created on a smaller scale with less staff, less technology, and more specific service capabilities. For example, a legacy TMC in New York provided signal timing throughout the city and monitored the tunnels that connected with Manhattan Island for incidents. More recently, the information gathering efforts of the surrounding TMCs in New York have been integrated to provide real-time travel information to all travelers in the area. In general, legacy centers rely more on their personnel and less on technology than newer TMCs. Faced with the need to change (e.g., initiative to share information with surrounding TMCs), legacy centers may have trouble adapting and require more advanced planning to ensure a smooth transition.

7.1.2. Number of staff

There is no formula that provides a calculation for the number of employees required to staff a TMC. The determination of the appropriate staffing level comes down to a judgment based on multiple factors, some of which may be unique to a TMC. Two important factors are the number of functions supported by the TMC and the workload associated with supporting each function. The list below provides a number of additional factors that impact staffing levels (adapted from reference 4). Although the list below was designed for traffic signal operations, many of the factors are applicable to TMCs with other operational capabilities.

- TMC budget
- Shift design and operating hours
- Design of TMC facilities
- Area of coverage responsibility
- Type and operational reliability of the detection system
- Type and complexity of traffic control systems (e.g., central vs. distributed)
- Standardization and operational integration of control equipment and hardware
- Frequency and type of traffic control systems deployed and associated degree of automation for status polling and corrective actions
- Quantity and complexity of technology (e.g., VMSs, CCTV, video sensors, advanced or adaptive traffic controllers)
- Type, stability, and complexity of the communications system and associated electronic equipment and hardware
- Implementation of low-maintenance and easy-to-operate systems based on effective integration and system planning, design, construction, and inspection in support of quality system operations
- Acquisition basis for signal system components and associated performance on a life-cycle cost basis
- Integration and amount of sharing with other TMCs and other agencies
- Institutional arrangements and organizational structure for integrated and inter-jurisdictional traffic operations and service delivery

- Degree and complexity of interaction and coordination with other support agencies (e.g., the media, police, emergency services)
- Operational strategies (e.g., fixed time, semi-actuated, full-actuated, time of day and day of week timing plans, traffic responsive, traffic adaptive)
- Level of data collection automation in support of traffic operations and design
- Response time requirements for corrective actions
- Availability and comprehensiveness of predefined response strategies and timing plans for non-recurrent events
- Quality of response and preventive maintenance programs
- Community requests for design modifications to timing changes, signal phasing, pedestrian provisions, etc.
- Support requirements (e.g., legal inquiries by law and insurance firms, rezoning applications, new developments, traffic impact studies, safety improvement studies)

7.1.3. Staffing structure

Figure 7.1 depicts a typical hierarchy of employee positions.[4] The number of supervisors affects the quality of TMC operations and how quickly decisions can be made in a crisis. Typically, supervisors (i.e., the decision makers) who handle day-to-day operations are highly accessible. Supervisors typically carry pagers and/or cell phones, and shift supervisors generally have their offices next to the control room.

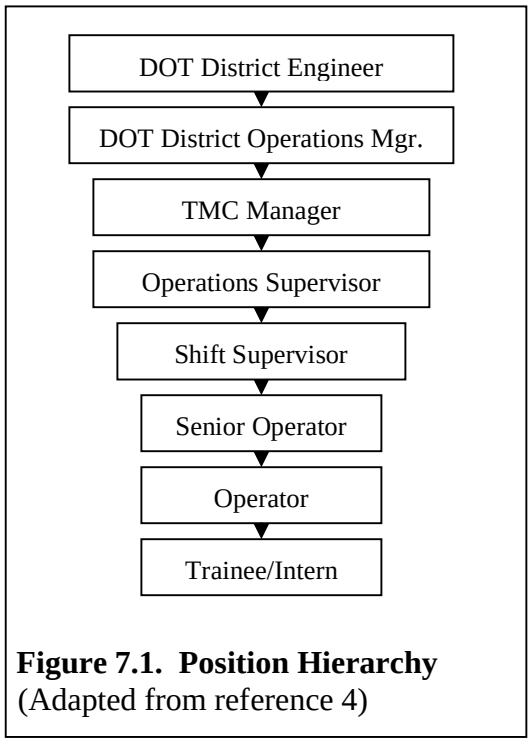

Figure 7.1. Position Hierarchy
(Adapted from reference 4)

The Nashville TMC is open Monday through Friday from 5:30 am to 10:00 pm and from 8:00 am to 8:00 pm on the weekends.[5] The hours of operation may be extended or shortened by a Tennessee directive, during a holiday (e.g., New Year's Day, July 4th), for special events (e.g., Tennessee Titans Football game), or to manage a major incident. Figure 7.2 depicts the basic organizational chart used by the Nashville TMC to cover those hours of operation. One shift supervisor and one operator cover the morning (5:30 am to 2:00 pm) and afternoon shifts (1:30 pm to 10:00 pm). Additional assistance is provided from a part-time operator during the morning (6:30 am to 9:30 am) and afternoon (4:00 pm to 7:00 pm) peaks. One shift supervisor and 4 part-time operators typically cover the two weekend shifts (8:00 am to 2:00 pm and 2:00 pm to 8:00 pm). Unless called to duty, the operations manager typically works from 7:00 am to 4:00 pm through the week. (Appendix A provides a case study of the Arizona TMC.)

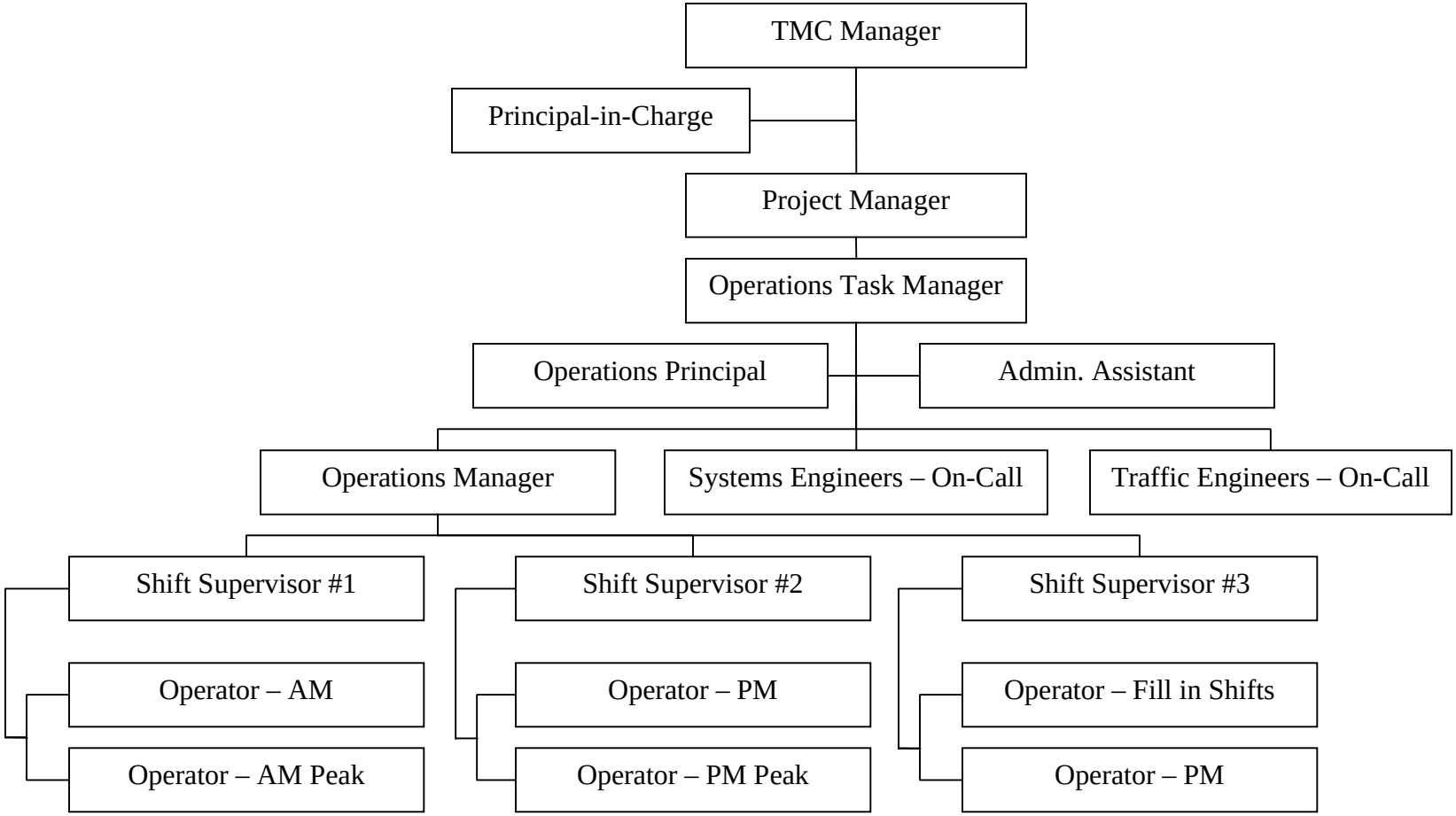

Figure 7.2. Tennessee DOT Sample Organizational Chart
(Adapted from reference 5)

7.2. Staff planning

Staffing plans prescribe human resource activities (e.g., succession planning, training programs) to handle potential environmental uncertainties (e.g., expansion of TMC services) and existing human resource needs (e.g., TMC manager retires, sudden incorporation of new technology).[6] In general, the term **workforce planning** is used to designate planning by a larger organization (e.g., Federal Highway Administration) with multiple units in various geographical locations. The term staff planning is more appropriate for smaller organizations (e.g., TMCs), which are typically in a single geographical location and do not oversee multiple organizational units.

A staffing plan should not cover an entire organization.[7] Different sections of an organization merit different levels of planning and analysis; some may not merit any planning or analysis. For example, jobs that can be filled quickly with known resources do not require staff planning. Staff planning efforts should only be focused on those areas of the organization that require advance planning (e.g., jobs that are critical to the organization, jobs that are difficult to staff). Parts of the organization that undergo change may require staff planning or a revision of an older staffing plan. For example, the introduction of ITS may require the identification of new recruitment sources to find employees with the appropriate set of skills to manage the technology. The purpose of focusing planning efforts on key human resources is to ensure that staff planning resources are used where they are needed most and will have the most impact.

Organizations have included the following types of information in staffing plans:[8,9]

- Budget information
- Classification information
- Compensation and benefits information
- Demographic data
- Diversity issues
- Labor market analyses
- Recruiting sources
- Job analysis information (e.g., employee KSAO's)
- Performance data and evaluations
- Redeployment plans
- Retention data
- Retirement plans
- Selection and staffing information
- Succession planning information
- Training and development information
- Turnover data
- Work/life balance issues

The core of a staffing plan includes the prediction (an estimate) of human resource needs in the future (i.e., demands), an assessment of human resource availability (i.e., supply), the differences between supply and demand (i.e., gaps), and the methods for reconciling the differences (i.e., solutions).[9,10] Staffing forecasts rely on data collection, analysis, and judgment. The

assessment of the workforce includes a count of the number of employees in each job (e.g., operator, field maintenance technician) and the characteristics or KSAO's (e.g., incident management experience, customer service skills) of each employee. Future needs may be forecasted based on projected attrition rates, potential recruitment sources, hiring strategies, etc. Often, the data collected for a staffing plan is incomplete, but is still suitable for use to devise staffing plans and strategies.[7] Attempting to collect more data at great effort and expense should be avoided in favor of using existing data to the fullest extent possible.

