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Manpower and Organization

MANPOWER AND ORGANIZATION STANDARD WORK PROCESSES AND PROCEDURES

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This manual implements Air Force Instruction (AFI) 38 201, *Management of Manpower Requirements and Authorizations*, by providing guidance for determining manpower requirements. This manual applies to all military and civilian personnel in the Regular Air Force, Air National Guard (ANG), and Air Force Reserve. Ensure all records created as a result of processes prescribed in this publication are maintained in accordance with Air Force Manual 33-363, *Management of Records*, and disposed of in accordance with the Air Force Records Disposition Schedule located in the Air Force Records Information Management System. Refer recommended changes and questions about this publication to the Office of Primary Responsibility (OPR) using the AF Form 847, *Recommendation for Change of Publication*; route AF Forms 847 from the field through the major command (MAJCOM) functional managers. This publication may not be supplemented or further implemented/extended. The authorities to waive wing/unit level requirements in this publication are identified with a Tier ("T-0, T-1, T-2, T-3") number following the compliance statement. See AFI 33-360, *Publications and Forms Management*, for a description of the authorities associated with the Tier numbers. Submit requests for waivers through the chain of command to the appropriate Tier waiver approval authority, or alternately, to the requestor's command for non-tiered compliance items. The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the Air Force.

SUMMARY OF CHANGES

This publication has been substantially revised and needs to be completely reviewed. Major changes include removal of rescinded forms, updated terminology, new management engineering process, and consolidation of AFMAN 38-208 Volume 1, *Air Force MEP—Processes*, Volume 2, *Air Force MEP—Quantification Tools*, and Volume 3, *Air Force MEP—Logistics Composite Model* into one manual.

Chapter 1

MANAGEMENT ENGINEERING PROGRAM OVERVIEW

1.1. Philosophy. The Manpower and Organization (M&O) function has four core competencies: (1) Requirements Determination, (2) Manpower Program Allocation and Control, (3) Organization Structure, and (4) Performance Management. These four competencies form the basis for all M&O activities. Specifics regarding the core competencies can be found in their applicable AFIs as referenced below.

1.1.1. Requirements Determination. M&O analysts assist senior leaders, commanders and functional managers, at all levels, in mission accomplishment by objectively quantifying manpower requirements for the distribution of Air Force manpower resources. Key services of this competency include peace-time manpower determinants development and wartime manpower requirements. Integral in any manpower requirements determination effort is a review of a function's processes with the goal of making process improvements as described in Chapter 2. Roles and responsibilities are outlined in AFI 38-201, Management of Manpower Requirements and Authorizations.

1.1.2. Manpower Program Allocation and Control. Concepts and performance guidance are provided in AFI 38-204, Manpower Programming.

1.1.3. Organization Structure. Concepts and performance guidance are provided in AFPD 38-1, Organization and Unit Designations, and AFI 38-101, Air Force Organization.

1.1.4. Performance Management. Performance Management is the Air Force's construct for a continual performance improvement system that focuses on mission accomplishment. Guidance is provided in AFI 38-401, Continuous Process Improvement.

1.2. Purpose of the Air Force MEP. The Air Force MEP provides the foundation for executing all M&O core competencies and helps senior leaders, commanders and functional managers improve productivity through the use of performance improvement techniques and procedures. The MEP provides the framework for developing Air Force Manpower Determinants (AFMD), MAJCOM-unique manpower determinants, and for providing products and services.

1.2.1. Team Approach. MEP and functional personnel build cohesive teams to reach study objectives and achieve productivity improvement goals. Formal study charters outline specific study objectives and responsibilities for all team members to work together to meet those objectives.

1.2.2. MEP Methodology. MEP methodology is built utilization performance improvement techniques.

1.2.2.1. Performance improvement. Takes a systematic look at a function to identify processes for potential improvement. Outcomes, outputs (products and services), processes, capital equipment, facility layout, customers, and suppliers are identified as part of a process improvement.

1.2.2.2. MEP Organization. Headquarters (HQ) United States Air Force (USAF/A1) gives program direction through related policy. The Air Force Manpower Analysis Agency (AFMAA) develops tools and techniques to carry out policy and furnishes MEP customer-related technical support. Analysts at all levels will implement the MEP**. (T-2)**

1.3. General Roles and Responsibilities.

1.3.1. Air Force and major command (MAJCOM) OPRs continually evaluate functions to determine the need to update or request development of a requirements determinant. This includes process changes, opportunities for process improvement, organization and mission changes, as well as indicators from Air Force management information systems.

1.3.2. ME analyst will manage and lead study efforts for requirements determinant development. **(T-2)**

1.3.2.1. Facilitate identification of on-site familiarization location(s), complete preliminary research, develop study plan, facilitate study workshop(s), develop Standard Work Document (SWD), and develop and staff requirements determinants.

1.3.2.2. Staff final results with appropriate functional office and AFMAA.

1.3.3. Functional personnel are the process owners of a function and make policy decisions. Functional personnel commit to study efforts for the duration and coordinate on study products. ME analyst and functional personnel partner with the appropriate OPR to accomplish performance improvement studies.

1.3.3.1. Formally announce study efforts to the field and communicate senior leadership commitment.

1.3.3.2. Provide a dedicated Air Force-level functional lead to partner with ME analyst during requirements determinant process.

1.3.3.3. Functional personnel will partner with ME analysts to

1.3.3.3.1. Appoint subject matter experts (SME) to serve as study team members.

1.3.3.3.2. Ensure appointed team members and SMEs participate in all workshops facilitated by ME analyst.

1.3.3.3.3. Identify the on-site familiarization location(s), complete the preliminary research worksheet, coordinate on the study plan, and participate in study workshop(s) to develop the SWD.

1.3.3.3.4. Ensure appointed team members and SMEs participate in all workshops facilitated by ME analyst.

1.3.3.3.5. Review and validate workload data as required by the study team.

1.3.3.3.6. Ensure all functional process outputs are identified and quantified.

1.3.3.3.7. Ensure process improvements are tested as needed.

1.3.3.3.8. Staff SWD through Air Force Functional leadership.

1.3.4. AFMAA will approve and post requirements determinants applicable to the Active Component, whether applicable to multiple commands, a single command, or a single location. **(T-2)**

1.3.5. NGB/A1M and Air Force Reserve Command (AFRC)/A1M will approve manpower determinants affecting the ANG and AFRC units, respectively. **(T-2)**

1.3.6. MAJCOMs perform process improvement studies for MAJCOM-unique functions.

1.4. Documentation Requirements. This publication contains examples and formats of various documentation requirements. These are referenced in the applicable section.

Chapter 2

REQUIREMENTS DETERMINANT DEVELOPMENT PROCESS

2.1. General Concepts. The goal of requirements determination is to develop a means of quantifying manpower requirements. Determinants may cover a wide variety of products including but not limited to: manpower assessments, manpower advisory study, manpower determinants, and models. It incorporates manpower requirements development processes with a strong emphasis on process improvement. Resource requirements reflected in a manpower determinant should be based on a function's processes which most effectively and efficiently accomplish the mission. Improving mission effectiveness and efficiency should be the goal of any modification to a function's current process. Efficiency does not necessarily mean decreasing resources, but rather improving the return on the resources used.

2.1.1. Manpower Assessments. Assessments are special efforts or initiatives, which serve a useful purpose in evaluating required manpower when formal determinant development is not feasible. Due to their situational application, assessments may or may not follow the discipline or rigor of the more formal manpower determinant development process. All measurement and analysis methods and tools employed for developing a formal manpower determinant are appropriate for use in accomplishing these assessments.

2.1.1.1. Assessments are used to address a wide range of special situations and comprise varying levels of effort, depth, scope, and applicability. They are appropriate when a lack of experience with new systems makes a formal manpower determinant impractical; when a determinant would be short-lived due to a system that is approaching phase-out; when determining the initial impact of a new mission; or when there is a need to provide commanders or managers assistance in rapidly evaluating manpower-related issues. Assessments are also conducted to determine the manpower needs of an Air Force level-of-effort or a level-of-capability function, such as a management HQ entity. The results of this type of effort are documented in a report, which addresses the specific situation and the needs of the requester. The report may define manpower or man-hour requirements as a "snap-shot" in time, but not necessarily provide a mechanism to determine or predict future manpower needs.

2.1.1.2. A man-hour assessment is conducted when only a portion of a function or work center is being evaluated. The resulting man-hours are added or removed from man hours normally earned by the work center before whole manpower needs are determined. The determination of total manpower needs is usually outside the scope of a man-hour assessment.

2.1.1.3. A manpower assessment is performed when an entire function or work center is within the scope of the effort and documents the total requirement.

2.1.2. Management Advisory Service. Management advisory services offer the functional manager or commander a wide range of consultant services. These services are provided to enhance productivity and improve mission performance.

2.1.2.1. Air Force MEP personnel perform these advisory services in a "client–consultant" relationship, and recommendations are released and/or implemented at the discretion of the client. A management advisory study (MAS) shall not be used as a method to quantify manpower. A MAS is used to provide advice**. (T-2)**

2.1.2.2. The results or findings of a MAS may indicate the need for a follow-on manpower assessment or a determinant development. Detailed information on conducting a MAS is provided at **Chapter 27.**

2.1.3. A manpower determinant is the basic tool used to determine the minimum level of manpower required to support a function. It is a quantitative expression representing a work center's man-hour requirements in response to varying levels of workload and serves to predict future manpower requirements. Manpower determinants are grouped into the two categories of single-location and multi-location.

2.1.3.1. Single-location determinants are developed from data collected at only one installation. Unique missions, differences in operations, facilities, etc., may necessitate development of a single-location determinant when the study team determines further analysis is warranted and the development of a variance is not practical in a multi-location study. A caution regarding single-location determinant development is the lead only has one input and, therefore, is unable to compare process flow and measurement data with other locations. To ensure the validity of the results, all data is thoroughly examined to ensure it is reasonable, logical, and accurate. The use of more stringent work measurement techniques (e.g., time study or work sampling (WS)) and more advanced tools (e.g., simulation) should be considered. Similar or related activities are normally grouped into what is called a "work center." Work centers represent homogeneous groups of related job responsibilities and tasks. These tasks or processes are accomplished by people working together and normally in close proximity to one another and identified in a single Functional Account Code (FAC). Approved organization structures are based on this concept. However, while current organizational lines provide logically defined work centers, this may not ensure economy. Therefore, existing organizational segments can be combined or divided, for work measurement purposes, if the result is a more economical and accurate determinant.

2.1.3.2. Multi-location determinants are based on data collected from two or more installations. The multi-location is preferred over single-location determinants because of application to more than just one location and, thereby, providing a higher return on the resources invested in the study.

2.1.3.3. An organization or function with many small work centers could have excessive over specialization and overhead manpower positions. Work centers should be consolidated to the maximum extent practical to avoid the mathematical rounding-up of multiple fractional manpower requirements resulting from the application of too many manpower determinants.

2.1.3.4. Examples of functions where work center consolidation would be appropriate are section or unit-level activities grouped under branch-level activities, where centers are manned with personnel of the same Air Force Specialty (AFS), and managed by a single individual.

2.1.4. AFMD Process. The manpower determinant process determines a function’s total monthly man-hours-to-workload relationship, and quantifies the minimum manpower required to perform required work. The SWD is used to enhance analysis and process improvement; it documents a production-oriented type work center's processes and resulting outputs to include all other ancillary work. A functional statement is developed and used for directed-requirement positions and non-production type work centers (e.g., for work centers without identifiable inputs and outputs, e.g., staff functions and minimum manpower situations). A function or work center's required monthly man-hours are ultimately converted to full-time equivalents (FTEs) by using the appropriate monthly man-hour availability factor (MAF) with overload factor (when applicable). Refer to AFI 38-201 for additional information on the overload factor.

2.1.5. Deliverables. The AFMD process can be broken into three deliverables: Study Charter, SWD, and AFMD. The purpose of these deliverables is to establish quality control points and to provide standardized products during the determinant process.

2.2. Familiarization. Familiarization determines the information needed to design and conduct the manpower determinant development study. As Familiarization progresses, the study lead should already be considering many of the topics discussed in functional research (e.g., best study approach, best measurement method(s) and techniques, proper work classification, special work requirements, the number of required measurement locations, potential outputs, work units (WU) and/or workload factors (WLF)).

2.2.1. Preliminary Research. Prior to developing the charter, the study lead conducts preliminary research. The primary goal of preliminary research is to understand the operational construct and mission of the function. The following are potential research sources for conducting preliminary research:

2.2.1.1. Documentation Review. To assist the preliminary research effort, request an appropriate bibliography of functional instructions, policies, and directives, etc. from the functional representative.

2.2.1.2. Organizational or Functional Websites. A functional website may supply a significant amount of information on present organizational structure, governing directives, and current and projected events concerning the function or work center under study. The accuracy and currency of the information collected should be confirmed with the functional representative.

2.2.1.3. Organizational Policy and Guidance. AFI 38-101 prescribes various organizational levels and standard structures and outlines procedures for establishing and modifying organizations.

2.2.1.4. Air Force Departmental Publications. Air Force Departmental Directives, series 10 through 99, provide functional policy and responsibility. Review the functional directives establishing or directing functional requirements. The policy and responsibility statements may be viewed as major tasking's or work processes for the function. When responsibility statements refer to other directives, research them, and identify functional tasking, products, and services. Request the functional representative identify command directives supplementing Air Force directives and establish command-unique workload.

2.2.1.5. Functional Publications. Review Department of Defense (DoD), Air Force, command, and other agency operating instructions, manuals, and policy correspondence.

2.2.2. Assigned Strength. Collect assigned military and civilian strength information from the base-level Military Personnel Section and Civilian Personnel Section for all input locations. Coordinate and validate this information with the work center supervisor. Also request the supervisor provide information on other full-time and/or part-time over hires, contract full-time equivalents (CFTEs), borrowed or loaned personnel. Finally, obtain information regarding documented, uncompensated, or lost overtime or compensatory time.

2.2.3. Manpower Determinant. If available, review the Process Oriented Description (POD)/SWDs, variances and workload drivers documented in an existing manpower determinant.

2.2.4. Occupational Survey Report. The Air Education and Training Command Occupational Analysis Division is responsible for conducting occupational analyses for every enlisted career field within the Air Force and for selected officer utilization fields. It is an operational scientific organization that interfaces with the senior enlisted and officer career field managers through Specialty Training Requirements Teams. Occupational surveys generally provide information in terms of the percentage of members performing specific jobs or tasks, the relative percentage of time spent performing tasks, equipment used, task difficulty, training emphasis, testing importance (for enlisted specialties only), and the skills necessary to perform tasks.

2.2.5. Reports. Review previous Air Force MEP studies, productivity reports, Air Force survey results, staff assistance visit reports, Air Force and Command Inspector General reports, and Government Accountability Office reports concerning the function or work center under study.

2.2.6. Management Inspections. These reports (e.g., Air Force and MAJCOM Inspector General, MAJCOM assistance visits, etc.) may contain information concerning the drawbacks of present operations. These reports provide clues concerning manpower utilization, process bottlenecks, and present recommendations for improvement.