7.2.1. Driving strategy

Staffing plans are driven by the strategy of the organization.[9,10] A more appropriate conceptualization of strategy for a TMC may be in terms of the functions performed, the services offered, and the overall mission of the TMC. The purpose of the staffing plan is to help ensure that the goals of the organization are met. More specifically, staffing plans address the human resources needed to meet the goals of the organization.

7.2.2. Objectives of a staffing plan

A well-crafted staffing plan should fulfill five key objectives:[11]

- Ensure appropriate staffing levels
- Ensure the organization employs staff with the requisite KSAO's in the appropriate positions when needed
- Ensure that the organization adapts to changes within the organization and in the external environment
- Provide a systematic approach for human resource management
- Provide a shared vision of human resource functions

A proper staffing level is required to ensure the efficient operation of an organization.[6,11] A staffing plan is designed to prevent periods of overstaffing and periods of understaffing. Overstaffing causes excessive payroll costs. An understaffed organization may not be able to meet consumer demands for service. For a TMC this could translate into slower response rates to incidents, or CMSs that remain broken for longer periods of time.

Organizations must determine what KSAO's employees should possess and how many employees in each job are required currently and in the future.[11] One method of determining who to hire from a pool of applicants is to consider which KSAO's are required. For example, an entry-level operator should be able to complete all of the training required to perform the position. Moreover, the characteristics of an operator who will work the night shift may differ from a day shift operator. The night shift may require an employee who can work independently and can handle more responsibility, in contrast to a day worker who may need more teamwork skills. Because the operator position requires an extensive amount of training, an applicant may need to be hired several months before the position is vacant so that the new employee is able to perform the tasks of the job when needed.

Organizations must also anticipate future changes either from within the organization or from external sources.[11] Staffing plans can be formulated in advance by anticipating future changes instead of relying on reactionary decisions. Key positions within the organization can be tracked

to determine when TMC employees plan to leave or retire. Lower-level employees can be groomed for promotion to fill key positions before the departure of higher-level employees. Economic growth or increases in gas prices may create a greater demand for services from TMCs. By anticipating the opportunity for growth, a TMC can request more money to hire more employees to expand operations and improve the services offered.

The staffing plan provides guidance to human resource decisions and activities by outlining a systematic approach to human resource management.[6,11] Human resource functions should be integrated to support one another. For example, performance evaluations should include an assessment of training that employees have completed, and training activities should enable employees to receive pay raises and promotions, possibly as part of a succession plan.

Staffing plans ensure that managers have a shared vision of human resource functions.[11] A staffing plan requires the input and support of all managers responsible for carrying out the plan within the organization. A mutual understanding of human resource management facilitates communication and cooperation among managers and helps to guarantee that employees are treated fairly.

7.2.3. Stakeholders

Identifying stakeholders is an important step in creating a staffing plan.[12] **Stakeholders** are the people who have some interest in the staffing plan and include those who are needed to develop the plan, those who are needed to provide input about the plan, and those who are needed to approve, support, and promote the plan. In part, the staffing plan is developed for the stakeholders, and identifying their needs will help to determine actions that need to be carried out to develop the staffing plan. Identifying stakeholders also aids in selecting the right group of employees and managers who can develop and carry out the staffing plan.

7.2.4. Planning horizon

Demand analysis was discussed in Chapter 2 as a method for collecting information to determine scheduling needs (also see Chapter 3). A schedule is a specific type of staffing plan with a short to medium planning horizon. In this chapter, staffing plans and demand analysis are discussed in the context of long-range human resource decisions (e.g., recruiting, hiring). Similar to generating a schedule, the planning horizon must be considered in terms of environmental uncertainties. The **planning horizon** is determined by a judgment of how far into the future predictions can be made, with some acceptable level of error.[9] The planning horizon can be determined by aspects of the environment that contribute to either uncertainty or stability. Greater environmental uncertainty is related to volatile social, economic, and technological conditions, high variability in demand, rapidly changing political and legal environments, smaller organizations, and poor management practices. Stable social, political, and technological conditions, strong management practices and systems, and stable patterns of demand permit longer planning periods. Typically, staffing plans include a variety of planning horizons, with some immediate concerns addressed more quickly (e.g., within 1 year), and others over the long term.[13] The length of the planning horizon should provide enough time to perform the action items of the plan. Often organizations find that a 5 year planning horizon is necessary to provide enough lead time to perform the recruitment, selection, training, etc. action items of the plan. However, the planning horizon determines the detail to which a staffing plan can be written.

More detailed planning can go into more immediate items, and more general plans with contingencies for environmental uncertainties can be used for long-term planning. Plans are usually updated annually or after a substantial change occurs within an organization (e.g., reorganization).

7.2.5. Assumptions

Due to future uncertainties, a certain number of assumptions must be made about future resources and needs.[11] An important step in creating a staffing plan is to make explicit and clarify all assumptions about the organization and the external environment. By recording all of these assumptions, the staffing plan can be more easily revised when a change that affects the assumptions occurs. In addition, if the staffing plan fails to accommodate future needs, then the assumptions can be reviewed to determine where errors in prediction occurred and to facilitate corrective actions. For example, a certain attrition rate of employees in a specific position may be assumed over the next 5 years based on the attrition rate from the last 5 years, and based on the assumed attrition rate 8 new employees may need to be hired over the next 5 years. However, if the wage of the position goes up, then the process of re-evaluating the probable hiring rate is facilitated by examining the assumption. Most likely the attrition rate will decrease, leading to a hiring need that is less than 8 employees in 5 years.

7.2.6. Demand analysis

The purpose of a **demand analysis**, in the context of long-term staff planning, is to forecast future staffing needs that will be required to operate and fulfill the mission of the organization.[6,9,14,15] Demand analysis predicts the number of employees needed in different positions throughout the organization and the characteristics the employees need to successfully perform each position. Predictions should also attempt to account for any changes in work, workload, or functions supported by the TMC. For example, if ITS is going to be introduced at a TMC in the next five years, then existing employees may need to be trained or new employees hired to operate and maintain the ITS, and fewer employees may be required if the ITS adds a level of automation.

Internal and external factors impact the nature of demand.[9] Internal factors include the services offered, service levels, budget constraints, and the structure of the organization. External factors include the legal climate (e.g., reducing or increasing speed limits), the economic climate (e.g., increasing gas prices), and changes in technology (e.g., implementing ITS). There are no hard-and-fast rules for conducting a demand analysis. Typically, shorter-range plans are driven by budgetary constraints and the budget is driven by some prediction about future workloads. Quantitative methods are often used for longer-range estimates.

7.2.6.1. Quantitative methods[16]

Quantitative methods rely on the assignment of numerical values to variables in an equation that is used to calculate estimates of future demand levels. Quantitative methods reduced the estimate of demand to a mathematical equation. The values of the variables may be known or require an estimate. The quantitative methods discussed below rely on the use of a "predictor," a variable or factor that underlies demand.[13] Two principles guide the selection of an appropriate predictor (or predictors). First, the predictor should be directly related to the work performed by the organization. TMCs should consider predictor variables that are directly related to traffic

management (e.g., traffic volume, number of incidents). Preference should be given to predictor variables that are in use by other human resource processes to maintain a consistent approach. If the budget is based on traffic volume, then traffic volume would be a more appropriate choice than the number of incidents to determine staffing requirements. Second, changes in the predictor variable should be proportional to the employee requirements. That is, as the demand predictor variable changes, the employee requirements should also change in a similar fashion. (Also see Section 2.7.1.1 on the identification of labor drivers.) Note 7.1 describes a set of formulas that may be used to calculate the relief factor or average over-coverage percentage for a group of positions.

Note 7.1. Relief Factor

The relief factor, or average over-coverage percentage, determines the number of employees that are required to cover a group of positions when employee absences (e.g., vacation days, sick leave) and other relief days (e.g., training days) are accounted for.(16) For example, a relief factor of 1.25 would suggest that an additional 10 employees are needed to cover the work of 40 employees when the vacation days, sick leave, training days, etc. of the original 40 employees are accounted for ($40 \times 1.25 = 50$). The first step in calculating the relief factor is to determine the average number of relief days per employee per year. A simple method for determining the average number of relief days is to determine the total number of relief days taken by all employees in one year and to divide the total by the number of employees involved in the total (see the formulas below). The relief factor is obtained by dividing the total number of work days of the organization (i.e., how many days per year does the group of employees work at the organization) by the total number of work days minus the number of relief days. The relief factor can be multiplied by the number of employees required for a group of position to determine the number of employees required to cover the group of positions and the resulting number of relief days.

TRD/NOE = RD
WD/(WD – RD) = RF
RF × NOE = FNOE

TRD = Total number of relief days per employee per year
NOE = Number of employees required for a group of positions
RD = Number of relief days per employee per year
WD = Number of work days per year for the group of positions
RF = Relief factor
FNOE = Full number of employees required when the number of relief days is accounted for

7.2.6.1.1. Conversion ratio

A simple method used to estimate future staffing needs is the conversion ratio.(9) A conversion ratio is based on the percent change in demand or workload. A current estimate of demand can be compared to a future estimate of demand. For example, assume that the total number of vehicles in the transportation system during the morning shift is 1,000,000 vehicles, and in five years the number of vehicles is expected to reach 1,500,000 vehicles, an increase of 500,000 vehicles. The conversion ratio is equal to 1,500,000 vehicles over 1,000,000 vehicles. The result suggests that demand will increase by 50 percent. The conversion ratio can be used to determine how many additional employees will be needed to handle the additional workload. The conversion ratio suggests that the number of staff will also need to increase by 50 percent to accommodate the 50 percent increase in workload. A staffing level of 8 employees would increase to an estimated 12 employees ($8 + (8 \times 50\%) = 12$ employees).

7.2.6.1.2. Demand estimate model

The demand estimate model below provides a projection of the future level of demand based on estimates of three variables: demand, the increase in demand over a certain planning horizon, and the change in the level of productivity.[9] The improvement of the demand estimate model over the conversion ratio is the addition of the change in the level of productivity, which allows for an estimate of change in the organization over time. For example, new operating procedures may lead to increases in the amount of demand that one employee can handle. The conversion factor in the denominator of the formula can be used to estimate the level of demand in employee requirements. Procedures described in Section 2.7 on demand analysis in the context of scheduling can be used for predicting demand and to estimate the variables in the demand estimate model.

$$E_n = \frac{(D + C)\frac{1}{P}}{X} \qquad \text{(Equation 7.1)}$$

Where: E_n = the estimated level of demand for services in *n* planning periods.
D = a current estimate of demand.
C = the amount by which the estimate of demand is expected to change (typically an increase) through *n* planning periods in the same units as *D*.
P = the average level of improvement in productivity predicted through *n* planning periods (e.g., if *P* = 1.05, the projected level of improvement in productivity is 5%).
X = a conversion factor estimated at the same time as the current estimate of demand. For example, by using the amount of demand one employee can handle, E_n will equal the amount of estimated demand per employee.