2.2.7. Specialty Training Material. Review specialty training standards (STS), on-the-job training (OJT) records, career development courses, and AFS course charts and outlines.

2.2.8. Management Information Systems. Copies of functional area system generated reports may aid in the development of historical frequencies of occurrence.

2.2.9. Equipment and/or Technology. Review equipment and/or technology (machinery or computer systems used, degree of standardization, etc.) listed on the automated data processing equipment account, and custodian authorization/custody receipt listing.

2.3. Study Charter. The study charter is an agreement between the functional and manpower communities. It identifies all key members and establishes roles and responsibilities. Additionally, it defines the scope of the study and sets the commitment level for leadership and establishes the official start date. The scope needs to be understood and communicated. An unclear study scope can result in wasted effort. The scope defines the study and clarifies the purpose. The scope helps to understand limitations to the study and anticipate the effort needed to complete the study. As the complexity of the effort increases the communication, coordination, level of effort, time, and study costs also increase. The primary goal is to understand the function under study, identify key members, and educate them on the determinant process.

2.3.1. Study Participants.

2.3.1.1. Study Sponsor. The study sponsor is the owner of the process or function and can make policy decisions. The sponsor represents the highest appropriate level in the functional organization for coordination and staffing, and should be the individual who has authority to approve process improvement initiatives. The sponsor commits to the study and provides high-level leadership for the functional community for the duration of the study. Typically the sponsor does not participate in day-to-day study activities, but delegates this responsibility and authority to a functional representative. The sponsor designates the study representative, signs the charter, and reviews and coordinates on study products.

2.3.1.2. Study Representative. The study sponsor's representative is the appointed focal point and works closely with the study lead to complete study and ensure milestones are met.

2.3.1.3. Study Lead. The study lead is the ME analyst with the authority to manage and lead a study. The study lead is responsible for the processes used to manage the study. The lead also has people management responsibilities for team members. The processes used to lead and manage the study include defining the work, building the study plan, managing the study plan, issues management, risk management, etc.

2.3.1.4. Study Team. The study team consists of the full-time resources assigned to work on the deliverables of the study. They are responsible for understanding the work to be completed; completing assigned work within the budget, timeline, and quality expectations; informing the study lead of issues, scope changes, and risk and quality concerns; and proactively communicating status and managing expectations.

2.3.2. Study Announcement Message. After the charter is signed, a study announcement message is released to the field. The announcement message notifies the affected functional and manpower communities across the Air Force of the intent to conduct a manpower determinant development study and requests Manpower and Functional community points of contact.

2.4. Functional Research. Functional research is vital to improve upon knowledge gained from preliminary research. The study lead performs comprehensive research on the function's mission, structure, and operating procedures. Examples of functional research methods include questionnaires, interviews, and on-site observations. The purpose is to refine the scope.

2.4.1. Questionnaires. A questionnaire is a quick and inexpensive tool to gather information. Design questionnaires to collect information not available from other sources and limit them to the specific data needed to meet the study objectives. Ensure the questionnaire serves a purpose, has clear objectives, and is formatted to achieve the objectives.

2.4.2. Interviews. The interview research method consists of four steps: Planning, opening, controlling, and closing the interview. Refer to professional military education courses for a detailed explanation of this process. Interviewing has two advantages: flexibility, and uncovering information not documented elsewhere. It is an excellent method to obtain information from workers on training, qualifications, and ideas for improvement, assigned tasks, and tasks not covered by normal procedures. Personal and group interviews may be used for gathering information. Both techniques provide valuable information, but each has advantages and disadvantages.

2.4.2.1. Personal Interviews. The primary objective of personal interviews is to collect information on what and how work is done, operating procedures, and workload volume. Provide interviewees with an agenda (time, subject, and material). Keep interviews informal but follow the organizational structure by starting at the top with commanders. Different personnel levels provide different information and perspectives based on experiences in the organization. Personal interviews reveal management's general attitude and knowledge of the people who work for them. Interviews can also be used to gather customer requirements and obtain leadership perspectives for the future. Individual interviews take more time but yield more data than a group interview. The interviewer focuses questions on a specific individual without having other group members waiting. This allows each individual to provide a unique perspective without being overshadowed by other members of the group. A disadvantage is personal interviews are not always complete, precise, or accurate. Sometimes personnel withhold valuable information, divulge inaccuracies, or simply give information that sounds good. When in doubt, verify the information with the source or a supervisor. Sources of information given in confidence should not be revealed unless required by competent authority.

2.4.2.1.1. Chief enlisted managers and 9-skill level superintendents provide broad career field information and current career field issues; however, technical familiarity with lower level tasks and procedures may not be current. In some fields, the superintendent manages several career groups and has no or very limited current lower level-work experience.

2.4.2.1.2. The 7-skill level noncommissioned officer (NCO) provides the best technical information. 7-skill level normally has about 12 years experience in the career field as a supervisor and/or worker.

2.4.2.1.3. The 5-skill level airmen and NCO provides the best information about processes and activities done within the work center.

2.4.2.1.4. The 3-skill level apprentice provides the most complete information about labor-intensive work and extra work details. The 3-skill level can often present an unbiased opinion from a fresh eyes perspective.

2.4.2.1.5. Group interviews are effective when time is limited and disagreement among group members is strong. Group interviews normally result in consensus, eliminating major disagreements. Information provided by one member often helps other members recall details and requirements. A disadvantage is "groupthink" versus individual expertise.

2.4.3. On-Site Observations. The local work center is a prime source for initial information and a place to ask for work demonstration. Consider visiting a representative cross-section of locations with the functional representative. Discuss and verify findings with the functional representative, local managers, and supervisors.

2.4.3.1. Use on-site observations to identify processes and outputs, working relationships, and physical arrangements to increase understanding of procedures and data obtained; and to obtain information on work environment and worker productivity (e.g., idleness, work distribution, discipline, cleanliness, work layout, excessive standards of living, etc.). With observation and understanding comes the enhanced ability to identify potential process improvements.

2.4.3.1.1. Advantages. Provides a means to evaluate and measure the facts in reports, interviews, questionnaires, and records; protects sources of information and focuses on facts; ensures recommended actions are based on what is seen rather than heard; identifies conditions for future studies; and provides the management engineering (ME) analyst a proving ground to test recommended changes or prepare for work measurement.

2.4.3.1.2. Disadvantages. Increased time and resources required to accomplish Familiarization may result in higher travel costs and may not allow observation of all cyclical processes of the function.

2.4.3.2. When conducting on-site observations, look closely at high volumes of work. People work harder when watched or unusual operating conditions exist. Avoid biases and do not let general impressions skew facts and findings. Avoid prolonged observations which often disturb people and reduce productivity. Also be aware of spikes in workload or cyclical work and the associated impact on manpower requirements.

2.4.4. Wrapping Up Functional Research. The preceding paragraphs identify common references and techniques used to conduct Functional Research. However, the study lead should always be thinking of other ways to research and become familiar with the function. As the study lead progresses with the study, background knowledge of the function, and ability to think through potential issues aid them in developing a comprehensive and successful study plan.

2.5. Study Plan. The study plan is a snapshot in time that outlines to the study sponsor the MEP approach, by mapping out responsibilities, timelines, costs, and team makeup. Furthermore, it identifies the approach, refines the scope, and outlines the workshop requirements and methodology used to capture data for the SWD. Ultimately, the study plan outlines how the study team intends to accomplish the necessary actions to draft the SWD.

2.5.1. Study Approach. One of the first decisions the study lead makes during development of the study plan is the general study approach. All study approaches require the study lead to evaluate current processes for potential improvement and ensure approved initiatives are implemented prior to determining man-hour or manpower requirements. Taking into account the nature of the work center under study (gleaned during the Preliminary and Functional Research), the following should be considered:

2.5.1.1. Does the situation warrant detailed measurement?

2.5.1.2. Can the study objective of creating an accurate manpower determinant be met via other manpower determinant techniques (i.e., functional model, directed requirement, minimum manpower, position manning) not requiring detailed measurement? Remember, non-measurement methods are normally the most expensive, i.e., non-measurement methods are more likely to produce requirements results not as efficient as those produced via measurement methods.

2.5.1.3. When work measurement is deemed appropriate:

2.5.1.3.1. What data is needed and how is the data to be collected? For example, is workshop measurement or field measurement the primary means to gather standard activity time (SAT) and task frequency?

2.5.1.3.2. Which work measurement technique(s) or tools are to be employed to measure the work?

2.5.1.3.3. What other data (e.g., historical workload counts, authorized and assigned strength, etc.) is collected for follow-on analysis and determinant development?

2.5.1.3.4. Which statistical tools are to be employed to determine data normalcy and man-hour model development?

2.5.1.3.5. Are there levels of service issues that need to be considered? Define levels of service prior to starting a manpower study and should already be supported by MAJCOM or higher governing documentation.

2.5.1.3.6. The selection of a particular manpower determinant approach and/or man-hour measurement technique should be fully justified and logical. If these criteria cannot be met with an initial approach, an alternative manpower determinant approach and/or work measurement method should be utilized.

2.5.1.3.7. When measurement is deemed appropriate, the study lead decides whether to use the workshop measurement method or field measurement method to collect required data. ME analysts are tasked to perform measurement and data collection, identify and document the study approach, determine measurement method(s) and measurement tool(s) to be used and the specific data to be collected. This information is documented by the study lead in a comprehensive measurement plan that is provided to the input locations. A workshop facilitated by the study team or use of the same-eyes approach (where the same ME analysts conduct measurement at all input locations) also requires planning and preparation.

2.6. SWD Development. The SWD contains outputs and sources of count, process descriptions, standard process times, and SATs. The SWD is a full description of the function's required work which can be defined using process flowchart, narrative description, a functional statement, directed requirement, staffing pattern, position manning, or minimum manning. The SWD is completed by compiling the individual processes plus any additional work not directly related to an output. SWD development is typically done through workshops. A workshop is defined as a scheduled meeting with a predefined agenda, facilitated by the study lead, and attended by functional subject matter experts (SME). The functional representative selects SMEs based on experience and knowledge. For specific workshop details refer to **Chapter 8.**

2.6.1. Components of the SWD. The minimum components are the Process Number, Process Title, Process Time, SAT, Definition, and Specific Source of Count for Workload Data. This information is required (1) to capture required work, and (2) for subsequent AFMD development. The SWD is the basic building block of the determinant and is written to facilitate work measurement and data analysis and computations. Functional characteristics, e.g. complexity, stability, and degree of standardization influence the level of SWD detail, the selection of the measurement approach, and the ultimate maintenance of the determinant.

2.6.1.1. Definition of Work Center Process Steps. Make sure the SWD content reflects only mission-essential processes assigned to the work center being studied and governed by a MAJCOM directive or higher. Omit assumed or inferred workload. Inferred work is work that is the responsibility of another work center or function. Assumed work is considered nice-to-do but is not necessary to work center productivity. Inferred and assumed work are not given manpower credit to the work center under study. To build a good SWD, develop an accurate and understandable definition for each process step.

2.6.1.2. A process is a sequence of work activities needed to accomplish an output. It is a procedure with a definitive input and output product. This facilitates price identification and examination of various levels of service options. A process involves worker interaction with such things as equipment, material, other people, and information. In most instances, the performance of a process by a worker has a definite beginning and end.

2.6.1.3. A process definition may only need a short phrase (for example, repairs carburetor), or it may need a breakout of the process into several steps (for example, disassembles carburetor, replaces part, reassembles carburetor, and inspects carburetor). Factors influencing the degree of definition detail needed are:

2.6.1.4. The Nature of the Activity.

2.6.1.4.1. A detailed process definition is suitable when an operation is highly repetitive and a specific sequence of steps are followed.

2.6.1.4.2. A less detailed listing of a process is suitable when a process can be done in a variety of ways. For example, management, research, and problem-solving activities may follow different steps each time completed; therefore, those activities can only be described in general terms.

2.6.1.4.3. Structure processes independently and mutually exclusive of each other and have definite beginning and ending points.

2.6.1.5. The work measurement method selected:

2.6.1.5.1. A measurement method such as operational audit (OA) usually needs processes defined at the step level to ensure accuracy of data.

2.6.1.5.2. For WS, the sampling level dictates the degree of detail needed. If sampling is done at the process level, a listing of step titles or a grouping of the steps in sentence format may provide enough detail for measurement.

2.6.1.5.3. In all cases, clearly write process definitions in enough detail so the measuring technician can easily identify when an activity occurs during measurement.

2.6.1.5.4. Setting up the correct process definition detail is a repetitive procedure requiring the manpower and organizational technician to use good judgment and common sense. Each work center produces different definition requirements that are addressed to obtain accurate data. During this procedure, remember:

2.6.1.5.4.1. Steps made purposely broad to cover as much work as possible can increase interpretation problems, cause inaccurate measurement, and hinder data analysis.

2.6.1.5.4.2. Steps not accurately reflecting duties and responsibilities increase the chance for inaccurate measurement.

2.6.1.5.4.3. Steps too detailed may result in an indiscernible sequence of events. When analyzing individual work center activities see instructions in Chapter 6, Work Measurement.

2.6.2. Preparation of the SWD.

2.6.2.1. Clearly state process titles and accurately describe the steps that are grouped under each activity. Use a noun form or an adjective and a noun form (for example, management, minor maintenance, officer classification, record processing). Make the process titles descriptive and easily identifiable.

2.6.2.2. State step titles in a single unit form with verbs in third person singular. Processes are described at the step level only (e.g., 1.1., 1.2., 2.3., etc.). In WS measurement, processes are described to the level necessary for accurate measurement. In either case, each definitive step of the process, from the beginning (input) to the end (output), are described in the sequence as it occurs in the process. This increases the chances of getting accurate unit times and frequencies at the time of measurement. Titles that are vague or written in plural form increase the chance of error in the associated unit time values and may make later analysis of data harder. The same step title may be used in different processes. For example, "Reviews Unit Manpower Document (UMD)" could be a step in processing a manpower authorization change request or in the process of applying a manpower determinant. See Table 2.1. Examples of acceptable and unacceptable step titles are listed below:

Table 2.1. Examples of Acceptable and Unacceptable.

ACCEPTABLE	UNACCEPTABLE
Types letter	Type letters
Inspects facility	Perform inspections
Attends meeting	Attend meetings
Prepares report	Prepare reports
Repairs pump	Repair pumps
Takes sample	Take samples

2.6.2.2.1. Including an indirect statement in the SWD is optional. If it is included, use the following statement: INDIRECT: Indirect work involves those tasks which are not readily identifiable with the work center's specific product or service. The major categories of standard indirect work are: Administers Civilian, Officer, and Enlisted Personnel; Directs Work Center Activity; Provides Administrative Support; Prepares for and Conducts/Attends Meeting; Administers Training; Manages Supplies; Maintains Equipment; and Performs Cleanup.

2.6.2.2.2. Format the SWD using the template provided on the AFMAA SharePoint site.

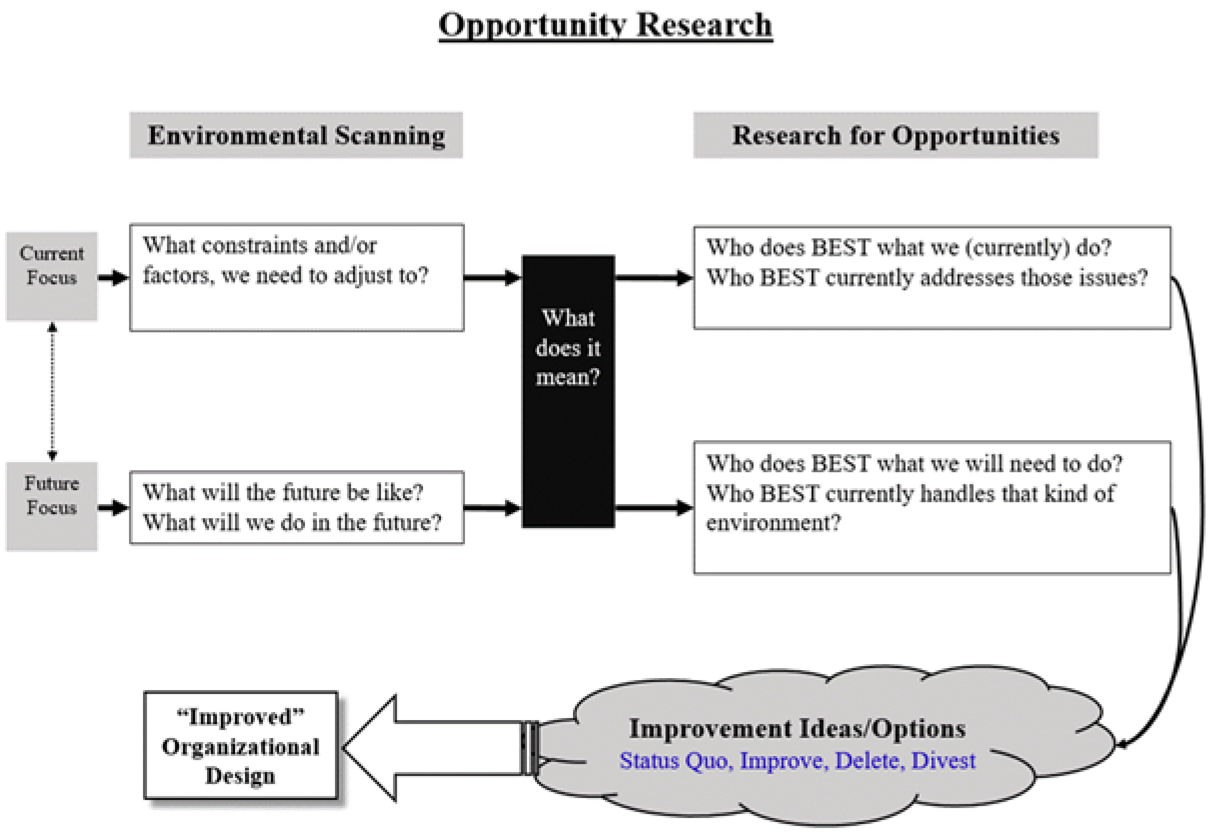
2.6.3. Finalize SWD. The study lead updates documents containing any adjustments from HAF coordination and validated test results. Once the SWD is finalized, the functional community implements and owns the SWD.

2.7. SWD Improvement Plan. The improvement plan, if required, informs the functional community of the steps needed to implement the SWD including follow on actions and established timelines. It is used to develop the SWD and outline the necessary changes needing to be implemented and/or tested prior to the SWD approval. The improvement plan is developed by resolving capability gaps identifying changes necessary to develop the most efficient SWD.

2.7.1. Identify Improvement Opportunities. This is a method to simply identify appropriate changes within the current process. Standardizing the process is considered an improvement along with eliminating rework, redundancy, and repetition. It is important to identify activities within the current process that may be eliminated or improved upon. The goal is to develop and use the most efficient process for the SWD. The following can be considered for identifying improvement opportunities.

2.7.2. Opportunity Research. Two main dimensions make up Opportunity Research: Environmental Scanning and the eventual Researching for Opportunities. For opportunity research two things have to happen. First, determine the environment (current and/or future), and the requirements in that environment. The environmental scan addresses these by identifying trends, restrictions, boundaries, developments, etc., impacting the function's processes. The workshop team can do this scan or specific processes or dimensions of the environment can be assigned to subgroups to focus on. This information is then run through the "filter" of, "So what does all this mean to the organization/process that is potentially changing?" The outcome of this analysis is an identification of areas where changes need to happen. Second, the workshop team has to figure out where the changes should come from and what the changes should be. Some improvement ideas may be obvious or intuitive. Other appropriate changes are not so obvious. Innovative thinking often requires looking outside the organization at how others are handling similar requirements, processes, activities, etc. If improvement ideas are only developed from within, the organization runs the risk of simply recreating its current state or missing a real opportunity to see what others have figured out. Comparison and benchmark organizations are identified, researched, and analyzed to generate possible improvement ideas which meet current and/or future requirements. Figure 2.1 provides an overview of this, with the "focus" path being defined by the intent of the study.

Figure 2.1. Opportunity Research Diagram.



Note: Figure **2.1** represents where to look for those improvement opportunities that are to be based on the focus (current, future, combination) of the study Table 2.2.

Table 2.2. Environmental Scanning.

Focus	Intent of scan	Breadth of scan (Environmental Dimensions of Interest)	Things to understand (Societal, economic, political, technological, or other aspects)	Research targets (Where to find ideas)
Current	What is going on now that impacts the process/ activity/ organization in the near term?	• Internal (mission) • Customer • Industry	Current limitations, policies, current customer impressions, improvement recommendations from customers, technology availability, funding situation	"Who currently is best in class in the work performed (or similar things)?" • Internal Brainstorming • Research Best Practices Clearinghouse • Site visit or bench-mark current leaders in similar process
Future	What changes are taking place now that redefines how the organization/process needs to work in the future?	• Customer (based on future requirements, initiatives) • Competitive (Policy, etc.) • Industry (Air Force Strat Plan, EAF) • Macro (Societal trends, economic, technological trends)	Longer term trends, strategic initiatives, customer initiatives, policy/budget projections, social changes, industry shifts, technology trends,	"Who does NOW what a function needs to be good at in the future to meet future requirements/ restrictions, etc.?" • Customer interviews • Benchmarking • Site visits • Information sharing • Best Practices Clearinghouse • Excellence awards winners
Combo	Both	Internal • Customer • Competitive • Industry • Macro	Both	Both

2.7.3. Strengths-Weaknesses-Opportunities-Threats (SWOT) Analysis. By examining internal strengths, the workshop team can discover untapped potential. Examining internal weaknesses, the study team can identify gaps in performance, vulnerabilities, and erroneous assumptions about existing strategies. The external opportunities and threats are the positive and negative characteristics of the external environment. Using information gathered from available sources, study teams can identify opportunities for improvement and assess threats to determine the organization's ability to defend against them. Using the information gathered in the analysis and the Environmental Scan, some analysis has to be performed to understand what it means to build the SWD. Whatever approach is taken to do SWOT analysis, some consideration should be given for the different dimensions of each aspect of the environment. The outcome of this activity is a list of things to exploit or overcome in order to excel in the future environment. Several Approaches can be taken.

2.7.3.1. The workshop team can create lists of Strengths-Weaknesses-Opportunities-Threats for the whole organization (or processes under consideration) using tools like flip charts, grease-boards, or electronic groupware. This would focus on all of the dimensions, and would consider any appropriate aspects for the processes.

2.7.3.2. Subgroups can focus on a single dimension of the environments, considering any appropriate aspects of information that may be useful (for example, group 2 might be assigned the competitive dimension of the environment). The analyst would consider things like technological, political and societal trends to create a SWOT for that dimension. The subgroups would then out-brief each other to create a master SWOT for the whole organization collectively addressing all aspects of the environment. Subgroups can focus on a single aspect to consider (for example, group 2 could focus on just technology), and would identify SWOT issues across all of the environmental dimensions and processes. Subgroups can be assigned the responsibility of generating one piece of the SWOT (for example, group 2 might focus just on THREATS). The analyst would need to be familiar with the Environmental Scan information across all of the different environmental dimensions. The subgroups would then out-brief to compile the master SWOT analysis. Subgroups (or individuals) can be assigned specific processes to evaluate against the environmental information. The master SWOT would then simply be the sum of the SWOTs for the different processes (plus any issues which may obviously cut across processes).

2.7.3.3. Use any other approach which evaluates the organization or its processes relative to the environmental scan information.

2.7.4. Conduct Field Testing. If applicable the functional representative and study lead validate test results. The functional representative and study lead beta-tests proposed SWD following the intent of the implementation plan. The functional representative ensures the draft SWD outcomes are achievable, and the study lead ensures process times and descriptions are accurate.

Chapter 3

ANALYSIS TOOLS

3.1. Process Flowcharting.

3.1.1. General Concepts. In the past, the Air Force MEP used standardized forms or office supplies and materials to create a graphic portrayal of how work flows through a work center. Now through the use of modern computer technology and software, ME analysts are able to electronically diagram, collect data, and simulate business processes and workflow. The development of modeling and simulation software has become a unique niche of the technology industry. This section discusses basic concepts for building a process flowchart to document a process and process improvement initiatives and how to analyze the physical layout where processes are performed.

3.1.2. Process Flowcharting. A process is a series of actions or continuous operations leading to a particular and desirable result or ending. In other words, the process produces a product or service for a customer. A diagram used to depict the step-by-step progression through a process is a flowchart. The process flowchart diagram is created by using connecting lines and a set of conventional symbols. Figure 3.1 provides a list of the most commonly used process flowchart symbols. Other symbols may be used but should be applied consistently. Provide a symbol key to identify the shapes used throughout the study.

Figure 3.1. Commonly Used Process Flowchart Symbols.

Symbol		Meaning	Examples
Elongated Circle		Start or Stop	Receives trouble report Machine operable
Diamond		Decision point	Approve/disapprove Accept/decline Yes/no Pass/fail Percent of split
Rectangle or square	*	Activity	Completes travel voucher Opens access panel
Circle		Connector (to another page or part of the diagram)	Process continues from page one
Arrow		Connects activities and indicates direction of process flow	From step one to step two
Note: * This symbol has a time associated with it.			

3.1.3. There are numerous techniques used to create and document process flowcharts. Two variations are presented in Figure 3.2 and Figure 3.3. Adding swim lanes to a process, (e.g., Sales) in Figure 3.3, is an easy way to illustrate demarcation points for various offices, work centers, or work elements owning a piece of the process. Another variation is to arrange the process flowchart according to the physical layout of the function. The ME analyst is not limited to these formats when deciding which technique is best to document the processes under review. However, ensure the format is consistent in final study documents. For example, do not use swim lanes on some processes and not on others.

Figure 3.2. Basic Process Flowchart Example.

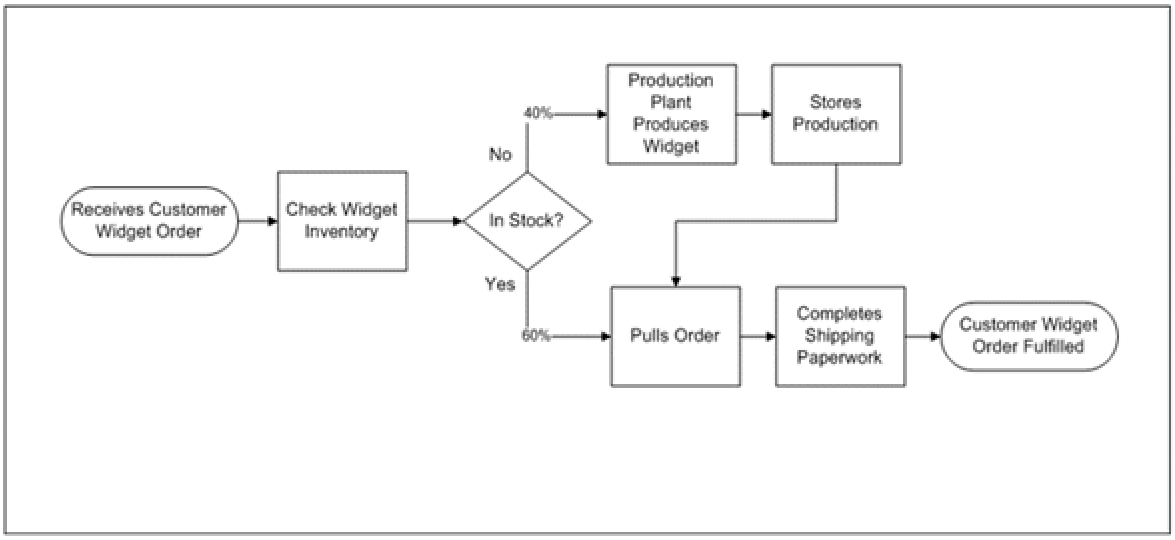
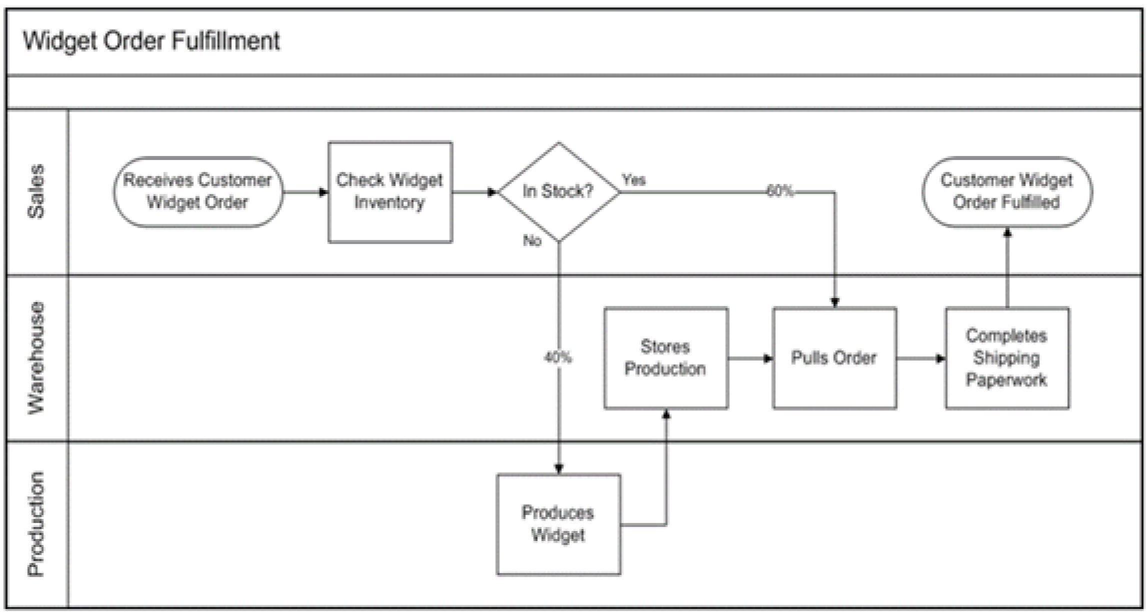


Figure 3.3. Process Flowchart Example Using Swim Lanes.