The level of accuracy in prediction depends to a great extent on how well each variable is estimated.[9] The estimation of each variable can be based on the previous experience of management and choices about the future. An example will help clarify the use of the formula. The volume of vehicles in the transportation system through the morning shift may be used as an estimate of demand. Assume that 1,000,000 vehicles are recorded for *D*. In 5 years (i.e., the planning horizon), the number of vehicles on the roadway is expected to increase by 500,000 vehicles. One method to help calculate the change in productivity is to determine if the amount of demand that one employee can handle has changed. For example, if 5 years ago employees could handle 180,000 vehicles and now they can handle 200,000 vehicles, then that represents an increase in productivity of about 11 percent. If the trend is expected to continue, then an 11 percent increase in productivity would be a good estimate. On the other hand, if the TMC expects to make no other changes other than to incorporate more ITS technology (i.e., a decision), then the increase in productivity can be based solely on the incorporation of ITS. If other TMCs experienced a 25 percent increase in productivity, then 1.25 would be an appropriate value for the increase in productivity. Assume that, on average, one operator is required for every 200,000 vehicles in the transportation system, and the increase in productivity is set to 25 percent. With a volume of 1,000,000 vehicles, 5 operators are required. With an increased

volume of 500,000 vehicles and an increase in productivity of 25 percent, the number of operators required will jump to 6 employees in 5 years.

$$E_{5\ years} = \frac{(D+I)\frac{1}{P}}{X} = \frac{(1{,}000{,}000 + 500{,}000)\frac{1}{1.25}}{200{,}000} = \frac{1{,}200{,}000}{200{,}000} = 6 \text{ employees}$$

7.2.6.1.3. Regression models

A **regression analysis** may be used to predict future staffing needs (see Section 2.7.3.3 for a discussion of regression models); however, it is recommended that a professional with statistical training perform the analyses.(9) Regression is a viable method if the number of employees and the amount of demand they handle are related. The model is based on how well changes in the amount of demand covary with changes in the number of employees who handle the demand. That is, as demand increases, the number of employees who handle the demand should also increase at a proportional rate. Historical data can be used to create a regression model, and projections of future demand can be plugged into the regression model to project the number of employees required.

7.2.6.2. Subjective methods

Any of the **subjective methods** for eliciting work analysis information discussed in Section 2.3.2.1 could be adapted for use as a technique to elicit forecasts about future staffing demand. Two additional subjective methods designed for forecasting staffing needs are described below.

7.2.6.2.1. Unit forecasting

Unit forecasting is a bottom-up approach.(11) Each division of the organization estimates the future need for employees over a planning horizon (e.g., 1 year). These predictions are handed up to higher levels of management for approval. At each level of management, the staffing requirements are summed. The final combination of employee requirements yields the total predicted demand for the entire organization, and is often presented to senior management for final approval. By placing the responsibility for estimating future needs with the people who oversee the employees and services of the organization, the demand forecasts are often more responsive to their needs and the demand for services from consumers. However, without measures to hold people accountable for their predictions, managers tend to overestimate their needs. Problems occur when lower-level managers place the needs of their divisions above the needs of the entire organization. One method of assessing accountability of staffing requirements is to conduct performance evaluations based on the number of employees in each division.

7.2.6.2.2. Top-down forecasting

Top-down forecasting, in contrast to unit forecasting, is driven by the judgment of senior-level managers.(11) Senior-level managers allocate a portion of the budget to employee payroll and divide the pool of money among their managers. Each subsequent layer of managers decides how to distribute the money for their division and to any other lower-level managers. Personnel decisions must be made within the budget provided to the managers. Through the top-down approach, forecasting decisions are constrained by budget allocations. The top-down forecasting method is efficient and adheres to a strict budget for the entire organization. On the other hand,

the budget may not allow appropriate responses to changes in consumer demand. Whereas unit forecasting focuses on adaptability to demand, top-down forecasting is consistent with a cost minimization strategy. Some combination of the two approaches may be used if both adaptability and cost minimization are desired.

7.2.7. Supply analysis

Supply analysis is used to identify the number of employees in each job, the KSAO's possessed by those employees, and the characteristics of hiring sources.[14,15] That is, supply analysis involves an audit of human resources within the organization (i.e., internal sources) and potential sources outside of the organization (i.e., external sources). Supply analysis should be conducted in the present, and projected into the future over a selected planning horizon. The results from a supply analysis provide a baseline from which the results of the demand analysis can be compared. The purpose of supply analysis is to determine whether sources of human resources will fall short of, meet, or exceed demand in terms of the number of employees required and the KSAO's required. For example, the introduction of ITS may increase the automation of TMC functions, which would reduce the number of employees required, but also increase the level of KSAO's needed by the remaining employees. Figure 7.3 depicts a model for forecasting future staffing levels based on the current staffing levels and estimated gains and losses.[17]

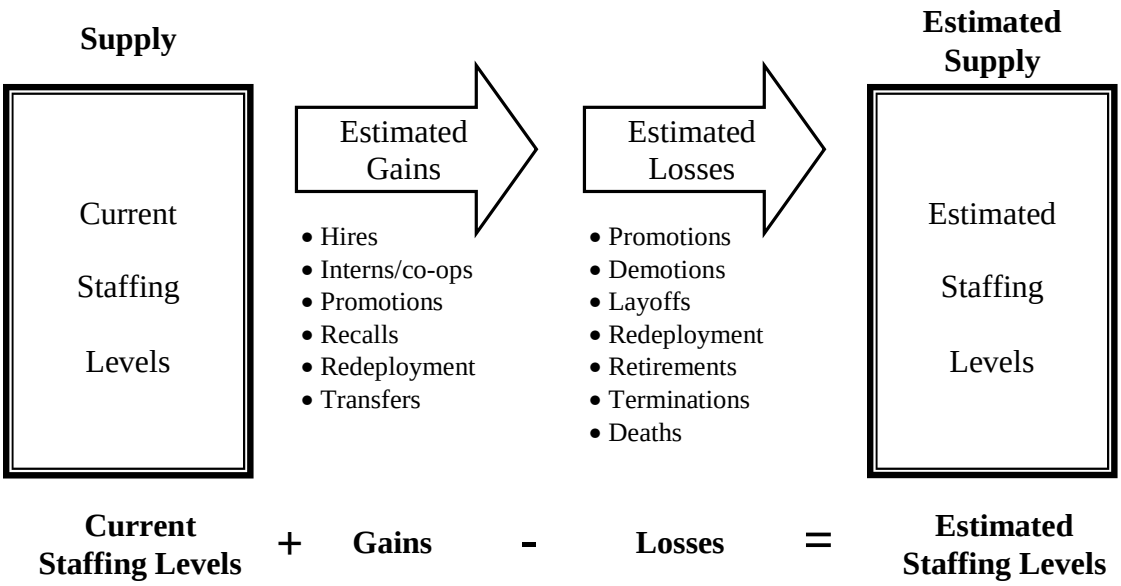

Figure 7.3. Supply Forecast
(Adapted from reference 17)

7.2.7.1. Internal sources

Internal sources include both the number of employees in each job and the characteristics of the employees.[11] In general, an audit of internal sources will be conducted in the present time and then projected into the future and compared with the demand analysis results. Although simple

Table 7.1. TMC Staffing

	Boston	Toronto	Milwaukee	Houston	Long Island	Detroit	Atlanta	Phoenix
				Operations				
Centerline Miles	7.5	60	63	122	165	180	220	254
Number of Operator Positions	10	9	3	18	5	6	12	6
Number of Prime Shift Operators	3+	3+	2+	12	5	4	5	2
Total Operations Staff	10	12	5	19	12	9	18	8
Number of Operation Staff Levels	3	3	1	1	2	2	1	2
Operations Staff Source	MassPike as contractor	Agency Staff (FT or PT)	Staff, Students	Agency Staff	Contractor Personnel	Temporary Part-time	Staff, Students	Agency Staff
Number of Shifts	3	3	2	3	3	2	3	3
Backup Operations Staff Resources	Supervision, Off-shift, Overtime	Supervision, Off-shift	Supervision, Professional Staff, Off-shift, Students	Varies by agency	Contractor Responsibility	Supervision, Off-shift	Supervision, Professional Staff, Off-shift, Students	Supervision, Off-shift
				Maintenance				
Number of Maintenance Staff	N/A	3+	3	3+	N/A	3	Combined with other functions	3+
Organization Responsible for Maintenance	Installation Contractor	Agency, Contractors	Agency District Office, Comm. Contractor, Maintenance Contractors	Agency District Office	Maintenance Contractor	Agency District Office	Agency, System Manager, PM Contractor	Agency District Office TMC Systems Team
Special Maintenance Elements	None	None	Information Technology Specialist	None	None	None	Information Technology Team	Systems Team
Types of Field Equipment	SCADA, VMS, Loops, CCTV, Gates, Overheight, FO Network, AM/FM Re-Broadcast	VMS, Loops, CCTV, FO Network, Ramp Meters, RWIS	VMS, Loops, Microwave Detectors, AVC, CCTV, Ramp & Freeway Meters, HAR, RWIS	VMS, LCS, Loops, CCTV, Gates, FO Network, Ramp Meters	VMS, Loops, CCTV, Coax Network, Ramp Meters, Traffic Signals	VMS, Loops, CCTV, Coax & FO & Microwave Network, HAR, Ramp Meters	VMS, Loops, Radar, VIDS, CCV, FO Network, Ramp Meters	VMS, Loops, PAD, CCTV, FO Network, RWIS

(Adapted from reference 18)

counts may be used to determine the number of employees in each job, some sort of job analysis procedure (see Section 2.3) is required to determine the characteristics (i.e., KSAO's) of the employees. Typically, the information must be updated at least once a year, because the characteristics of the internal sources will change as a result of attrition, training and development, promotion, job experience, etc.[9] TMCs experience a high degree of turnover because of a lack of a career path, opportunities in the private sector, and high stress levels associated with the job, the use of external sources may become critical for staffing.[4] Table 7.1 displays the resources at several TMCs throughout the United States and Canada, including information on operations and maintenance.

7.2.7.2. External sources

The depletion of internal sources through employee attrition and voluntary turnover, retirements, deaths, and discharges may require an organization to use external sources to hire new employees.[9] In addition, the growth of the organization and the promotion of diversity require hiring from outside the organization. In addition to postings within the agency and agency surplus personnel, TMCs have reported success using nearby community colleges as an external recruiting source.[4] Several TMCs have developed relationships with nearby colleges in a proactive move to attract potential employees. Common backgrounds for operations personnel include those who have worked with traffic equipment, air traffic controllers, bus and train operators, radio operators, clerical/administrative personnel, students, dispatchers, and transit police. Several TMCs have found a poor fit with engineers because the positions did not challenge them. An audit of external sources in a supply analysis involves collecting relevant job analysis information on external hiring sources. Questions that drive the job analysis may be, "Are there enough prospective employees in known hiring sources and do they possess the necessary KSAO's to be hired and succeed in the job?" The answer to the questions should be considered over time, for if the answer changes or is expected to change (e.g., community college stops offering critical class on traffic management) then changes will need to be made regarding the use of the external hiring sources. Recent job applicants and hires should be scrutinized and instructors at the community college may be contacted to collect information about hiring sources.

7.2.8. Gap analysis

The purpose of **gap analysis** is to reconcile the differences between the demand analysis results and the supply analysis results.[14,15] The results of a gap analysis identify the differences between staff characteristics (i.e., the number and characteristics of the employees) and the projected future needs. If the supply equals the projected demand then no staffing changes are necessary. On the other hand, the number of personnel and the requisite KSAO's may fail to meet future needs when demand exceeds supply (i.e., a gap). Conversely, the number and characteristics of the workforce may exceed future needs when supply exceeds demand (i.e., a surplus). Gaps and surpluses are mitigated through solution analysis.

7.2.9. Solution analysis

The purpose of **solution analysis** is to formulate ways of closing gaps or reducing surpluses.[14,15] Solution analysis takes into account the information gathered from the demand analysis and supply analysis in an attempt to address the information yielded from the gap analysis. The trade-off between the benefits and the costs of potential strategies must be weighed. Solution analysis involves general planning to take action if certain conditions occur, and/or plans to take more immediate actions to reconcile the gap analysis results.

7.2.9.1. Planning

Solution analysis typically involves two types of plans.[11] An **aggregate plan** focuses on groups of employees in specific, typically lower-level jobs. For example, an aggregate plan may forecast the number of operators or maintenance personnel needed in the next six months to five years. A **succession plan** focuses on critical, typically higher-level positions that must remain filled. Often a succession plan covers specific employees in critical positions and employees who could be promoted to a critical position. For example, a succession plan may include

information on when a TMC Manager intends to retire and potential candidates for the position, if any, within the TMC or the DOT.

7.2.9.1.1. Aggregate planning

Two strategies for aggregate planning include scenario planning and "what if" planning.[7] Scenario planning involves formulating several likely events (i.e., scenarios) and considering the staffing implications that would arise from each event. The staffing plan is designed to address the commonalties among the likely scenarios. For example, assume that a budget increase is slated for approval in one month to increase the number of operator positions and the new budget will allocate money for 2 to 5 new operators. Based on the 4 different scenarios (i.e., 2 new operators, 3 new operators, etc.), at a minimum, preparations should be made to hire 2 new operators. Once the budget is finalized, the TMC will be in a better position to hire the number of newly authorized operators than if no plans had been put together.

"What if" planning involves planning for less certain events. Strategies are formulated to handle possible events.[7] For example, what if more than one operator left a TMC and created gaps in the schedule that could not be covered by the remaining operators under the current schedule? Potential solutions may include revising the schedule, using overtime, having managers fill in, redeploying other employees, using retired employees, etc. Although "what if" plans are not entirely spelled out, preparing for future events with some planning will improve the quality of a response when the event does occur.

7.2.9.1.2. Succession planning

The first step in succession planning is to identify the key management positions that must be filled.[9,11,13] Typically, these positions are upper-level, senior management positions, or positions that the organization has difficulty filling. The second step is to create a plan for when an employee from a key position does leave. The successor may come from inside the company or from an external hiring source. The purpose of the succession plan is both to facilitate the transition from one employee to another and to groom specific employees from within the organization for promotions to higher-level positions. For example, often a successor will work alongside a departing employee for a short period of time. There is ample opportunity to groom an internal successor for advancement. With an external hire, however, there may be less time (if any) for preparations to assume the new position. If none of the internal sources have the potential to reach the qualifications of the position, then external sources will have to be used. In general, a succession plan should include at least one employee who can fill each key position, even if just as an interim appointment. Keep in mind that the promoted employee will also vacate a position. A succession plan requires a list of the qualifications required for the critical positions, and employees who either meet the qualifications or who may meet the qualifications with training and development over time.

A traditional tool used for succession planning is a replacement chart.[9,11,13] The replacement chart focuses on internal sources and is similar to an organizational chart, but only lists positions included in the succession plan and potential replacements for each key position (see Figure 7.4). For example, a single replacement chart may list a single key position and every potential replacement. Succession related information is often included below the job title, such as a judgment of when the replacement could take the position. The replacement chart helps to

remove bias from promotion decisions and ensure that the most qualified individual is promoted. In addition, the replacement chart can be used as a tool to aid in grooming employees for advancement. Potential replacements can be given feedback about their performance and what they need to do to be promoted (e.g., improve communication skills).

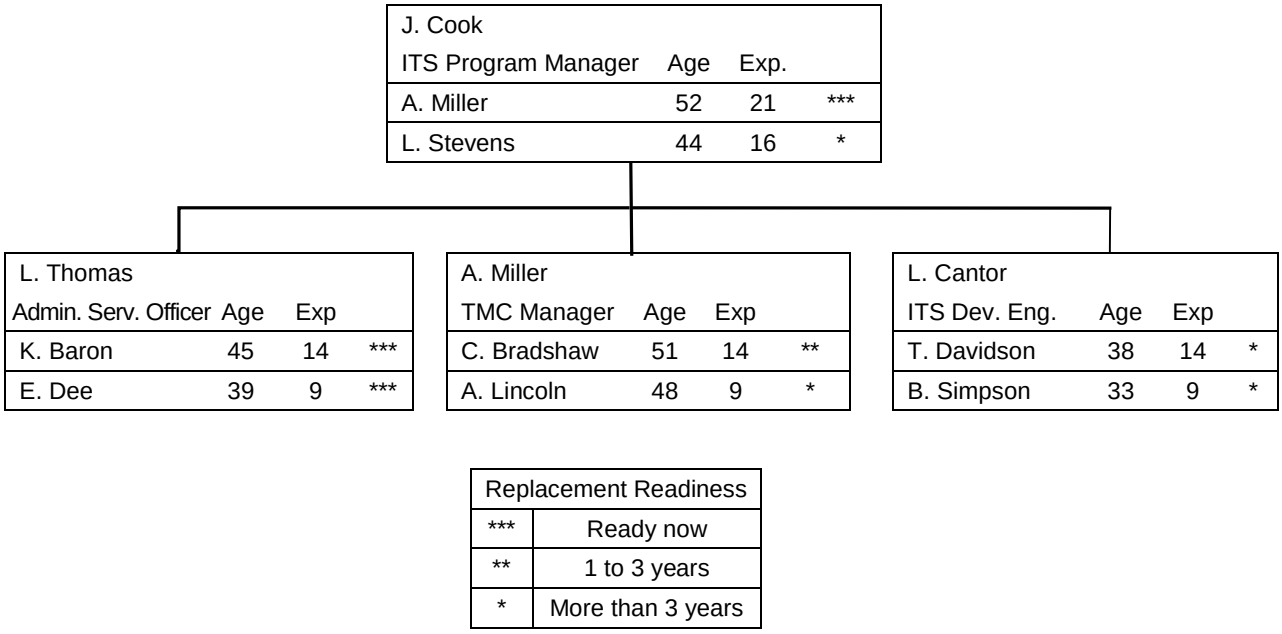

Figure 7.4. Simple Replacement Chart
(Adapted from references 10 and 13)

Succession planning can also be used to identify training and development needs of upper-level employees. Succession planning adopts an investment-style approach to managing high level employees. (11) Organizational resources are invested in the training and development of senior employees. This investment may entail a significant cost to the organization. Not only will succession planning prepare the employees for promotion, but they may also become more marketable for jobs outside of the organization.

7.2.9.2. Actions

Whereas aggregate plans and succession plans are contingent on some future event occurring (e.g., upper-level manager leaving), **action plans** lay out a list of items that will be completed regardless of future events (e.g., increase incentive plan, hire two new maintenance personnel within a year). However, an action plan may need to be revised if the organization undergoes a significant, unanticipated change (e.g., budget cuts). The purpose of an action plan is to provide an explicit account of the methods that will be used to ensure that the actions are carried out.(6) The action plan identifies resources and strategies that are required to successfully complete the plan, and establishes accountability among stakeholders.

Actions will vary in the amount of time required for implementation.(7) For example, if existing recruitment sources are failing to provide applicants, and an action plan is written to hire two new maintenance employees, then enough time should be allocated to find a new source, recruit

applicants, and hire two new employees. Additional time may be needed if initial training is an essential requirement for performing the job.

7.2.9.2.1. Gap mitigation strategies

In general, there are three categories of strategies that may be used to mitigate gaps or shortages of human resources.[11] The organization can implement strategies to retain the current workforce, change the way that internal resources are used, and/or acquire more workers from external hiring sources.[4,14,17] The list below provides examples of retention strategies. As many of the retention strategies are incentives to work for the business, most of them will also help attract external hiring sources to apply for and accept a job with the organization.

- Training and development strategies
    - Conference fee and travel expense reimbursement
    - Formal training reimbursement
    - Individual development plans
    - Job rotation
    - Lateral transfers
    - Mentoring
    - On-the-job training
    - Tuition reimbursement
- Compensation/incentives
    - Pay level
    - Awards
    - Bonuses
    - Company vehicle or discount on the purchase of a vehicle
    - Laundry services
    - Other benefits (e.g., cafeteria benefits)
    - Life insurance
    - Medical insurance
    - Number of vacation days, sick days, personal days, and holidays
    - Retirement plan
- Career-based strategies
    - Career counseling
    - Create career paths
    - Promote from within the organization
- Organizational programs
    - Child care programs
    - Diversity programs
    - Work/family programs
- Motivation and morale improvement strategies
    - Employee empowerment
    - Employee recognition
    - Flexible work schedules
    - Timely and thorough communication
- Miscellaneous strategies
    - Match charitable contributions

    - Organizational assessment surveys
    - Safe and attractive facilities

The list below offers strategies for changing how internal human resources are used.

- Change the design of the schedule
- Cross train employees
- Demotion
- Job rotation
- Lateral transfers
- Overtime
- Promotion
- Redeployment
- Job redesign
- Relocation

The list below offers strategies associated with acquiring more workers from external hiring sources, including both a list of potential external sources and strategies associated with recruitment.

- External sources
    - Hire new part-time staff (e.g., job sharing)
    - Hire new permanent, full-time staff
    - Internship and co-op programs
    - Rehire retired employees (possibly part time or temporarily)
    - Subcontract work
    - Hire employees under alternative arrangements (e.g., temporary employees, seasonal employees)
- Recruitment strategies
    - Employee referral bonuses
    - Give hiring authority to recruiters (e.g., on the spot hiring authority)
    - Housing consultation
    - Outreach efforts (e.g., job fairs, radio advertisements, Internet postings)
    - Relocation bonuses
    - Signing bonuses

For many potential employees the compensation package will be the most important factor. Compensation should be compared to similar jobs at other organizations to ensure a competitive pay rate.[4] Not only will a level of pay that is lower than the industry standard diminish the total number of applicants and the number of applicants who accept offers, but it will also cause a higher rate of turnover. Career paths help to establish a reasonable length of tenure in a position and potential lines of promotion. A lack of career paths is one of the most frequent complaints from TMC employees.[18] Many TMCs have found it difficult to create career paths because of the small size of the organization. Career paths may need to be extended through the department that oversees the TMC.