3.1.4. Guidelines for Developing Work Center Process Flowcharts. Since a process flowchart shows relationships between different steps and helps to locate or pinpoint problem areas, it is important to include key people in the process flowcharting activity, e.g. suppliers, customers, workers, and supervisors. Process flowcharts help the people involved with the process understand and communicate how the process is performed and then aid in process improvement efforts.

3.1.4.1. Break apart complex processes by creating sub-processes. Develop the sub-process process flowchart and use the sub-process title as the description for the activity within the higher-level process flowchart. Consider using a special formatting symbol on the primary process flowchart, such as "predefined process," to make identification of sub-processes easier. However, remember to include a symbol key in your documents to identify all shapes used in the process flowchart.

3.1.4.2. Process flowcharting is partly an art and takes time to create a finished product ready for posting. Thoroughly inspect the chart for discrepancies.

3.1.4.2.1. Ensure all activities have an arrow leading into and going away from them.

3.1.4.2.2. Avoid overlapping or crossing over connection lines and arrows because these can make it difficult to follow the path and adds confusion to the chart. Use circle connectors to avoid this situation.

3.1.4.2.3. Avoid overcrowding the process flowchart. Use consistent spacing between symbols, and ensure there is enough room for connecting arrows to indicate direction of flow. Also, try to maintain consistency in the size of the symbols. This can be a challenge for activity boxes with varying amounts of descriptive text. Remember, symmetry makes a process flowchart more presentable.

3.1.4.2.4. Choose and consistently apply a font size IAW the process flowcharting checklist found on the AFMAA SharePoint site. This is especially important when process flowcharts are converted to pictures before importing into documents. Also, use title case in activity descriptions and titles.

3.1.4.3. Verify and validate the process flowchart. Ensure the technical experts agree with the process flow and clearly understand activity descriptions. Remember, include only MAJCOM or higher HQ-directed workload.

Note: The steps to develop and analyze a process flowchart are described in Table 3.1.

Table 3.1. Steps to Develop and Analyze a Process Flowchart.

Step	Action	Description
1	Identify and define the process	Determine the title of the process. Where, when, and why does the process start and finish? What stimulus causes the process to start? What product or service is produced as a response? What is the output?
2	Describe the current process	Determine the level of detail to be included on the chart. From the starting point, chart the entire process. Work slowly and include every step along the way, right through to the finish. If need be, brainstorm the activities that happen within the process without concern of the sequence, then place them in order later. When the ME analyst and/or SMEs agree the process is complete, connect the activities using arrow connectors.
3	Chart the ideal process (optional)	Try to identify the easiest and most efficient way to go from the "start" to the "finish." This makes it easier to find improvements.
4	Search for improvement opportunities	Study the process flowchart. Find areas that hinder the process or add little to no value. If an ideal process was charted, compare and question any differences.
5	Update the chart with the improved process	Build a new process flowchart that corrects the problems that were identified.

3.1.4.4. Some questions to address during process analysis:

3.1.4.5. What is produced by the process? Why is it needed? What Air Force requirement is satisfied as a result?

3.1.4.6. What is actually done? Are all steps included? Can the process or some steps be eliminated, combined, optimized or automated?

3.1.4.7. Where should the process or steps be done? Are environmental conditions conducive to accomplishment of the process?

3.1.4.8. Are processes and/or steps in the right sequence? Can some be combined or simplified by moving them ahead or back?

3.1.4.9. Are the right people doing the work? Do the people have the right skills? Is the work being done at the most effective and efficient organizational level?

3.1.4.10. How are the process or steps being done? Can the process or steps be performed more efficiently or effectively with different equipment or work area layout?

3.1.4.11. Have proper administrative controls been set up? How often is work checked for accuracy? What inspections can be merged with operations?

3.1.4.12. Are conditional factors built for rework or errors and does management know what the error rate is?

3.1.4.13. At what stage in the process do most of the errors occur?

3.1.4.14. When would an error be caught if present checks were left out? Are there fail-safe measures that can be put in place to eliminate the need for human detection, harm, or error? How serious is the result of errors not found? Is a sampling check for errors enough?

3.1.4.15. Is there duplication of effort in whole or in part?

3.1.5. Identify process improvements during process flowcharting exercises prior to the measurement and development of manpower equations and determinants. The idea is to base the work center's manpower requirements on the most effective and efficient way to perform the work.

3.2. Layout Analysis General Concepts.

3.2.1. Layout analysis studies are used to improve production, ease physical exertion, and shorten distances of travel for material and personnel. These studies concentrate on the physical flow of work, may lead to substantial improvements, and are very useful as an aid to other method improvement techniques. A layout study is defined as a systematic method to analyze procedures and facilities and to develop a plan providing an optimum workable arrangement of personnel and equipment.

3.2.2. The primary objective of a layout study is to arrange equipment and facilities to achieve material flows at the lowest cost, with the least amount of handling, and in the shortest amount of time. Additional objectives include:

3.2.2.1. Increasing efficiency by getting a straight-line flow of work and minimizing backtracking in work processing.

3.2.2.2. Providing each employee with enough space to work efficiently while, at the same time, minimizing total space. Air Force Office of Safety and Health/Occupational Safety and Health Administration standards specify minimum work space requirements.

3.2.2.3. Providing the best working conditions in the space available.

3.2.2.4. Allowing expansion, reduction, and rearrangement of space to meet changing needs.

3.2.2.5. Eliminating items of furniture and equipment not needed in the work center operation.

3.2.3. Potential benefits of an effective layout are:

3.2.3.1. Improved production. Streamlining the flow of work increases production and improves quality. Labor costs are correspondingly lowered. Every moment saved in travel and delays aids in increasing the production rate.

3.2.3.2. Increased employee comfort and safety. A more comfortable employee in a safe environment generates higher productivity and takes less time off.

3.2.3.3. Reduced labor turnovers. A more comfortable, attractive office helps recruit better employees and helps keep present employees. Consideration of the individual employee often produces pride and loyalty.

3.2.3.4. Improved supervision. Careful layout planning makes controlling the work flow and inspecting easier for the supervisor.

3.2.3.5. Improved quality. Better layout reduces distractions and worker fatigue, eliminates frustration and undue pressures, and improves the quality of workmanship.

3.2.3.6. Better space utilization. Valuable floor space is used more efficiently through effective planning and layout.

3.2.3.7. Reduced costs. Cost is the most important benefit. Speeding production, controlling waste, and reducing labor expenses all save money.

3.3. Layout Analysis Applicability. Steps necessary to conduct a layout study vary with each situation. The techniques presented in this chapter may give more information than necessary for a given study, but all might apply. Flexibility is the key word.

3.3.1. The mere drawing of a proposed layout does not constitute a layout study. A hasty examination of the work center or function may reveal inadequacies in the present layout, but a thorough analysis of procedures and facilities usually reveals underlying causes for problems creating a low productivity environment. Accurate and detailed definition of the problem is essential for problem solution.

3.3.2. Normally, layout studies are originated due to problems caused by one or a combination of these: Ineffectiveness of current layout or work flow; changes in volume of production or services; changes in mission, product, service, or equipment; changes in the number of people in the work center; computerization; poor work environment; frequent accidents; obsolete facilities; or new facilities.

3.3.3. Classify layout analysis studies according to the magnitude of the effort.

3.3.3.1. Minor change to present layout.

3.3.3.2. Major rearrangement of existing layout.

3.3.3.3. Relocating into other existing facilities.

3.4. Two Common Techniques Used for Layout Analysis.

3.4.1. Flow Diagrams.

3.4.1.1. Prepare a scaled layout chart of the area under study. Use a standard scale when preparing the chart (for example, 1/4 inch = 1 foot).

3.4.1.2. Record on the layout, as near the point of occurrence as possible, each step in the work process. Use the same symbols as on a process flowchart.

3.4.1.3. Number each symbol in sequence. If the diagram is being used in conjunction with a process flowchart, match each step to the chart.

3.4.1.4. Connect the symbols with a line to show the path traveled by the person or material under observation.

3.4.1.5. When presenting two or more work flows, use a different color for each flow.

3.4.1.6. Study the flow diagram for improvement possibilities. Use the diagram checklist in Table 3.2.

Table 3.2. Diagram Checklist.

1. Work Flow:
1.1. Does work flow follow a relatively straight line with minimum backtracking and crossover? Where are the bottlenecks?
1.2. Has each step been questioned and analyzed?
1.3. Have other work flows been considered?
1.4. Does furniture and equipment spacing consider at least minimum space requirements per worker as outlined in AFI 32-1024, *Standards Facility Requirements*?
1.5. Does layout consider person-person and person-equipment work flow relationships?
1.6. Is there excess furniture or equipment?
1.7. Would movement of furniture or equipment reduce or eliminate the number of moves or distances?
1.8. Does layout recognize nature of work such as privacy or security considerations?
2. Diagram:
2.1. Does diagram portray its story clearly?
2.2. Is diagram too elaborate and/or cluttered?
2.3. Is it easier to understand than a chart or narrative description? Is it more effective?

3.4.2. String Diagrams.

3.4.2.1. Mount a scaled layout chart (e.g., 1/4 inch = 1 foot) on material e.g. plywood or cork that holds pins, nails, tacks, etc.

3.4.2.2. Insert pins, etc.; on the layout at each place people or material stop along the path through operations and processes in the work area. Put a pin on each exact location. Additional pins may be placed along the path to show the exact route.

3.4.2.3. Starting with the entry point in the flow, connect the pins with a string by looping each pin, in correct sequence, to the end point of the flow.

3.4.2.4. Label or otherwise identify each step.

3.4.2.5. Use different colors or types of string to represent different workers, products, or materials.

3.4.2.6. String may be measured to get distances, using the same scale as on the layout chart.

3.4.2.7. Analyze the completed diagram for areas needing improvement (and congested masses of string indicating process bottlenecks). Refer to the diagram checklist at Table 3.2.

3.5. Layout Analysis Development.

3.5.1. Analyze all data collected. This systematic approach is recommended.

3.5.1.1. Determine facility location.

3.5.1.2. Plan overall layout.

3.5.1.3. Plan detailed layouts.

3.5.1.4. Plan processes and machinery around material functions.

3.5.1.5. Plan the layout around processes and machinery.

3.5.2. Consider these needs.

3.5.2.1. Set up space, storage, production, service, safety, people, and type of work.

3.5.2.2. Furnish better working conditions to include lighting; use of colors; ventilation; noise levels; safety; access areas; walls, partitions, and floors; communications; and location of break areas, lavatories, water fountains, and locker rooms, etc.

3.5.2.3. Set up telephone/information system needs including: number and placement of phones and lines, intercom systems, and cabling, etc.

3.5.2.4. Set up a work flow following the simplest and shortest path.

3.5.3. Prepare proposed process flowchart and work distribution charts to optimize work flows and travel. Document the proposal on a revised flow or string diagram.

3.5.4. Check all recommendations, discuss them with work center personnel and the functional supervisor, solicit recommended changes, and delete impractical data from analysis.

3.5.5. Look at the differences between the proposed layout and present layout and evaluate these differences. Does the proposed layout:

3.5.5.1. Produce a better product or increase production?

3.5.5.2. Smooth the flow of work or reduce effort?

3.5.5.3. Minimize material handling?

3.5.5.4. Reduce costs, waste, and scrap?

3.5.5.5. Release floor spaces or reduce wasted space?

3.5.5.6. Decrease maintenance?

3.5.5.7. Eliminate congestion or improve housekeeping?

3.5.5.8. Facilitate scheduling or reduce quality checks?

3.5.5.9. Make supervision easier?

3.5.5.10. Reduce accidents or improve morale?

3.5.5.11. Allow for future expansion?

3.5.6. Finalize proposed layouts, charts, and graphs necessary to present study recommendations.

3.5.7. Include a concise implementation plan in enough detail for systematic implementation.

3.6. Implementing the Proposed Plan.

3.6.1. Present all recommendations and the proposed implementation plan to the supervisor, then to other key senior leadership personnel. Recognize it is the unknown rather than the new that creates apprehension. Sell major ideas of the study in the order of anticipated acceptability to management. Start off with those of a less controversial nature and follow with those most likely to involve more client hesitance. A close alternative may often be readily accepted, thereby avoiding complete rejection of an idea or proposal.

3.6.2. On acceptance of final implementation plans, make sure all affected personnel are fully informed of the entire plan and specific responsibilities. Set up a trial period to test new procedures and layout arrangements. Continued contact during the test period is necessary to make sure all work center personnel understand, and to revise any aspects of improvement actions contrary to study objectives. Ensure all recommendations are instituted as planned.

3.7. Systems and Procedures Analysis General Concepts.

3.7.1. Systems and procedures analysis is a specific technique used to solve information and paper flow problems. Systems and procedures are essential parts of the management process. These concepts put managerial decisions into action and provide for routine handling of recurring situations.

3.7.2. Systems and procedures analysis is well suited for looking at paper flow and clerical activities. This analysis studies the flow of paperwork, the forms used, and where and how work is done.

3.7.3. The following terms are used in systems and procedures analysis:

3.7.3.1. System. A network of related procedures integrated to meet an organization's objectives.

3.7.3.2. Procedures. A sequence of operations set up to get uniform processing by telling what actions are to be taken, who takes them, the sequence to be followed, and the tools to be used.

3.7.3.3. Method. A manual, mechanical, or electronic means for individual operations.

3.7.3.4. System Diagram. A system diagram is a chart made to aid comprehension of a general activity and its components. It is used for doing relatively coarse analysis of an entire system. There is no specified form; however, the form used should give a framework for the procedures making up a system. The elements in a system diagram should include the system description; procedures action; organizational elements; skills; equipment;

information inputs, resources, and outputs; and objectives and goals. Information for doing a system diagram is collected through normal fact-gathering methods. Entries for each of these recommended sections are described below.

3.7.4. System Description. Tell how the system is related to the mission, functional activities, and managerial goals.

3.7.5. Procedures Action. Summarize what is in each procedure. Use one sentence for each procedure.

3.7.6. Organizational Elements. List all the elements responsible for doing the procedures action statement in enough detail for clarity.

3.7.7. Skills. List the Air Force specialties needed.

3.7.8. Equipment. List the equipment used.

3.7.9. Information Inputs. List information entering the system or procedure. The entry identifies the source of the information. There is not always an input to each major action, nor is it necessary to list the output of the preceding step as an input.

3.7.10. Information Resources. List data sources such as reports, files, records, guides, and directives. Include in this section information resources added to, or updated as part of, the action.

3.7.11. Information Outputs. List all information created or dispatched as a result of the procedure. Identify the format and destination of the outputs if going outside of the procedure. There is not always an output from each major action.

3.7.12. Objectives and Goals. Rank, for each procedure, the qualitative aspects of performance and the quantitative measures used.

3.8. Preparing a Procedure Chart.

3.8.1. A procedure chart is specifically designed to give, in symbol format, the type of work found in an administrative environment.