7.2.9.2.2. Surplus mitigation strategies

For the most part, gap mitigation strategies focus on adding positive features to a job. In contrast, as listed below, the surplus mitigation strategies include both positive (e.g., training) and negative (e.g., layoffs) actions.[8,11]

- Across-the-board pay cuts
- Attrition
    - Resignations
    - Retirements
    - Deaths
- Downsizing/rightsizing
- Employee training
- Early retirement incentives
- Elimination of services or functions
- Expand operations
- Furloughs
- Hiring freezes
- Job redesign
- Layoffs
- Leaves of absence
- Redeployment
- Reduce outsourced work
- Reduce work hours
- Reduction in operations
- Switch to variable pay plan
- Training
- Terminations
- Voluntary severance

7.2.9.3. Recruitment

The purpose of this section is to discuss recruitment in greater detail, and contrast internal recruiting with external recruiting. In general, there are two critical questions to answer, "How many people should be recruited into the applicant pool?" and "When should recruitment begin?"[11,13] These recruitment questions can often be answered by examining past efforts; otherwise a best guess will need to be made. Often, recruitment and selection require the development and use of screening criteria (e.g., required KSAO's), recruitment methods (e.g., newspaper, Internet), marketing strategies (e.g., advertise attractive aspects of the job), selection instruments (e.g., interview, letters of reference), and selection criteria (i.e., who should receive an offer).[19] To apply for a job, the job seeker must believe that a potential job exists, that there is some sort of match between their job qualifications and the job requirements, and that the job merits the effort to apply.[13]

All aspects of selection should also include elements of recruitment. A job applicant who leaves an interview with a positive view of the organization will be more likely to accept a job offer, and to communicate the positive aspects of the organization to others even if no offer is

extended. Research also suggests that it is in the best interest of the employer that recruiters honestly portray jobs to potential employees.[13,19] Although fewer applicants tend to accept offers based on realistic previews, applicants who accept an offer tend to stay longer with the organization and report higher levels of job satisfaction than those who received specious favorable reviews.

7.2.9.3.1. Internal recruiting

An organization may choose to recruit from within or to recruit from external sources. Hiring from within offers a number of benefits.[11] The organization has had an opportunity to observe the employee's behavior within the organization, and has performance data on the employee. The employee has experience working in the organization, and often in a job related to the open position. Promotion from within creates a career path within the organization and may improve the motivation of other employees. Promotion from within portrays an organization that provides opportunities for its employees, and rewards its employees for working with the organization. Internal recruiting and hiring is less costly and time consuming than pursuing external sources.

Internal recruiting may also become very political and competitive within an organization.[11] Conflict may arise when several employees apply for the same position, and relationships among co-workers may deteriorate. Motivation and job satisfaction may suffer when an employee feels that the other candidate was less qualified. Hiring from within may also cause the KSAO's possessed by members of the organization to stagnate by missing opportunities to hire new staff members with new skills. In addition, by hiring from within another vacancy is created and must be filled.

Several steps can be taken to mitigate the adverse affects of hiring from within.[11] Openings should be posted in a place where all employees can read them. The description of the opening should not guarantee that the position will be filled. Specific, objective feedback should be offered to employees who are not selected. An important component of feedback is information about how the employee can improve the chances of receiving an offer for a future opening.

Internal recruiting is recommended under several conditions.[11] When time and/or money are limited, an organization may be well-served by hiring from within. Internal recruiting is appropriate for organizations that want to maintain the status quo, organizations that want to maintain stability, and organizations that are confronted by few external threats. Typically, public services such as TMCs face little threat from external competitors in the same service sector. However, as a government agency, TMCs compete with other government agencies for the allocation of funds.

7.2.9.3.2. External recruiting

Conversely, external recruiting promotes a strategy of embracing change, and is useful for organizations in volatile environments.[11] If an organization is in dire need of change, then recruitment should focus on upper-level positions. Hiring from outside sources allows an organization to expand and update the KSAO's of its employees. New employees may bring new ways of thinking, and new methods for conducting work. New employees also foster diversity in an organization's workforce.

However, external recruiting is more costly and often more time consuming.[11] New employees often need more time to adapt to the new environment, meet the other staff, and learn the operation of the organization. More risk is associated with outside recruits. There is less knowledge about how the recruit will behave or perform within the organization. The new employee may have the required ability level, but clash with the culture of the organization. Finally, external recruiting may have a negative impact on the morale and motivation of existing employees who feel passed over.

The recruitment sources used determine the number and characteristics of the applicants. Common advertising sources include newspapers, magazines, technical or professional journals, direct mail, television, and the Internet.[13] Employment agencies (e.g., executive search firms, state agencies), educational institutions (e.g., technical/trade schools, alumni placement offices), and professional organization meetings (e.g., conventions) may also be used as recruitment sources. Other sources include career fairs, walk-ins, and employee referrals.

7.2.10. Evaluation

Evaluation of the staffing plan should be ongoing.[6] Information (e.g., recruitment statistics, attrition and retention rates) should be continuously updated. The purpose of staffing evaluations is to ensure the continued success of the staffing plan. The evaluation should confirm that those who are responsible for certain aspects of the staffing plan follow through, and determine whether any changes need to be made to the staffing plan in light of new information. Finally, the changes that result from the staffing plan must be managed.[6] It is important to manage the impact of the staffing plan on current employees.

7.2.11. Additional resources and examples of workforce plans

The primary mission of the Office of Personnel Management (OPM) is to support civilian Federal agencies with recruitment, hiring, and retention efforts. OPM's Web site hosts an assortment of work-related information available to the public (http://www.opm.gov/). The OPM Web site maintains a section devoted to workforce planning (i.e., staff planning; http://www.opm.gov/workforceplanning/index.asp), and includes Web pages on the 5 Step Workforce Planning Model (http://www.opm.gov/workforceplanning/wfpmodel.htm), a list of examples of existing staffing plans used by Federal agencies (http://www.opm.gov/workforceplanning/WhosDoingWhat.asp), and additional resources and links (http://www.opm.gov/workforceplanning/BestCase.htm).

The Federal Highway Administration's (FHWA) Workforce Planning and Professional Development Task Force Final Report is available online (http://www.fhwa.dot.gov/reports/workforce/). In addition, the U.S. Department of Transportation's Workforce Plan 2003-2008: FY 2005 Update is available online (http://dothr.ost.dot.gov/DOT_workforce_plan_05_update_final_031505_v2.pdf). The U.S. DOT's Workforce Panning Guide from 1999 is also available (http://dothr.ost.dot.gov/guide.pdf). Both the FHWA and the U.S. DOT staffing plans are based, in part, on the guidelines from OPM's 5 Step Workforce Planning Model.

The National Academy of Public Administration (NAPA) is an independent organization that was chartered by Congress in 1967 to assist government agencies at all levels with management and administrative issues (http://www.napawash.org/). In particular, NAPA has extensive experience with workforce planning, and has released a report on the issue titled *Building Successful Organizations: A Guide to Strategic Workforce Planning*.

The RAND Corporation is a nonprofit research organization that provides expertise and analytic services to the public and private sectors (http://www.rand.org/). RAND conducts research in numerous content areas (e.g., education, health) for a variety of purposes (e.g., improve business practices, public policy advocacy). Among the publications available to the public (http://www.rand.org/publications/) is a technical document on workforce planning (http://www.rand.org/publications/MR/MR1684.1/MR1684.1.pdf).

7.3. Event planning

This section pertains to staff planning methods for specific events a TMC may encounter. TMCs would benefit from creating a staffing plan to handle potential emergencies and special events. Although the exact time when an emergency will occur is not known in advance, the probability of an emergency event (e.g., severe flood, hazardous chemical spill) occurring over a range of months or years may be high. Many events faced by a TMC are common enough to warrant a staffing plan tailored to the event or more general planning for a group of related events.[4] The purpose of an emergency plan is to ensure that the full performance capability of the TMC is realized when an emergency event occurs (e.g., toxic chemical spill on a major highway). Planning is necessary to ensure that all components of the TMC mitigate the emergency to the fullest extent possible under different operating conditions, even components of the TMC affected by the emergency. Emergency planning may require some degree of generality because the specifics of the emergency will not be known in advance.

Special event planning (e.g., regular season Major League Baseball game ends, Presidential visit), on the other hand, can progress with a more specific and comprehensive plan because a number of factors are known in advance and similar special events have likely occurred in the past. Special event management can represent a significant portion of a TMC's workload, and must be included in staffing calculations.[4,20] Special event management may require one or more employees solely dedicated to the task. Because a technical document has been written on planned special events (see reference number 20), this document will focus on emergency planning.

7.3.1. Staff shortages

Perhaps the most common element of event planning is a lack of the necessary staff to effectively handle the situation.[4] In addition, a staffing shortage may occur because of poor scheduling or because one or more employees did not report to work. Several methods for handling staff shortages should be formulated in preparation for when the situation arises. (Also see Section 3.9 on making real-time scheduling decisions.) The list below contains several common strategies:

- Access additional staff from a temporary agency or contractor

- Call in employees who have been promoted or moved to other sections of the organization
- Call in off duty employees
- Call in retired employees
- Create a list of volunteers within the organization who can perform critical duties during a staff shortage
- Cross train staff to perform other critical duties (e.g., train technical staff or maintenance personnel to perform operations duties)
- Decrease the level of service or number of functions supported
- Have management, supervisors, or shift leaders perform the duties of their subordinates
- Place employees on-call in case of emergencies
- Redistribute workload among available staff
- Retain the current shift and/or call in the next shift early

7.3.2. Emergency management

7.3.2.1. Emergencies

Emergencies are unplanned events that may have any number of adverse consequences (e.g., death, injury, disruption of normal operations). [21] Natural disasters and terrorist attacks often occur without warning. Even for events that can be predicted to some degree (e.g., a blizzard), the advanced warning is often short and the information imprecise. The most effective strategy is to plan well in advance for events that may occur in the future, and to execute the plan when the event occurs. This strategy requires organizational coordination, communication, and informed decision-making. Developing an operational plan for an emergency also often requires a high degree of coordination with other agencies.[4] For example, a blizzard may require the coordination of emergency medical services, police, and snow plow services. The first part of the staffing plan defines when the plan should go into effect.[2] Emergency procedures include the actions employees should perform. The emergency plan should specify training that will familiarize the staff with the alarm systems, emergency equipment, and the location of the equipment. The list below contains examples of external emergencies:

- Earthquakes
- Floods
- Hurricanes
- Tornadoes
- Woodland fires
- Winter storms
- Homeland security threats

Emergency actions also need to be formulated for emergencies that occur within the TMC.[22] The following list suggests events for which a staffing plan should specify the necessary actions to take and the proper authorities to notify about the event. The list below contains examples of internal emergencies:

- Communication loss
- Loss of power
- Fire
- Smoke
- Severe weather
- Flooding

7.3.2.2. Emergency planning

The Federal Emergency Management Agency (FEMA) has prepared a guide for business and industry on emergency management that covers how to prepare for, respond to, and recover from an emergency (http://www.fema.gov/pdf/library/bizindst.pdf).[23] The four step procedure for creating an emergency plan that is recommended by FEMA is summarized below.

The first step in planning for an emergency is to form a team that will write the emergency plan.[23] The support and leadership of upper level management is critical. The authority and the structure of the planning team should be defined along with the team's objectives. The team objectives should include a schedule that outlines a list of priorities and their planning deadlines. In addition, the planning team should be allocated a budget for research, printing, consulting services, and other related expenses.

The second step involves identifying the capabilities of the organization before an emergency occurs, potential hazards, vulnerabilities to the hazards, and the capabilities of the organization during the emergency.[23] Capabilities of TMCs include services provided to the public and the facilities and equipment required to deliver the services, services provided by outside vendors that support TMC operations, lifeline services within the TMC (e.g., electrical power, water, sewer, gas, telecommunications, and transportation), and any other remaining operations, equipment, or personnel that are critical to the continued operation of the TMC. Internal resources include personnel (e.g., employees), equipment (e.g., first aid kit, flashlights), facilities (e.g., first aid stations), organizational capabilities (e.g., evacuation plan), and backup systems (e.g., backup generator). Also consider external resources (e.g., fire department). Potential hazards can be determined by considering the types of emergency events that have occurred in the past, common events in the geographical location, events that the TMC is designed to handle, and events within the facility that could result from a technical or structural failure or from human error. Finally, the impact of each hazard on personnel, property, business, and all internal and external resources and capabilities can be determined.

The third step involves developing and writing the plan. An executive summary should summarize the work conducted as part of Step 1 and Step 2.[23] The core of the emergency plan should provide a detailed account of the work conducted in Step 2. In addition, a plan should be developed that outlines a comprehensive approach to the management of each emergency. Support documents (e.g., emergency phone numbers, maps, resource lists) should be included in the plan document. The emergency plan should also include a list of training activities and training schedules to familiarize employees with the emergency plan.

The fourth step involves the implementation of the plan.[23] Implementation of the plan includes building awareness of the plan, training employees to execute the plan, and testing and

evaluating the plan to ensure that the procedures will work under emergency conditions. Revisions should be made as necessary.

7.3.2.3. An example of an emergency plan

After the 2004 hurricane season, the Georgia DOT commissioned the Severe Weather Response Plan to provide a more proactive approach to managing severe weather events that affect the state's transportation system.[24] The plan was designed as a quick reference, stand alone document that did not supersede existing DOT policies and procedures, but instead clarified the communication and coordination between the TMC's four traffic management units: the Offices of Traffic Signal/Electrical Facilities, Intelligent Transportation Systems Engineering, the Highway Emergency Response Operators, and the NaviGAtor Operations Center. The plan covered all four organizational units, assigned responsibilities to appropriate stakeholders, and provided a consistent approach in an effort to improve the management of an emergency. Four severe weather events indigenous to Georgia were identified: hurricanes/tropical storms and depressions, rain/ice/snow/wind storms, tornados, and floods.

Four sources of information were used to write the plan.[24] First, existing response plans, memos, and other related documents used or referenced by pervious emergency management efforts for each of the four units were collected. Second, interviews were conducted with staff from all four units. Third, existing information and documents were collected, including training manuals, operations manuals, operations plans, and procedure manuals. Fourth, publicly available information from the National Atmospheric and Oceanic Administration and the National Weather Service was collected.

The plan defined hazards (e.g., roadway debris, power failure) that may result from the severe weather events.[24] Each hazard included a discussion of organizational units that could be affected, a description of the potential effects of the hazard, and key concerns. Next, the role of each organizational unit was outlined, including general responsibilities, personnel resources and responsibilities, equipment needs and responsibilities, communication responsibilities, and the organizational unit's impact on the other three organizational units. The response to an emergency event was divided into pre-event planning, event response, and post-even evaluation. The plan included explicit details about when an emergency event was declared. Typically, an emergency is declared by the Office of Maintenance; however, planning efforts may begin before an emergency is declared and emergency operation procedures may be enacted at the discretion of the State Traffic Operations Engineer. Reports from the National Weather Service often prompt initial emergency planning efforts.

The Appendices included an extensive list of contact information.[24] The list below outlines the contact information contained in the Severe Weather Response Plan.

Telephone listing for the Emergency Operations Center (To be copied and distributed to TMC personnel upon initiation of emergency procedures):

- Weigh Stations
- Rest Areas
- Area animal control and humane societies

- Utilities (emergency phone numbers)
- Frequently requested information
    - Department of Revenue/Local Tax Commissions (automobile tags)
    - DOT Office Planning (bicycle paths)
    - DOT Tollway Administration (cruise cards)
    - DMVS Dispatch (HOV violations)
    - Department of Motor Vehicle Safety (driver's licenses)
    - DOT District Traffic Ops (driveway permits)
    - Driver's License Facility (handicapped parking permits)
    - Public Service Commission (hazmat laws)
    - State Patrol Post/New DMVS (motor vehicle reports)
    - DOT – Right of Way (outdoor advertising)
    - DOT Overweight/Size Permit Office (overweight/size truck permits)
    - DOT Traffic Safety & Design (railroad crossing)
    - DOT Maintenance (rest areas)
    - DOT Map Sales (state maps)
    - DOT Traffic Courts (traffic courts for particular roads)
    - Department of Revenue (truck licensing IRP & IFTA fuel permits)
    - DOT Maintenance Office (wildflower program)
- Country/City emergency and nonemergency phone numbers
- Traffic Operations
- District Engineers
- State Patrol
- State Tollway Authority
- Radio Stations
- Other Important Numbers
    - Adopt-A-Highway
    - Airport Information
    - District Safety Officer (claims)
    - Driver's License Information
    - Suspended/Revoked License
    - State Emergency Management Agency/Office of Homeland Security
    - General Information
    - State Forestry Commission
    - Ground Transportation
    - Emergency Units
    - Impound (DOT)
    - Bus and Rail Information
    - Office of Communications
    - Permits
    - Public Service Commission
    - School Closing Information
    - State Information Directory
    - State Planning and Widening
    - Towing Service
    - Traffic Court

    - Travelers Aid
    - *TMC 888
    - Welcome Center
    - Map Sales
- District Information
    - District Engineer
    - Construction Engineer
    - Maintenance Engineer
    - Traffic Operations
    - State Review Coordinator
    - Technical Supervisor
- DOT Directory
    - Information
    - Road conditions
    - Court Map Sales
    - General Offices
    - Administrative Division
    - Construction Division
    - Credit Union
    - Materials & Research Laboratory
    - Operations Division
    - Planning and Programming Division
    - Pre-Construction Division
    - Permits
    - District Engineer
    - Administration
    - EEO/Training
    - Construction
    - Contract Administration
    - Maintenance-State Highways
    - Pre-construction
    - Traffic & Safety
    - Utilities
- 911 Centers by interstate exits
- Wrecker Services by interstate exits
- Airport phone numbers
- Airline phone numbers
- Surrounding state information and contact information

7.3.2.4. Additional resources on emergency planning

In addition to the FEMA emergency planning guide, the American Red Cross (http://www.redcross.org/services/disaster/0,1082,0_606_,00.html), the Occupational Safety & Health Administration (http://www.osha.gov/SLTC/etools/evacuation/index.html), and the Institute for Business & Home Safety (http://www.ibhs.org/docs/openforbusiness.pdf) also provided information and tools for emergency preparation.

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Appendix A: Arizona TMC Case Study

The purpose of Appendix A is to review aspects of the design and operation of a specific TMC. The Arizona TMC was envisioned as a central point for statewide transportation management operations, and included a variety of partnerships with other national, state, and local government agencies (e.g., police and fire departments, Arizona DOT HAZMAT) and nongovernment agencies (e.g., media).[1,2] The TMC has an administrative unit, a project development unit, and a unit that maintains the day-to-day operations of the TMC (see Figure A.1). The TMC Manager, Administrative Services Officer, and ITS Project Development Engineer report to the Assistant State Engineer (i.e., ITS Project Manager). The TMC Manager oversees operations, traffic analysis, and information technology. The Traffic Analysis section is staffed by Transportation Engineering Specialists who are responsible for adjusting the ramp meter timings and complete monthly incident reports.

The TMC performs three primary functions: Incident Management, Traffic Management, and Traveler Information Update.[1,2] The TMC is in operation 24 hours a day and 7 days a week. Each day has three shifts: morning (6:00 am to 2:00 pm), evening (2:00 pm to 10:00 pm), and night (10:00 pm to 6:00 am). Operators and shift supervisors are required to arrive in the control room 5 to 10 minutes before their shifts start to receive a briefing from the previous shift. Operators are allotted one 5 minute break every hour and a 15 minute break that may not be added to another break every shift. Breaks may not be used to arrive late or leave early. To cover the functions and hours of service, operations included the following staffing levels:

- Full-time state employees
    - 1 Operations supervisor
    - 3 Operations shift supervisors
    - 9 Operators
- Part-time students and interns
    - 3 Operators per shift

During each shift a minimum of two people must be on duty, and one of them should be a full-time, certified operator (see Appendix B for the certification test).[1] Arizona also uses interns to help staff the operator positions. Interns work the same 8-hour shifts as full-time operators. When school is in session interns are limited to working 3 shifts per week (24 hours per week) instead of the typical 5 per week (40 hours per week). Interns must be accompanied by at least one full-time employee when working in the control room. In some cases, the requirement for having at least one full-time, certified operator on duty may be waived on the weekend if attempts to find additional full-time, certified operators have been exhausted and one of the noncertified operators possesses an extensive amount of experience.

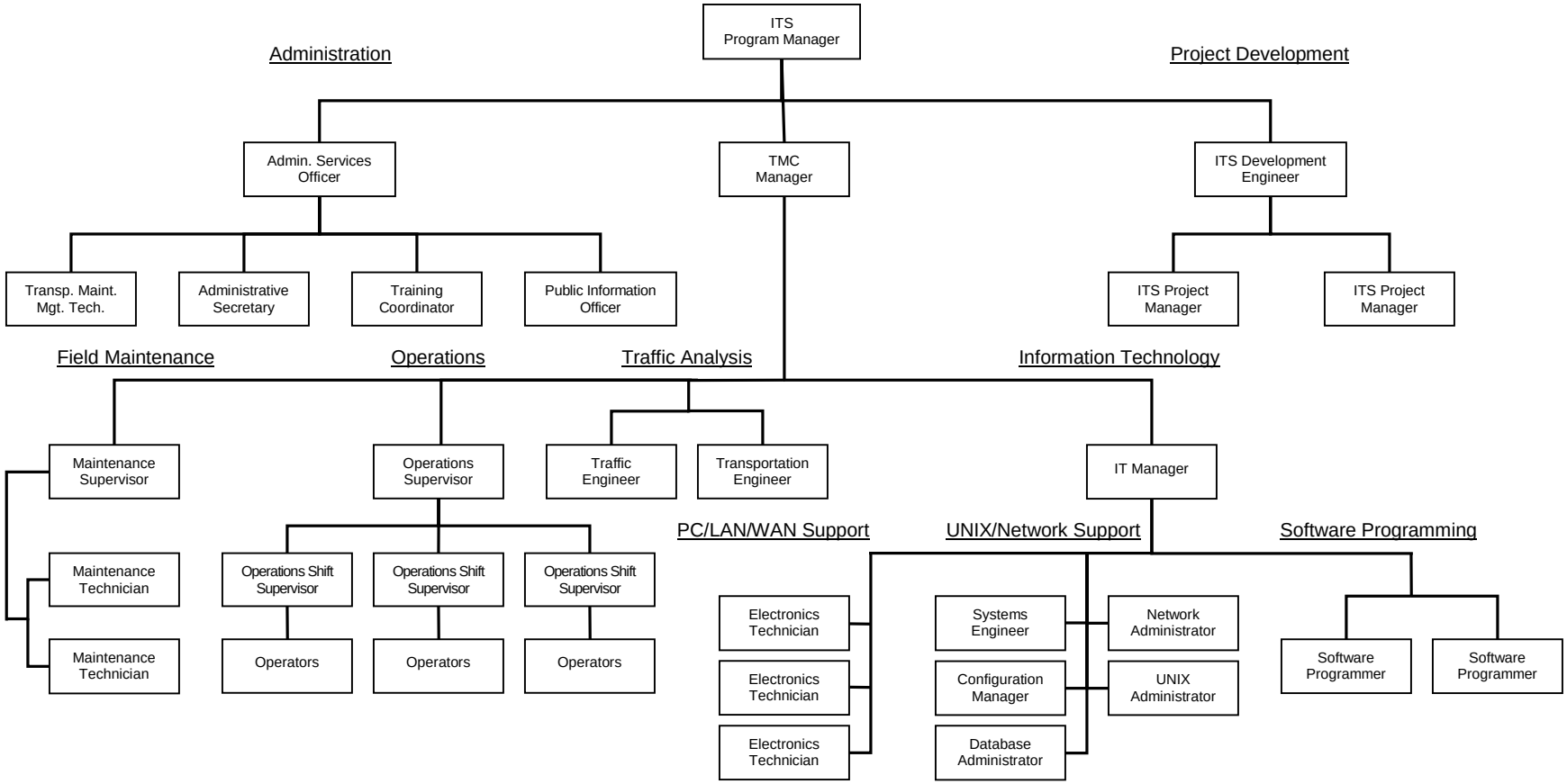

Figure A.1. Arizona Department of Transportation Organizational Chart
(Adapted from reference 1)

There should also be at least one shift or operations supervisor on duty or on callback at all times (see Appendix C for the certification test for shift supervisors).[1,2] Supervisors are responsible for scheduling, training, and certifying their employees and for creating staffing plans, conducting performance appraisals, approving leave, and making other personnel decisions. Schedules are posted on Friday by 10:00 am for the next week and include all leave and training times. In general, shift supervisors handle scheduling arrangements within their shifts, and the operations supervisor has final authority over the schedules and resolves scheduling problems between shifts.