3.8.2. It follows the flow of information between work stations and shows decisions made and actions taken by individuals in these stations. It also shows interrelationships between two or more forms, forms and material, or forms and workers.

3.8.3. A procedure chart gives a quick, accurate, and comprehensive picture of the total activity. It is used to show both existing and proposed procedures. When properly done, a chart is clear and can easily give a complete and correct picture. The objective is to chart normal routine action, recognize possible alternatives, and stay in the main stream of the procedure. If done well, the procedure chart shows the following information about a procedure:

3.8.3.1. The title, number of copies, and source of each document entering the procedure.

3.8.3.2. The method of preparation, organizational element, and person preparing each document originating in the procedure.

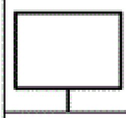
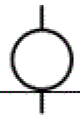
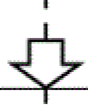
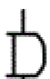
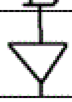
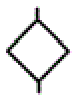
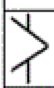
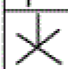
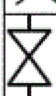
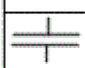
3.8.3.3. A symbol, with a short explanation to show each step in the procedure.

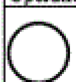
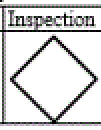
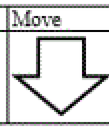
3.8.3.4. Processing times and movement distances (optional).

3.8.3.5. Final disposition of each copy of each document involved in the procedure.

3.8.3.6. Some common chart symbols and uses are found in **Figure 3.4**

Figure 3.4. Common Procedure Chart Symbols and Usage.

	FOR PAPERWORK ACTIVITY
	Origination: When a new document is created.
	Operation: When some physical operation on the document is performed.
	Move: When a document changes location or personnel.
	Delay: When a document is idle.
	File: When a document is placed in or removed from a formally organized file.
	Inspection: When a mental verification process is performed.
	Information Take-Off: When data is moved from one document to another.
	Destroy: When a document is destroyed.
	Gap: To omit activity not pertinent to the study.
	Cross Over: To show that a document has taken a non-intersecting horizontal.
	Item Change: To show that a document has taken on a different meaning.

FOR PERSONNEL ACTIVITY		
Operation	Inspection	Move
		

3.8.4. Preparing a procedures chart starts with completing a narrative describing the work being done in step form, who is doing the work, and where it is being done.

3.8.4.1. Chart preparation begins with entering basic information on the chart such as: Procedure Title, Data, and Analyst.

3.8.4.2. All charting starts in the upper left corner and goes down and across to the right on the chart. The personnel activity flow is always on the left side of the procedure chart.

Vertical columns are drawn to keep apart each individual organizational element used on the chart.

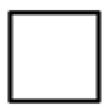
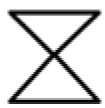
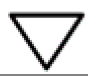
3.8.4.3. There is only one personnel column per chart, but there is a document column for each organizational element on the chart. Explanatory comment generally goes with each symbol.

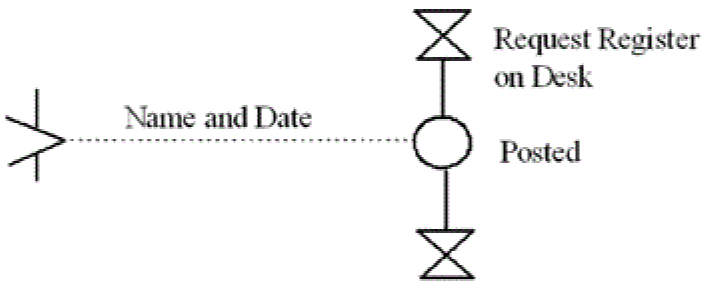
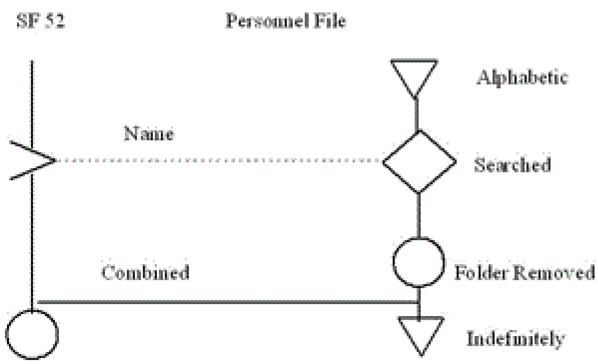
3.8.4.4. Use present tense with personnel symbols (what the person does) and use past tense (what is done to the document) with the document symbols.

3.8.4.5. If pertinent to the study, give the estimated processing time after each document symbol and show the distance moved with each move symbol.

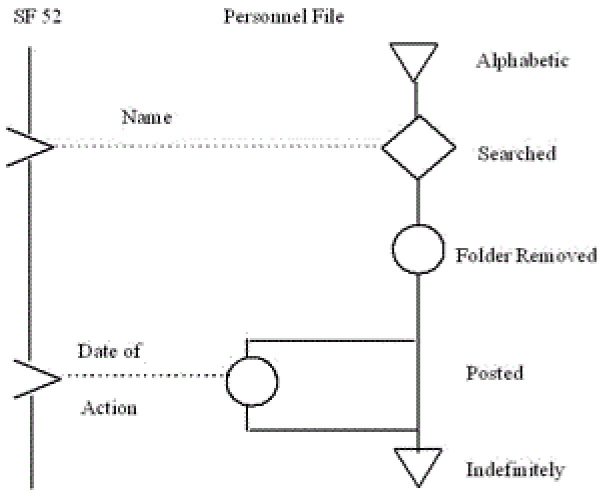
3.8.4.6. Follow the rules in Figure 3.5 to prepare a Procedure Chart.

Figure 3.5. How to Prepare a Procedure Chart.

Procedure Chart A document can be introduced into a Procedure Chart in only three ways: Describe the document **Title (Form Number, if Any) - Number of copies**		
Purpose	Shape	Example
Origination		Request for Personnel Action (RPA) (SF 52) - 3 copies
Gap (from outside procedure area)		RPA (SF 52) - 3 copies
File (removed from a formal file).		RPA (SF 52) - 3 copies Organizational Source

Title (Form Number, if Any) - Number of copies Organizational Source
(1) For Example: RPA (SF 52) - 3 copies Organizations Division
(2) To introduce existing logs or registers: 
- When documents are introduced into the procedure by removal from a formal file, the file symbol is used as follows:
File Title Method of arrangement
(1) For Example: Contract File by contract number
(2) Example of a document being removed from a formal file and not immediately returned but used separately in the procedure: 

(3) Example of a document being used and immediately returned to the form file:



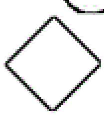
- When action on a document is delayed, the D Delay symbol is used in this manner.

D Cause of Delay (except when in "In or Out Baskets" which is awaiting pickup.)

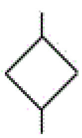
(1) For Example, waiting in an "In Basket";

D  SF 52
"In Basket"

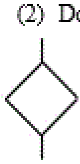
- The  operation symbol is perhaps one of the most used of all. Its use covers any action that can happen to a document for which there is not some other symbol.

- The  inspection symbol is used to indicate a mental verification process. The following are typical examples.

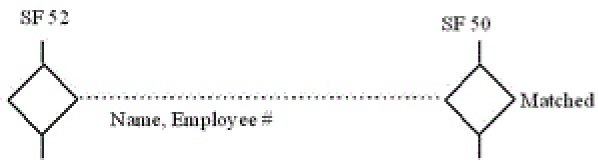
(1) Document checked against a mental standard.

 SF 52
Reviewed

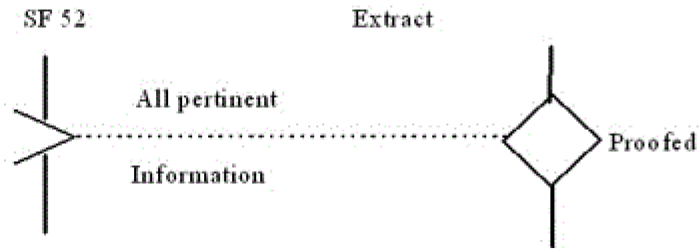
(2) Document checked against materiel received.

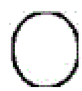
 Packing Slip
Checked against items received

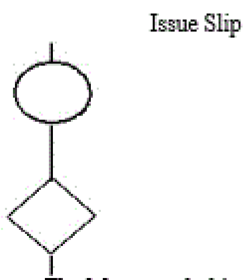
(3) Two documents matched by some common factor.

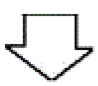


(4) Two documents compared (proofed): One of the documents is the standard, and the other document is changed if any discrepancy is found.

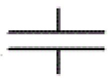


(5) Repetition (verification) of an  operation.

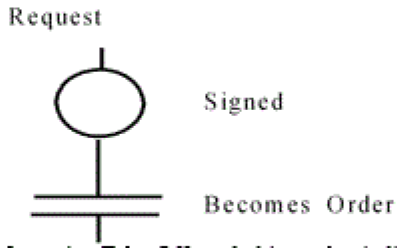




- The Move symbol is used to show that the document has either changed personnel or physical location. The symbol explains by noting how the paper moved and, if desired, the distance moved as follows:



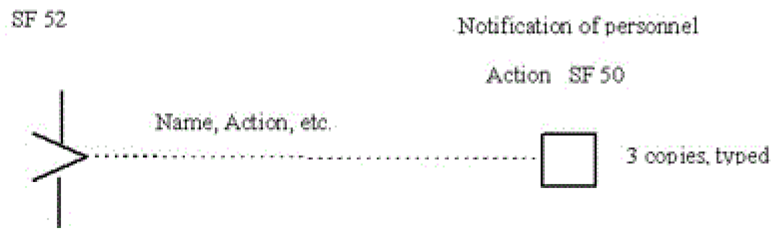
- The Item Changed symbol is used to indicate that a document has taken on a new significance in the procedure. For Example:



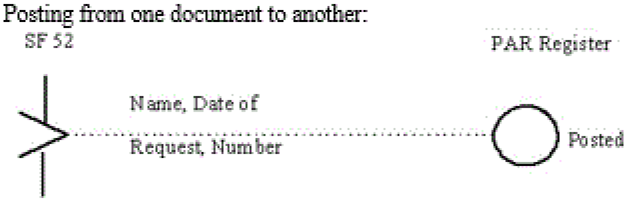
- The Information Take-Off symbol is used to indicate that information is moving from one document to another for the completion of some action.

Typical examples are:

(1) Origination of one document either wholly or partially from another:

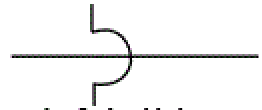


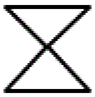
Posting from one document to another:



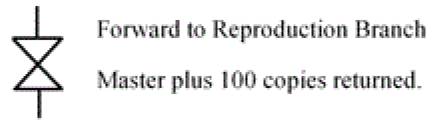
(3) Proofing (reading a source against the extract):

- The Cross Over symbol is used to show that a vertical and a horizontal flow line do not intersect. The half-circle is always on the vertical line as follows:



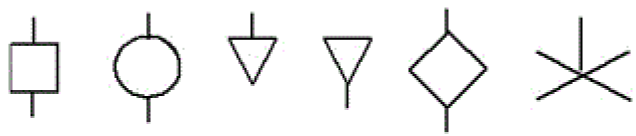


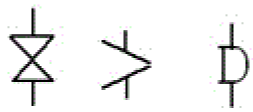
- The Gap symbol can also be used to show activity that is not pertinent to the study. It should always explain differences in form, number, etc., of documents which enter the uncharted activity and do not return or are altered during that time. For example:

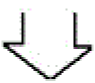


- Flowlines are the connecting links between symbols. The following rules apply in their use:

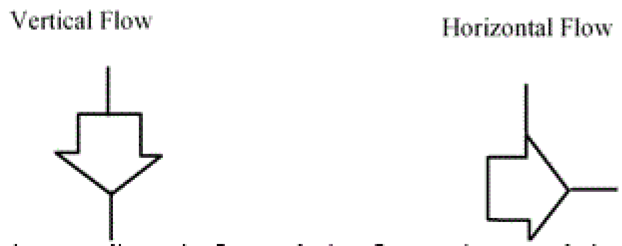
(1) Solid flowlines go into the top of symbols and out of the bottom as follows:



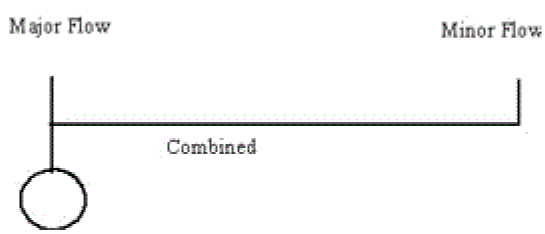




(2) An exception to the above is the Move symbol. The flow line can be adjusted to show horizontal flow as follows:

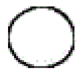


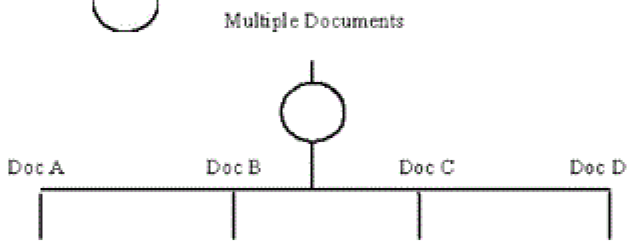
(4) Considerations regarding major flows and minor flows are important during analysis and presentation. This relationship is shown by always having the minor flow document move to join the major flow when used in combination. For example:



(5) All symbols fill the space between two guidelines on the chart form except the Item Change symbol which fills only half. If desired, symbols can be reduced to one half this size.

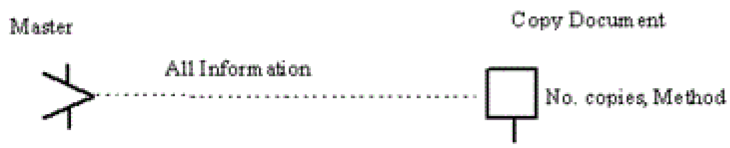
(6) Each time a new vertical document flow line is begun, the contents of that flow should be listed. For example:

(a)  On a Separation Operation:

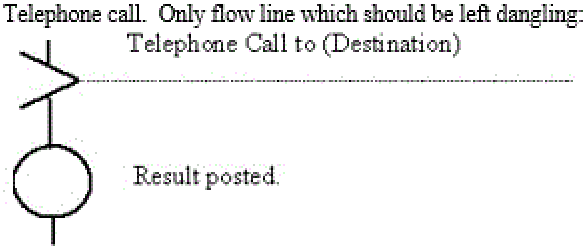


(b) On a horizontal move (from one organization to another):
- Often used combinations:

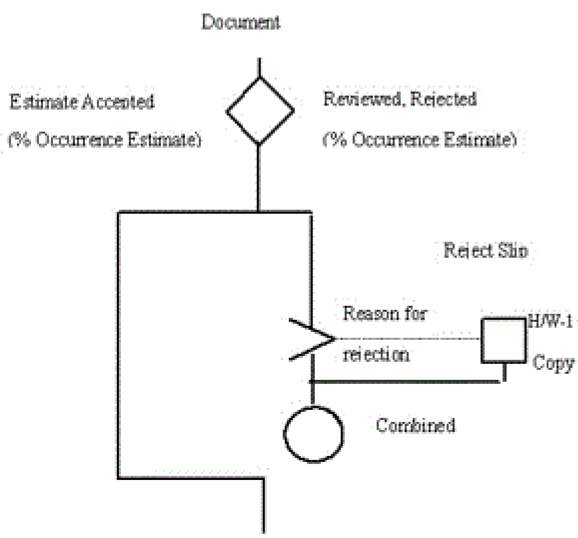
(1) Reproduction of copies from a master document



Telephone call. Only flow line which should be left dangling:



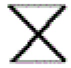
(3) Short alternative courses of action:



(4) Distribution of documents:
- All document flow lines end with one of the three following terminal symbols:

(1) The  Destroy symbol is used when a document is physically destroyed.

(2) The  File symbol is used to show the intersection of a document into a formal file.

(3) The Gap  symbol is used to show a document leaving the procedural area. It may go to a destination either in or outside the organization involved.

3.9. Work Distribution Analysis General Concepts.

3.9.1. Division of work is a potential area for productivity enhancement and is an aspect of skill determination for manpower determinants.

3.9.2. Work distribution analysis is a technique used to evaluate specific steps and find each individual's contribution to work center activity. This technique is useful when the work center consists of several people and skills contributing to the same product or service.

3.9.3. Work distribution analysis looks at work counts and man-hours associated with each responsibility.

3.9.4. This technique is a good tool to check and compare present and proposed procedures during study preliminary research and consultant studies.

3.10. How to Prepare a Work Distribution Chart.

3.10.1. Preparing this chart takes three basic steps, and each step is completed accurately and in detail.

3.10.2. First, have each person in the work center complete an activity task list. Use this to record each duty activity and type of work done and estimate the average number of hours spent on each.

3.10.2.1. The activity list does not merely quote an AFS or job classification statement. Use the task list to record a complete description of what each worker actually does. Do not include ambiguous phrases like checking, administration, or make contacts.

3.10.2.2. Number tasks by activity to help in developing a work distribution chart. The WU volume aid in work distribution analysis.

3.10.3. The second step is to complete a work center activity list. This list records the basic processes done by the work center. It includes all the major activities completed to meet assigned objectives.

3.10.4. The third step is preparing a work distribution chart. The activity list gives the information needed to do the chart.

3.10.4.1. First, list the activity of the work center in the left column of the chart, in order of relative importance. Leave space between each line.

3.10.4.2. The columns headed Tasks are for listing the work done by each person. Complete a column for each person in the work center, listing each of the tasks in summary form. Relate each task to the activity list in the left column. Clearly separate the different tasks, since analysis is impossible if a miscellaneous task is placed on the same line as the major job or operation of the work center.

3.10.4.3. For purpose of analysis, list individuals doing the activities in the first column by grade, beginning with the person in charge.

3.10.4.4. Record the hours per week spent by each person on each task in the proper column.

3.10.4.5. Enter work count data on the chart when relevant. If possible, enter the work count as the number per week to be consistent with hours shown on the work distribution chart. If a weekly count is not representative, enter the natural frequency of occurrence (e.g., /MO or /YR).

3.10.4.6. Sum the hours spent by all workers on each operation and enter the total in the column beside each item in the operation or process list.

3.10.4.7. Total the hours for each person.

3.11. Work Distribution Analysis.

3.11.1. After completing an initial work distribution chart, do a systematic analysis of the recorded findings. These questions help in examining the detail.

3.11.1.1. Are skills being used properly? Is everyone being used in the best possible manner, or are special skills and abilities being wasted? Persons with higher skills should not do tasks that can be done by lower skill levels.

3.11.1.2. Is work distributed evenly? Measure the relative importance of tasks assigned to persons engaged in similar tasks. For example, two clerks of equal ability and grade normally should be charged with similar volumes of work. Spread the urgent and important tasks as evenly as possible to make certain all work is done according to schedule.

3.11.1.3. Are tasks spread too thinly? Performances of the same task by many workers may mean duplication of effort. The assignment of a task to one person sets responsibility and enriches the job.

3.11.1.4. Are individuals doing too many unrelated tasks? A large number of tasks in any one column may show the individual has too many different tasks. Greater efficiency results if workers are assigned related tasks.

3.11.1.5. Are the work center's efforts misdirected? Is the work center spending too much time on relatively unimportant operations or unnecessary work? Instances of misdirected effort are very often found in miscellaneous or administrative processes.

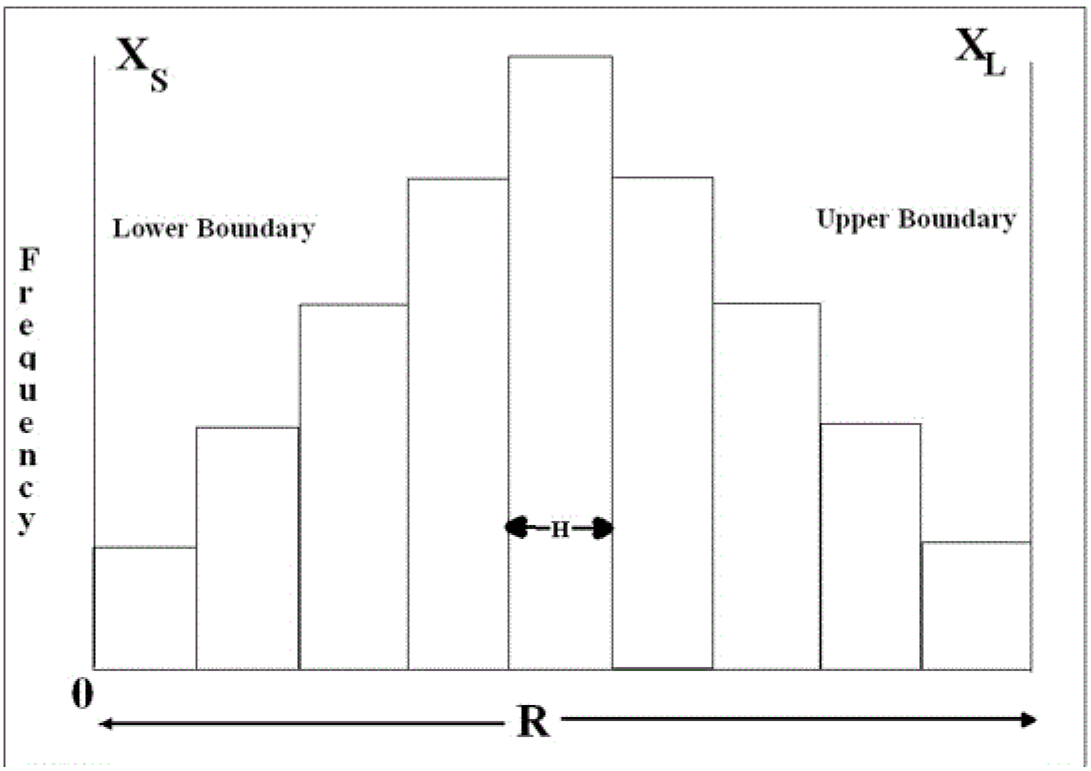
3.11.1.6. Are there excessive supervision or consultation tasks? Resistance to delegation of authority can restrict creativity and cause unnecessary delays.

3.11.1.7. What activities take the most time? Are these activities ones taking the most time? Normally, the largest total time is spent on what is considered the major activity in the organization. If the activity is a continuing one with several steps, the engineer may make a more detailed analysis by preparing a work distribution chart. Circle such man-hour totals to mark them for future process analysis.

3.11.2. The answers to the above questions help develop improvement proposals. Prepare a new responsibility chart or distribution chart showing the recommended process and division of work. This best displays proposed changes and compare them with present procedures. Associated reductions in man-hour requirements should be displayed to support the change.

3.12. Histogram Chart General Concepts. A Histogram is a graphical representation of the distribution of a series of quantitative observations. The graph is usually a bar chart showing how the same parameter, measured on different components, is distributed within certain minimum and maximum limits. The histogram is constructed by dividing the range of a variable into equal intervals. A bar chart is then drawn showing how many data are located in each of the intervals. A histogram provides information by means of the shape of the distribution and the dispersion. See Figure 3.6.

Figure 3.6. General View of a Histogram.



3.13. Procedures to Develop a Histogram.

3.13.1. Count the number of samples (n) for the process you are analyzing and record the total counts.

7.9	7.3	7.4	7.9	8.1	7.8	7.9	8.1	8.4	7.8	8.3	7.8	7.3	7.8	7.5
8.2	7.9	7.8	7.4	7.0	7.7	7.8	7.3	7.7	8.0	7.4	7.4	7.6	8.3	7.7
7.5	8.0	8.1	7.4	7.5	8.2	7.5	8.3	7.7	7.8	8.0	7.5	7.9	8.0	7.7
8.4	7.6	7.7	7.7	7.7	8.7	7.9	8.2	7.8	7.3	7.6	7.5	7.7	8.1	7.9
7.7	7.8	8.3	7.9	7.7	7.8	7.4	8.1	8.1	8.1	7.2	8.2	7.6	8.7	8.0
(n = 75)														

3.13.2. Identify the range (R) of data you have gathered. This number is the difference between the largest (XL) and smallest (XS) value in the data.

$$R = XL - XS \xrightarrow{yields} 8.7 - 7.0 = 1.7$$

3.13.2.1. Separate the data into classes (K). See below to identify the number of classes for different numbers of data points.

Points Counted	Classes (K) To Use
Less than 50	5 - 7
51 – 100	6 - 10
101 – 250	7 - 12
Over 250	10 - 20
Note: To avoid having the same point as both the upper value of a class and the lower value of the next class, decrease the upper value by the correct decimal. Therefore, in the below example, the range of the 1st class is from 7.0 $< X <$ 7.2, the 2nd class from 7.20 $< X <$ 7.40, etc.	

3.13.2.2. Determine the width of each class (*H*) using the formula, *H=R/K*. Since the number of samples in the example is 75, use 10 as a convenient divisor. For the data used in this example, the class width is1.7/10=0.17. After rounding to the nearest tenth, *H*=0.20.

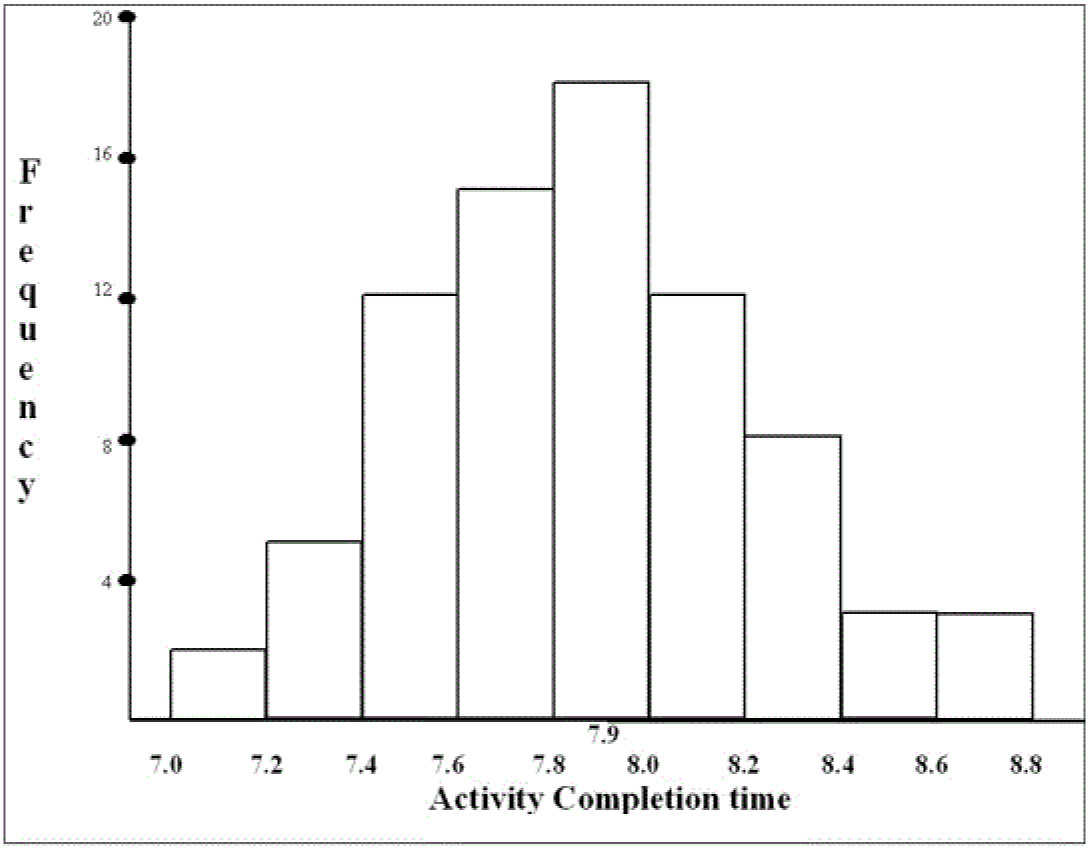
3.13.2.3. Identify the boundaries for each of the classes in the Histogram. Begin with the value of *XS,* the smallest number in the range of counts, and add the class width *H*. Continue to add the class width until the number of classes selected in the example is reached. In this example, *XS*=7.0 as the lower boundary. Adding 0.20 yields the 1st class ranging from 7.0 to 7.20. The next class begins at 7.20 and extends to 7.40.

3.13.2.4. Identify the number of samples in each class to determine the frequency of occurrence and enable the construction of the Histogram. These counts give a horizontal Histogram.

(H) Class	**Number of Counts**	**Total**
7.00 - 7.19	I	1
7.20 - 7.39	~~IIII~~	5
7.40 - 7.59	~~IIII~~ ~~IIII~~ II	12
7.60 - 7.79	~~IIII~~ ~~IIII~~ ~~IIII~~	15
7.80 - 7.99	~~IIII~~ ~~IIII~~ ~~IIII~~ III	18
8.00 - 8.19	~~IIII~~ ~~IIII~~ II	12
8.20 - 8.39	~~IIII~~ III	8
8.40 - 8.59	II	2
8.60 - 8.79	II	2
n = 75		

3.13.2.5. Construct the Histogram to show the samples in each class for this example. The data in this example is centered around a value of 7.90 and is very close to a bell shaped curve. The Histogram gives a view of where the counts are centered and the amount of dispersion of the data. See Figure 3.7.