As is typical among service operations, personnel costs account for the single largest expenditure of the Arizona TMC budget (see Figure A.2).[2] Furthermore, training costs have been listed as a separate item. The costs involved with personnel relative to other budget items support the importance of effectively staffing and scheduling TMCs.

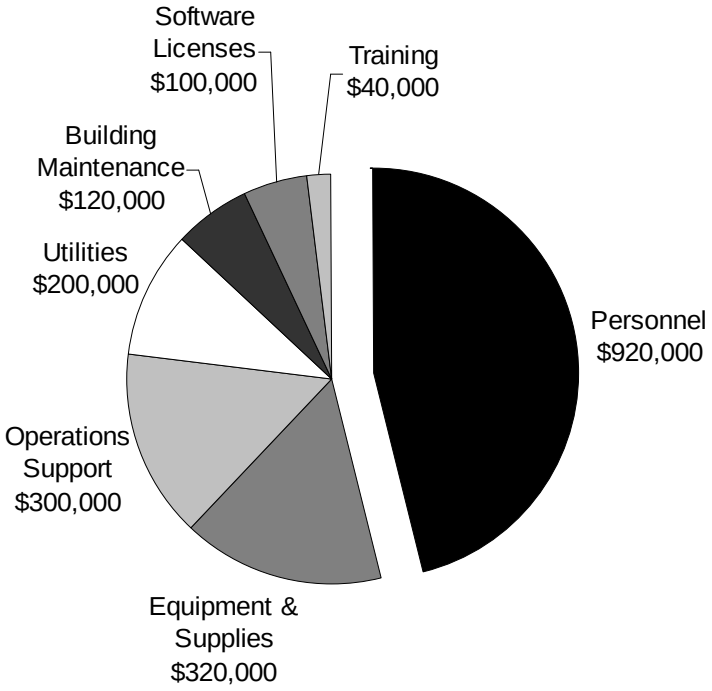

Figure A.2. Annual Costs
(Adapted from reference 2)

A couple of aspects of Arizona's facility stand-out.[2] First, the TMC has four operator workstations and one training workstation in the control room. As a result, the TMC can not staff more than four operators unless alternative arrangements are made (e.g., use the training workstation, use a temporary workstation) or the center is renovated. Second, the operations staff's offices are closest to the control room, which facilitates communication between operators and supervisors.

Appendix A references

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Appendix B: Operator Certification Test

Operator Name:		Date Demonstrated	Operator Initial	Supervisor Approval
TELEPHONE ETIQUETTE				
	Telephone Greeting			
	Transfer a Call			
	Handle Citizen Complaints			
	Cell Phone			
	Panasonic Backup Phones			
	Fire Ring-Down Phone			
	Meridian Phones			
SIGN-IN PROCESS				
	Beginning of Shift			
	Log-in PC			
	Open Control Room Folder			
	Open HCRS & Internet			
	Check Open Incidents			
	Open Rural or Metro Mercure			
	Open ICON System			
	Open PageGate Paging Screen			
	Check VMS Schedule			
	Start Shift Log/Sign off on Previous Shift Log			
	Read E-Mail			
	Check Weather Maps			
	Road Closure Faxes			
CAMERAS				
	Rural Console/Tucson Cameras			
	Metro Console/Tunnel Cameras			
	Tour Through Cameras/Face away from sun.			
	Report Failures			
	Add Direct TV Channel to Console Monitor			
	Change Camera on Video Wall			
	Check Presets			
VMS				
	Location of all VMS & Maps			
	Sign Selection			
	Edit Text			
	Edit Display			
	Display New Message			
	Display Library Message			
	Activate Multiple Messages at One Time			
	Blank Message			
	Blank Multiple Messages at One Time			

OPERATOR CERTIFICATION TEST

Operator Name:		Date Demonstrated	Operator Initial	Supervisor Approval
VMS Continued				
	Monitor Sign Status			
	Report Failures			
OPERATOR CONSOLE				
	Identify/Explain Elements			
	Loop Detectors			
	CCTV Systems			
	Proper Use of Cameras			
	VMS Purpose			
	Traffic Signals			
	Report failures			
	EAS			
	DPS Pager			
PAGEGATE SYSTEM				
	How to access the system			
	How to create a message			
	How to send a message			
	View sent messages			
	View failed messages			
	PageGate Paging Binder			
	Call Groups			
	ALERT Groups			
	ADOT Admin. Major			
OUTLOOK SYSTEM				
	TOC AMBER ALERT Paging Group			
	TOC (Phoenix Camera & VMS Repair)			
	TOC (Rural Camera & VMS Repair)			
	TOC (Operators)			
	TOC (SE Group)			
TABLE OF ORGANIZATION				
	Traffic Operation Center			
	Maintenance Orgs.			
	Construction Orgs.			
	Landscape Orgs.			
	Districts			
	Administration			
	Org Chart-TTG			
RADIO				
	800 MHz			
	Talk Groups			
	What is different about 800 series?			
	VHF			
	Talk Groups			
	Activity Log on Screen			
	Patch two channels and verify communication.			
	Rebooting the System			

OPERATOR CERTIFICATION TEST

Operator Name:		Date Demonstrated	Operator Initial	Supervisor Approval
CALL-OUT NOTIFICATION				
	Questions for DPS			
	Milepost/Direction/Route			
	Size of Spill			
	Cattle in the Area			
	What lanes/ramps, etc. are to be closed			
	Estimated Duration			
	In construction zone?			
	Injuries			
	Call out Procedures			
	Who is on call-back?			
	District Differences			
	How to notify			
	Haz/Mat Notification			
	Cable Damage Notification			
	Snow Procedures			
	Locate Snow Plans			
	Identify Road condition			
	Snow Codes			
	When to refer			
	Which Org is in field			
	Snow Desks			
	Immediate notification items			
	Stop Sign Down			
	Light Pole Down			
	Guard Rail Damaged			
	Crash Barrels/Barricades			
	Right of Way w/Cattle			
	Red Traffic Signals			
ESCALATION PROCESS				
	Maintenance Districts			
	Construction Districts			
	Signs/Striping Groups			
	Troubleshooter Groups			
STRUCTURE HITS				
	Statewide Notification			
	Phoenix Metro Notification			
	Bridge Group Notification			
STATEWIDE ITS MAINTENANCE EQUIPMENT				
	Escalation of Notification			
	Who to notify for:			
	VMS			
	Cameras			
	Field equipment			
	Call-back procedures:			
	Identify problem			
	Notify person on call back			
	When to Notify supervisor			

OPERATOR CERTIFICATION TEST

Operator Name:		Date Demonstrated	Operator Initial	Supervisor Approval
I-10 DECK/TUNNEL				
	Log on to Wonderware System			
	PLC System			
	Describe Critical Alarms/Procedures/Resetting			
	Ventilation System			
	Start/Stop Fans			
	Fan Pitch			
	Low/High Speeds/Procedures			
	Lighting			
	Lane Indicators for Lane Closures			
	Step up/Down Lights			
	During Tunnel closures			
	Step up Fans			
	Step up Lights			
	Monitor Closure			
	Who/When to Notify			
RWIS				
	Open Internet			
	Open RWIS			
	Open Tabular List			
	Show All			
	Verify all cameras at all RWIS sites are current			
	Print RWIS List			
	Highlight problems on printed report			
	Close Internet			
BUILDING EQUIPMENT				
	Control Room			
	PC Repair			
	Metro & Rural VMS Repair			
	Printers			
	Monitors			
	HCRS/511			
	Internet			
	Gate			
	Air/Heat			
	Lighting			
	FAX			
	Alarm System			
	Doors			
	Generator			
	Halon System			
	Power Supply			
	Alarms in Equipment Rooms			
	Camera Cameleon			
	ICONS System			
	PageGate			
	Motorola Radio			
	Truck Escape Ramp Computer			

OPERATOR CERTIFICATION TEST

Operator Name:		Date Demonstrated	Operator Initial	Supervisor Approval
HCRS/511				
	Sign on			
	Create an Entry			
	Choose Type of Highway			
	Route Number			
	Direction			
	Milepost			
	Nearest Crossroad			
	ITIS Code			
	Duration			
	Restrictions			
	Public Notes			
	Internal Notes			
	Priority			
	Continuous/Recurring			
	Check Your District's HCRS Entries			
	Create Test Floodgate			
	Which entries go into 511?			
	Which entries are visible on Internet?			
HCRS/HIM				
	Event ID Number			
	Incident Type			
	ITIS Category			
	ITIS Description			
	Level of Severity			
	Freeway			
	Nearest Cross Street			
	Additional Information			
	Reporting Party			
	Radio/Tele. No.			
	Injuries			
	Fatalities			
	Lanes Blocked			
	Type of Vehicle			
	Notes:			
	How to create			
	How to edit			
	Confirm			
	What happens/Time Stamps			
	Monitor the Incident			
	Update an Incident			
	Response Time/Response on Scene			
	Incident Cleared/Incident Closed			
	Terminate an Incident			
	Print Incident Report			

OPERATOR CERTIFICATION TEST

Operator Name:		Date Demonstrated	Operator Initial	Supervisor Approval
AMBER ALERT				
	Explain procedure for Amber Alert			
	Floodgate			
	Create and remove test messages on 511 (verbal & typed messages)			
	511 Verification			
	Outlook and PageGate Paging			
	VMS			
	EAS			
	E-mail Notification			
	Steps to clear the alert.			
TOUR PROCEDURES				
	PIO			
	Tour Calendar			
AZTECH				
	Location of TMCs			
	Location of TMC Cameras			
	ADOT Video Access			
TRAINING				
	Monthly Training Schedule from HR			
	Where to Direct Insurance Questions			
	Where to Direct Training Requests			
	BTS/Pecos/Procedures			
	How to Obtain FEMA Training			
MANDATORY 6 MONTHS YEAR TRAINING				
	New Employee Orientation (NEO)			
	Computer Security Awareness			
	Ethical Issues			
Every 5 years	Cultural Diversity			
Every 5 years	EEO, AA, ADA			
Every 5 years	Preventing Sexual Harassment			
	Fire Safety			
OPERATOR QUARTERLY CERTIFICATION TEST				
	Completion of Operator Quarterly Certification tests as assigned.			
	Date of Last Test			
BY THE END OF THE 6TH MONTH				
	One shift with DPS dispatch			
	One shift riding with roadway maintenance			
	One shift riding with landscape or construction maintenance			