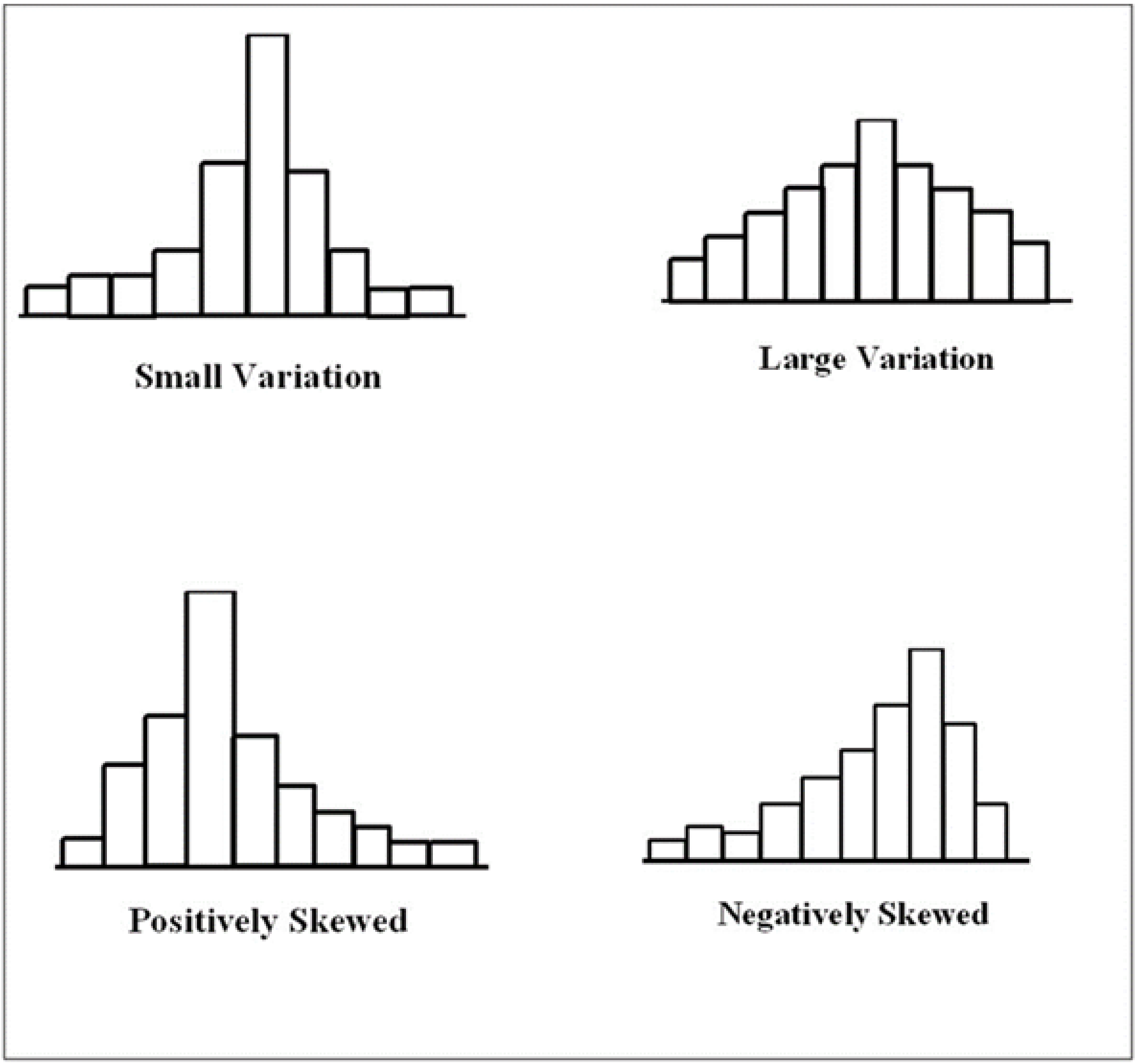
Figure 3.7. Histogram of Data.



3.13.3. The data in a Histogram may not always be symmetrical as depicted in the example. The data could be tightly centered around a point or greatly dispersed, or even bi-modal (having two distinct clusters around separated frequencies) potentially indicating two separate populations under study. In each case, evaluating the results of the chart furnishes useful information about the event or process being analyzed. See Figure 3.8.

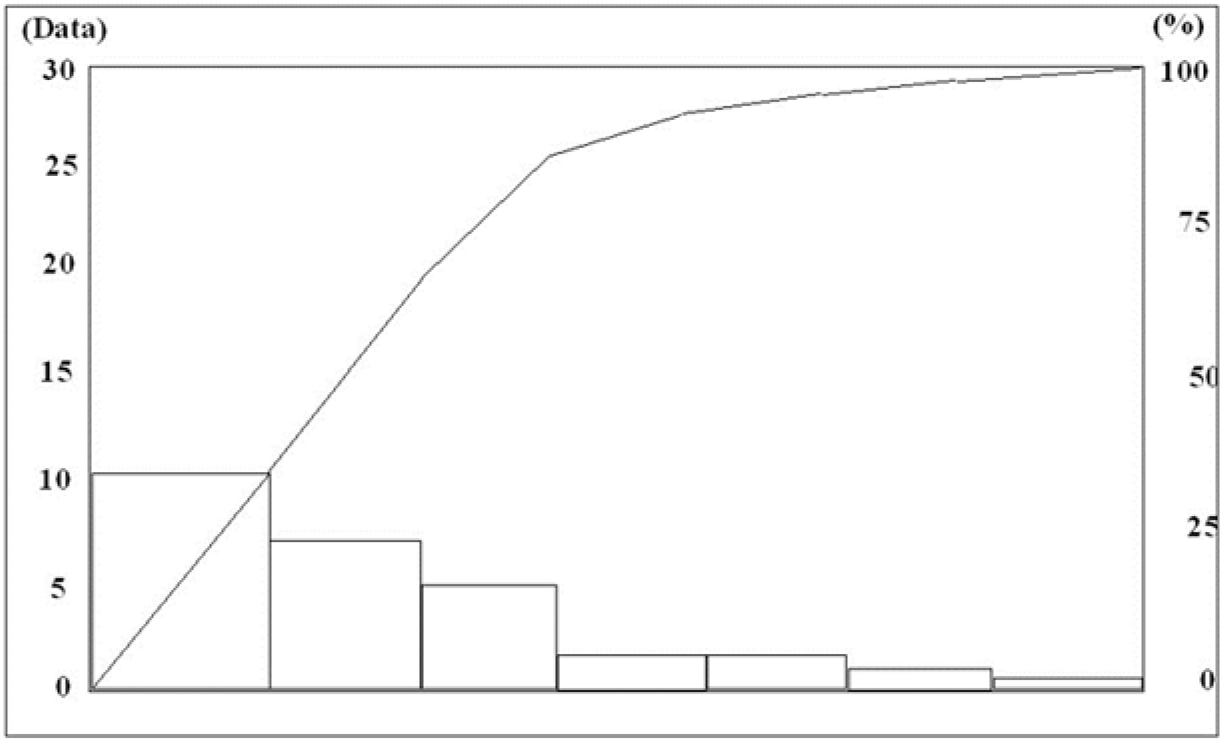
3.13.4. Be aware of twin or multiple peaks. Their appearance indicates the data is coming from two or more different sources. If this is the case, stratify the data so the histogram uses only one data source.

Figure 3.8. Four Histograms Displaying Potential Results.



3.14. Pareto Chart General Concepts. A Pareto chart identifies problems that should be solved first in terms of complaints, defects or cost. The Pareto chart is useful because it shows the areas experiencing the most problems and should be addressed first for correction. See Figure 3.9. Pareto analysis is a statistical technique in decision-making used for the selection of a limited number of tasks that produce a significant overall effect. Utilizing this principle, also known as the 80/20 rule, roughly 80% of a work centers processes come from 20% of the efforts.

Figure 3.9. Pareto Chart.



3.15. Procedures to Construct a Pareto Chart. Determine what factor (cost, defects, etc.) you want to use to evaluate different processes. The samples for this factor are itemized into the processes you'll evaluate. For example, if errors are occurring in a supply organization you can evaluate the number of errors in the processes of Receiving, Shipping, Storage, Delivery, etc. For documentation and validation purposes, specify the source of all counts.

3.15.1. Select a period of time to evaluate. The time period can range anywhere from a day, week, month, quarter to years. The samples for each process evaluated should come from the same time period for meaningful evaluation.

3.15.2. Draw horizontal and vertical axis for the diagram. The processes are listed along the horizontal line. The samples for the factor being evaluated are scaled on the left vertical axis. Values of 0 to 100% are scaled along the right vertical axis.

3.15.3. Total the samples for each process and use bars to represent the process. The process with the largest total of samples is placed first on the far left. The remaining processes are entered, ranging from those with the largest samples to the smallest. If several processes have few samples, combine the samples and identify as other.

3.15.4. Use a line to show the cumulative total when adding each additional process. The line goes from the tallest bar to the right and up until it reaches the right axis at the 100% point.

3.15.5. Usually, the tallest bars indicate the largest contributors to the overall problem. Dealing with these areas first is logical. However, most frequent doesn't necessarily equate to most important.

3.16. How to Use a Pareto Chart. Use care when selecting the factor to evaluate different processes as potential candidates for problem solution. Using total defects can show one process as a potential candidate. But, by selecting cost of defects, a different process may show a larger impact. When a change is made to a process as a solution to a problem, draw another Pareto chart after operating under the new process and check if the process has decreased in relation to the other processes evaluated.

3.17. Scatter Diagram General Concepts. The scatter diagram shows the relationship between two variables. The relationship is termed correlation or the influence one variable has on the other. The variables could come from the potential WLFs of a determinant study, a cause-and-effect diagram, or any other source generating variables. The diagram is composed of an x-axis and y-axis. The effected variable is placed on the y-axis and the cause variable is placed on the x-axis.

3.17.1. Procedures to Develop a Scatter Diagram. Draw a scatter diagram by collecting the data to plot the samples. The individual samples are formed by the intersection of the (x, y) values.

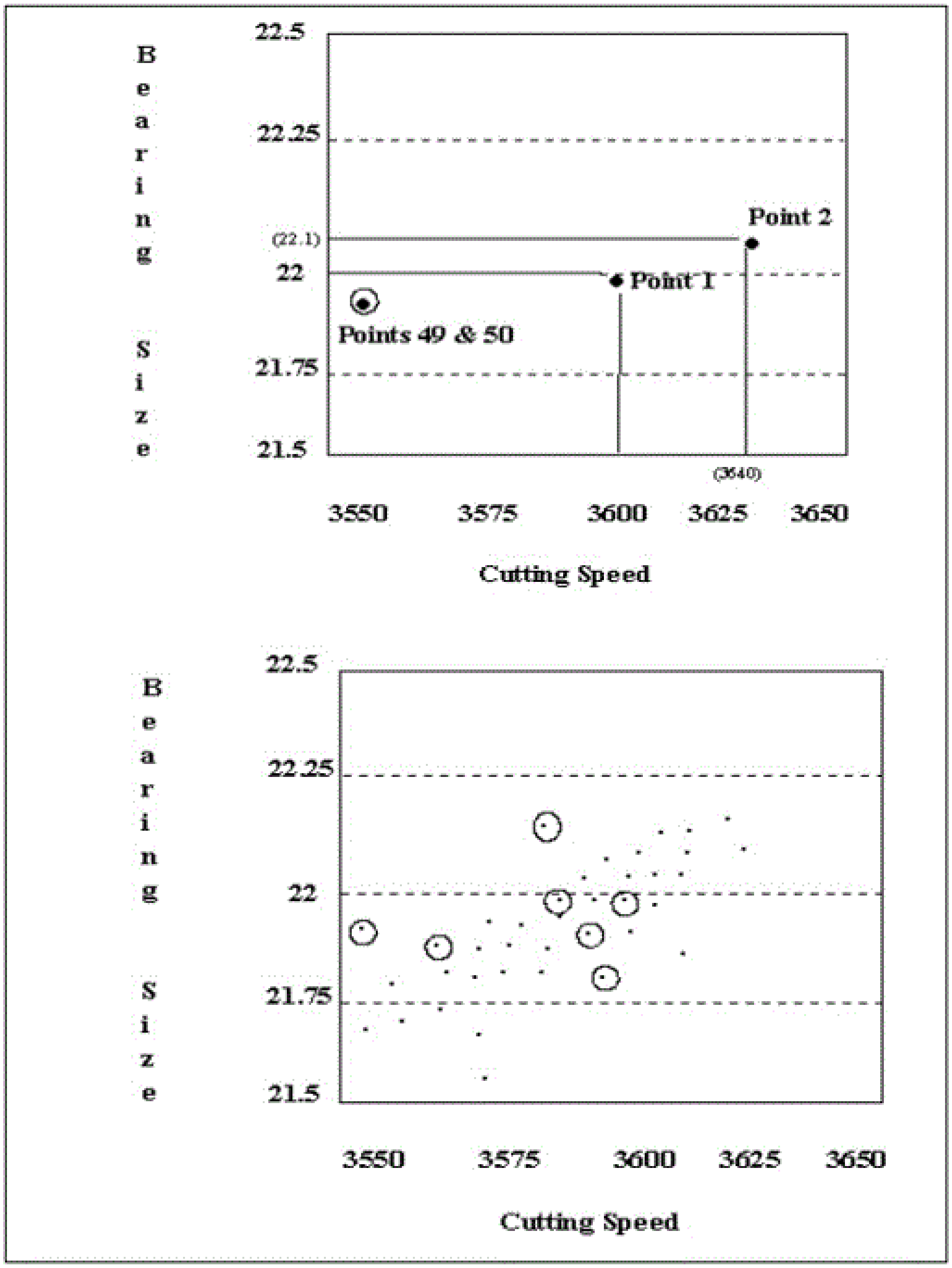
3.17.1.1. Collect 50 to 100 (x, y) data pairs that form the samples on the diagram. See Table 3.3 for a partial listing of point pairs.

Table 3.3. A Partial Listing of Data Point Pairs.