Appendix C: Shift-Supervisor Certification Test

Shift Supervisor Name:		Date Exhibited	Shift Supervisor Initial	Supervisor Approval
SKILLS				
	Have a Certificate as a TOC Operator			
	And:			
	Locate all districts by name in			
	State on Map of Arizona			
	Locate Troubleshooters and sign /			
	striping technicians' regions.			
KNOWLEDGE				
	Know which Orgs belong to which Districts			
	Know Traffic Operations Policy for**:**			
	Customer complaint resolution			
	Variable Message Sign usage			
	Read, know where to find:			
	Statewide ITS Strategic Plan			
	Know policy exists, where & how to find it			
	ADOT Policy/Procedures for:			
	Leave Policy - *R2-5-401*			
	Holiday - *R2-5-402*			
	Conduct - *R2-5-501*			
	Scheduling - *PER - 4.02*			
	Overtime - *PER - 8.05*			
	Ethics - *PER - 9.02*			
	Grievance - *PER - 9.01*			
	Safety - *SAF - 1.01*			
	Procurement - *SUP - 3.03*			
	Travel - *FIN - 6.02*			
	BTS/PECOS - *FIN - 10.05*			

Appendix C: Shift-Supervisor Certification Test

Shift Supervisor Name:		Date Exhibited	Shift Supervisor Initial	Supervisor Approval
RESPONSIBILITY				
	Manage Shift Personnel			
	Set shift schedule			
	Process leave and OT requests			
	Monitor training needs for all shift personnel, complete forms and schedule mandatory training.			
	Ensure all operators are certified within six months of hire.			
	Submit training requests to Training Officer.			
	Provide Operator Orientation: Review Binders Org Charts Leave Policy Acceptance Tests Log On Process for New Operators Staffing Guidelines Rules/policies Shift Logs Web-gate Paging System			
	Receive/review and comment on employee grievances.			
	Prepare EPAS Planners			
	Prepare EPAS Score Form			
	Review Incident Reports			
	On a bi - weekly basis – review TOC Operator Certification Tests for new operators on your shift.			
	Conduct Training			
	Operator training for FMS			
	HCRS training			
	ADOT radio training			
	Incident handling training			
	VMS Training			

Appendix C: Shift-Supervisor Certification Test

Shift Supervisor Name:		Date Exhibited	Shift Supervisor Initial	Supervisor Approval
	Other Duties			
	Visit a district once each year			
	Assist PIO with customer complaints /resolution			
	Review Operations Manual –report			
	Suggest changes to Supervisor			
MANDATORY 6 MONTHS SUPERVISOR TRAINING				
4 hrs - every 3 years	EEO/AA for Supervisors and Managers			
3 hrs	Substance Abuse Awareness			
4 hrs	Preventing Violence in the Workplace			
4 hrs	Operational Management			
2 days	Personnel Actions & Selection Interviewing			
8 hrs	Performance Management			

Glossary of Terms

Definitions have been provided for technical terms used in the technical document that may be unfamiliar to the intended audience. Sources for definitions that were adapted or taken directly from sources are cited with the definition.

ability. A relatively enduring intellectual, physical, or sensory capability.[2,3]

action plan. A part of a **staffing plan** that includes a list of human resource activities the organization plans to perform.

acyclic schedule. A scheduling system without a fixed pattern of **shift** assignments that requires the generation of a new employee schedule over each **planning horizon**.[4]

aggregate planning. A **staffing plan** for groups of employees in specific, typically lower-level **jobs**.[5]

attention. The general allocation of sensory-perceptual resources (possibly involving motor functions) to a subset of possible inputs.[1]

caffeine. A chemical constituent of some food products that causes elevated neural functioning and may affect behavior.[1]

circadian rhythm. A biological rhythm with a period of about 24 hours.[1]

composite task. A set of one or more related **discrete tasks** that support a given TMC **function**. Composite tasks are associated with general goals.[2]

compressed operation. A type of **continuous** or **discontinuous operation** that allows employees to work longer than 8 hours per day and less than 5 days per week.[4]

continuous operation. An operation that maintains service or production 24 hours a day and 7 days a week.[4]

cortisol. A hormone that promotes waking.[6]

days-off scheduling algorithm. A set of directions that assign employees to a weekly schedule based on the number of employees required each day.[7,8,9]

default task allocation principles. General guidelines for assigning **tasks** to employees.[1]

demand analysis. A collection of techniques used to predict future levels of demand for goods or services to determine employee scheduling or staffing requirements based on past levels of demand or related variables.[9]

demand modification. A strategy that is used to influence consumers and their demands for services.[9]

department scheduling. A method of schedule administration that involves an appointed manager generating and implementing a work schedule for a group of employees.[10]

discontinuous operation. An operation that includes a break in service or production. In a discontinuous operation employees do not work either 24 hours a day or 7 days a week.[4]

discrete task. One element of a set of related **tasks** required to accomplish a **composite task**. Discrete tasks are specific work objects, typically short in duration, that are the most basic, yet meaningful elements of work.[2]

divided attention. The form of **attention** required when an operator must perform two or more concurrent **tasks**.[1]

dynamic task allocation principles. Guidelines for assigning **tasks** to employees when more than one employee in the same **job** is on duty at the same time.[1]

economic standards. Standards that establish criteria for delivering services in the most economical method feasible.[11]

error. An inappropriate response by a person or system.[1]

fatigue. A state associated with low energy, motivation, and productivity, generally caused by physical or mental exertion.[1]

fixed schedule. An employee scheduling system that maintains a consistent pattern of **shift** assignments over a long or indefinite time period.[4] Fixed schedules may assign employees to dedicated **shifts**, with each employee working the same times and days each week, or to a schedule that rotates in a repetitive, cyclic pattern.

flexible schedule. See **acyclic schedule**.

focused attention. See **selective attention**.

function. A capability or ongoing activity of a TMC that contributes to the accomplishment of the TMC's mission.[2]

gap analysis. A collection of techniques used to reconcile the differences between the results from a **demand analysis** and a **supply analysis**.[12,13]

individual differences. Known or estimated distributed variations in physical or mental performance variables.[1]

job. A collection of similar **positions** grouped together (e.g., administrative assistant).[3]

job analysis. A collection of methods that are used to determine the elements of work (i.e., **tasks**) and the attributes required by employees to perform the work successfully.(3)

knowledge. The specific information necessary for employees to perform their **jobs**.(3)

long-lived actions. Large real-time adjustments to a schedule that have a big effect on changing service output.(14)

mean absolute deviation. The average difference between the predicted demand and the actual demand.(15)

mean absolute error. See **mean absolute deviation**.

mean forecast error. The sum of the difference between the actual and forecasted demand divided by the number of time periods included in the calculation.(15) The mean forecast error is used to diagnose bias in a demand model.

mean square error. The average of the squared deviations of the differences between the forecasted demand and the actual demand.(15)

melatonin. A hormone that promotes sleep.(6)

peak load. The maximum rate or capacity that a system or component is designed for or is able to perform or support.(1)

planning horizon. The length of time that a plan extends into the future.(16)

position. A collection of **tasks** performed by one employee.(3)

productivity standards. Standards that establish performance targets for employees to complete **tasks** consistently and in a certain amount of time.(11)

regression analysis. A set of statistical techniques that examines the association between variables or factors.

running sum of forecast errors. The sum of the difference between the actual and forecasted demand.(15) The running sum of forecast errors is the numerator of the **mean forecast error**.

scheduling efficiency. A calculation that determines the theoretical amount of slack time employees will experience given certain scheduling requirements.(9)

selective attention. The **ability** to continuously or willfully focus on a restricted set of desired inputs while excluding other concurrently impinging sets.(1)

self-scheduling. A method of schedule administration that involves a group of employees generating their own work schedule.[10]

service standards. Standards that establish criteria for consistent service for consumers.[11]

shared task allocation principles. Guidelines for assigning **tasks** to groups of employees or teams.[1]

shift. The basic unit of a scheduling system that comprises of the hours in a 24-hour period that an employee is scheduled to work.[4]

shift-scheduling algorithm. A set of directions that assign employees to **shifts** with variable start times within a work day.[7,8]

shiftwork. Any type of employment that includes working hours outside of the traditional day work **shift** from about 7 am to 10 pm on a regular basis.[6]

short-lived actions. Small real-time adjustments to a schedule that have a small effect on changing service output.[14]

simple moving average. A data analytic technique that smoothes raw demand data by imputing a measure of past demand with the mean of the data centered over a specific time period and several adjacent time periods.[15]

skill. Proficiencies in performing **tasks** such that requirements for accuracy, latency, timeliness, or quality are met consistently.[2,3]

solution analysis. A collection of techniques used to resolve the differences between the results from a **demand analysis** and **supply analysis** found in a **gap analysis**.[12,13]

staffing plan. A plan that often includes human resource planning and possible actions in preparation for future events and immediate action items that address existing human resource needs.[17]

stakeholder. An individual who has an interest or stake in the object under consideration.

stress. The collective mental and physical conditions resulting from when an individual experiences one or more biomechanical, physiological, or psychological stressors beyond a comfortable level.[1]

subject matter expert. An individual who is knowledgeable and/or experienced on a specific topic of information and can serve as a competent source on the topic.[3]

subjective methods. A set of methods that elicits information from **stakeholders**.

succession planning. A **staffing plan** for critical, typically higher-level **positions**.[5]

supply analysis. A collection of techniques used to identify internal and external sources of human resources.[12,13]

sustained operation. A type of **continuous operation** that allows employees to work as long as possible, typically longer than 12 hours per day, to maintain a "nonstop" work rate.[4]

synchronization. The adjustment of the circadian system to time cues in the environment.[18,19]

task. The most basic, yet meaningful, element of work.[2,3]

task allocation. A set of principles used to ensure the optimum assignment of work activities to employees.

task complexity. A characteristic of a **task** that is often based on the number of subtasks and their individual and aggregate difficulties.[1]

task difficulty. A characteristic of a **task** that is often based on the likelihood of an **error** occurring during task performance.[1]

task-oriented job analysis procedures. A **job analysis method** that is used to determine the elements of work performed by an employee.[3]

team scheduling. A method of schedule administration that involves sets of employees electing team leaders to oversee scheduling decisions.[10]

weighted moving average. A data analytic technique that smoothes raw demand data by imputing measures of past demand with the mean of the data centered over the specific time period.[15] Weights are assigned based on proximity in time to the imputed data period.

work analysis. A generic term that includes a set of methods used to examine different aspects of **jobs**.

worker-oriented job analysis procedures. **Job analysis** methods that are used to determine the characteristics of employees required for successful completion of work **tasks**.[3]

workforce plan. A more extensive **staffing plan** used by larger organizations with multiple units is several geographical locations.

workload. An indicator of the level of total effort required to carry out one or more **tasks** at a specific performance level.[1]

workload analysis. A method used to examine aspects of a work system to ensure that employees are capable of performing the work.

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