Number	Bearing Size (mm)	Cutter Speed (rpm)
1	22.0	3600
2	22.1	3640
49	21.9	3550
50	21.9	3550

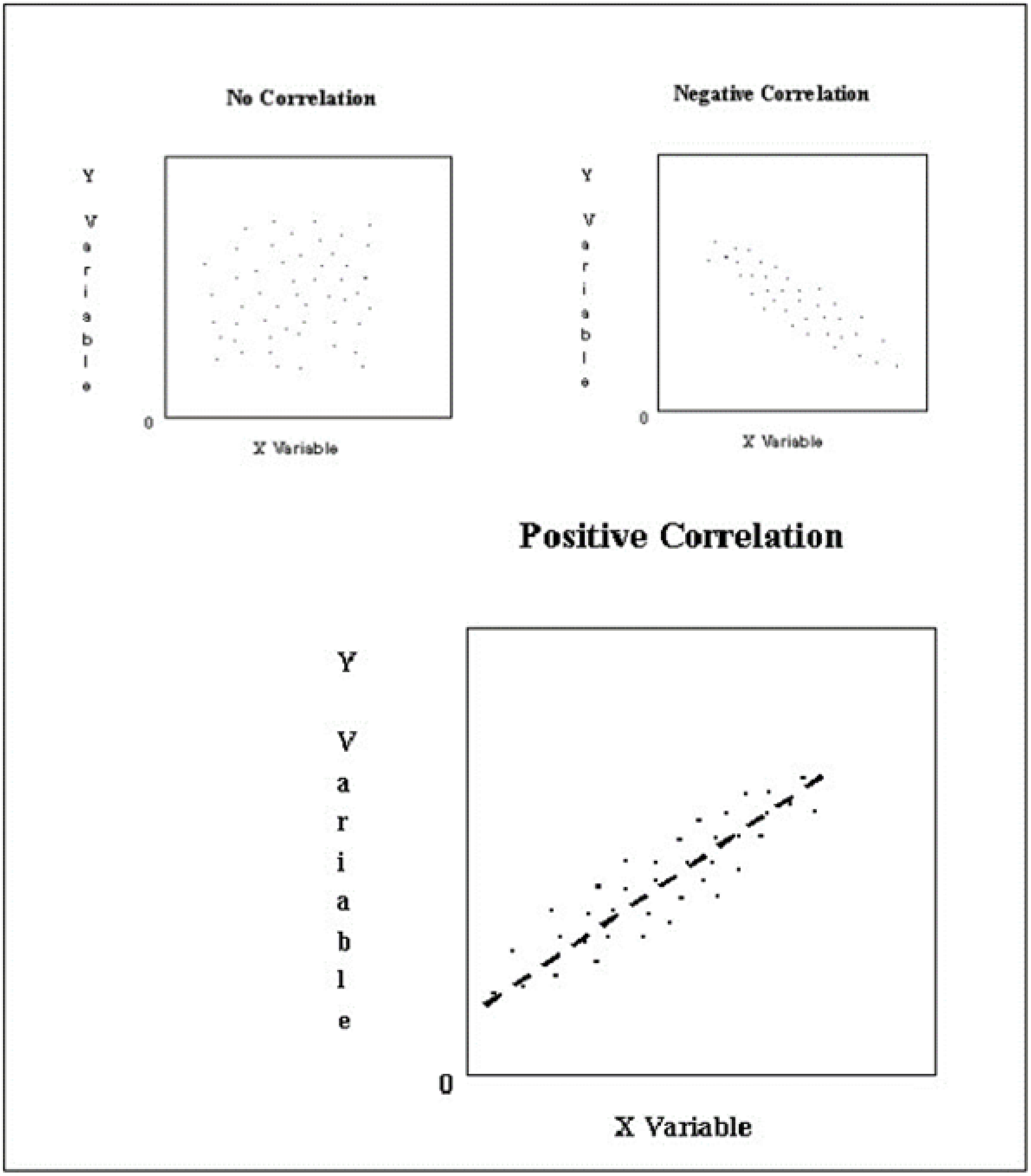
3.17.1.2. Draw and label the x-axis and y-axis. Plot the individual samples on the scatter diagram. If samples overlap, place concentric circles around the point, with a circle representing each additional point. See Figure 3.10 for an example of how to plot the samples and a scatter diagram.

Figure 3.10. Plotting a Scatter Diagram.



3.17.2. How to Interpret a Scatter Diagram. After the samples are plotted on the chart, observe if one variable affects the other. See Figure 3.11 for a variety of possible results.

Figure 3.11. Scatter Diagram Outcomes.



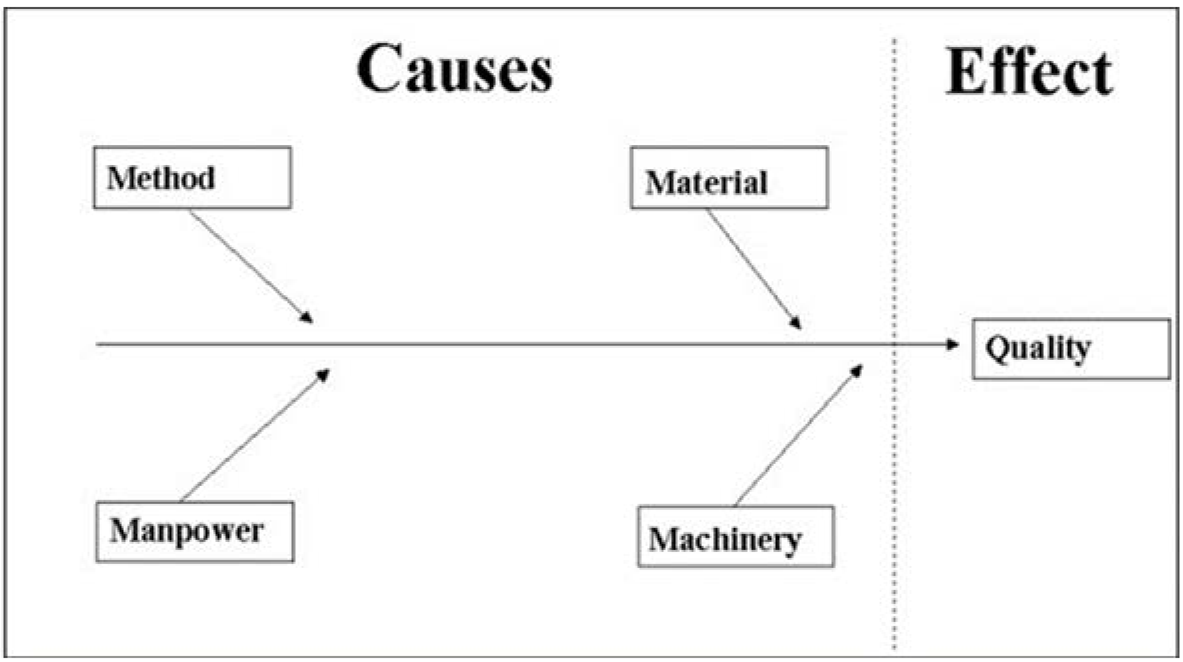
3.17.2.1. If, as one variable increases in value the other also increases, there is a positive relationship or correlation. The closer the samples are to an imaginary line extending from the lower to the higher samples the stronger is the impact of one variable on the other. The more dispersed the samples from the imaginary line the weaker the relationship.

3.17.2.2. The diagram indicating No Correlation shows the data points scattered all over the diagram. There is no indication of a distinguishable impact of one variable on the other.

3.17.2.3. The diagram indicating Negative Correlation shows as one variable increases in value, the other decreases. As with Positive Correlation, the closer the samples are to an imaginary line extending from the lower to the higher samples, the stronger the impact of one variable on the other.

3.17.3. Cause-and-Effect Diagram General Concepts. A cause-and-effect diagram (also known as an Ishikawa Diagram) is used not only to identify a potential problem but also to analyze it as well. Any problem can have many possible causes. The cause-and-effect diagram allows the user to identify potential causes of a problem in logical groups depending on the problem type. The primary factors causing a product or service quality problem usually relate to unwanted changes in manpower, work processes, equipment, or raw materials. To find the elements coming into play, follow a logical approach to identify the potential causes of a problem. Figure 3.12 illustrates the structure of a cause-and-effect diagram.

Figure 3.12. Cause-and-Effect Diagram.

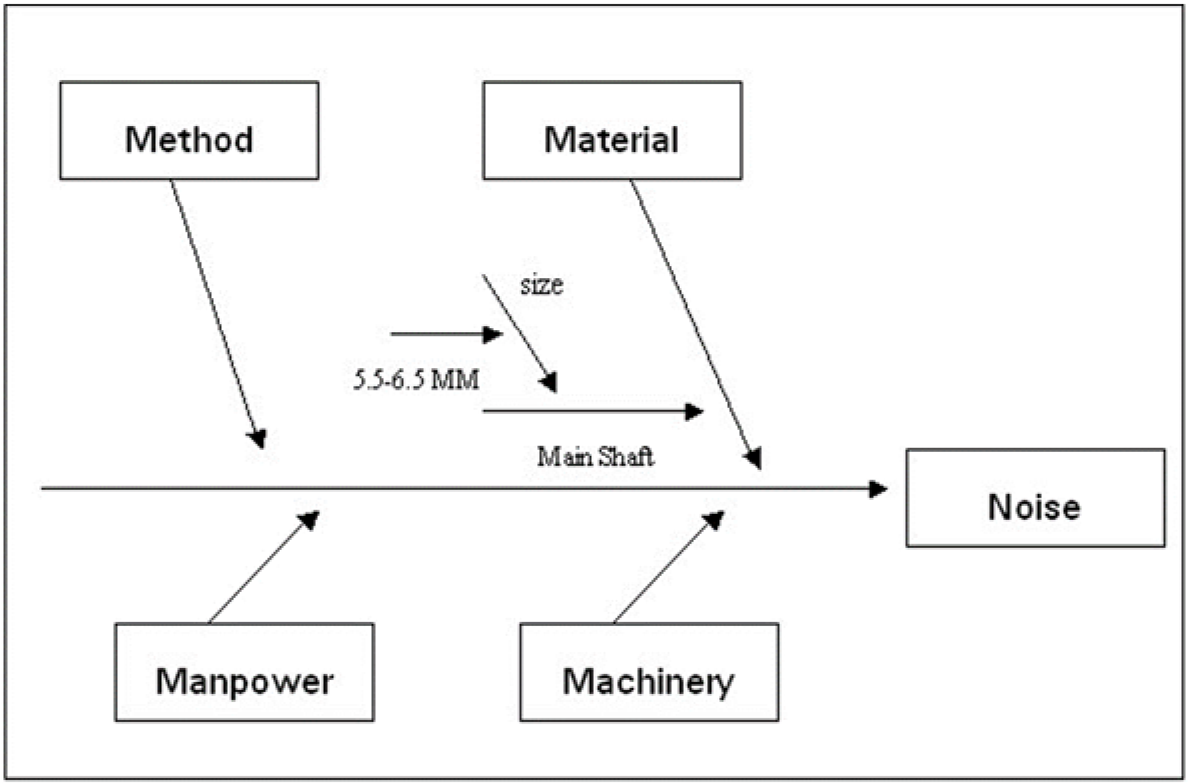


3.17.4. Procedures to Develop a Cause-and-Effect Diagram. Identify what the problem is and briefly state it on the right side of the diagram. Enclose this statement in a box. Draw an arrow towards the problem statement extending to the left.

3.17.4.1. Identify the major categories of causes that potentially could cause the problem. Connect these categories to the line pointing to the problem statement.

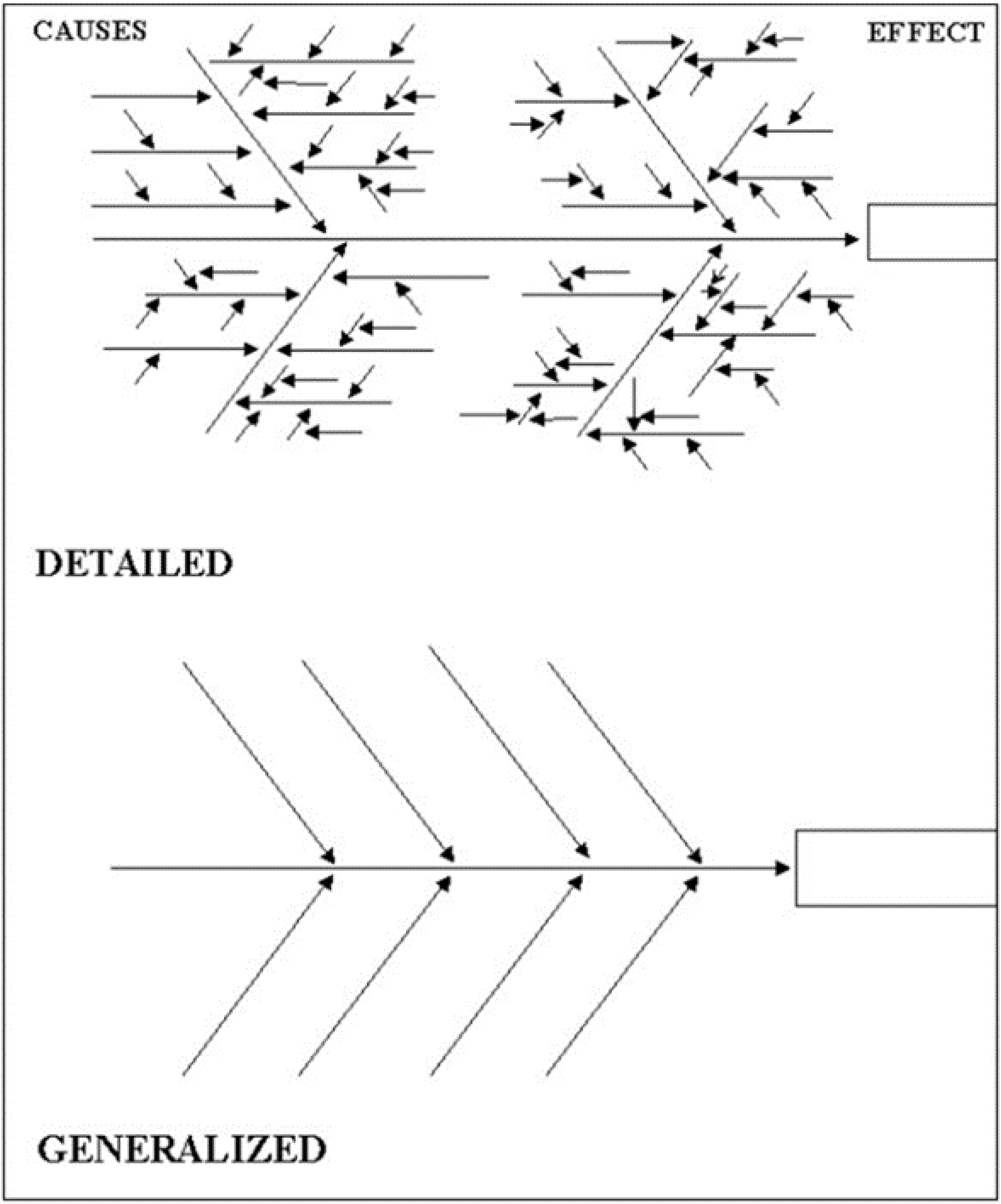
3.17.4.2. List the factors in each of these categories that could cause the problem, using an idea generating methodology such as the Nominal Group Technique or Brainstorming. Each of these branches can have branches identifying more specific causes of the stated problem. See Figure 3.13 for an example of this branching.

Figure 3.13. Detailed Listing of Causes.



3.17.4.3. A very important element of identifying the potential causes of a stated problem is to have personnel familiar with the needs for completing the product or service. If a knowledgeable group of people is present, a very detailed breakdown of potential causes can be identified. If the personnel are not familiar with the processes or needs, then too generalized a listing of potential causes could result. See Figure 3.14.

Figure 3.14. Detailed and Generalized Listing of Causes.



3.17.5. Benefits of Using a Cause-and-Effect Diagram. Any type of problem can be displayed on a cause-and-effect diagram. It doesn't have to relate to quality or timeliness. For example, personnel, safety, and scheduling problems can also be analyzed using this diagram.

3.17.5.1. The level of knowledge about the factors influencing the problem is soon evident by the level of detailed breakdown of the potential causes of the problem. The more branches to the causes the greater the depth of knowledge of the personnel generating the causes.

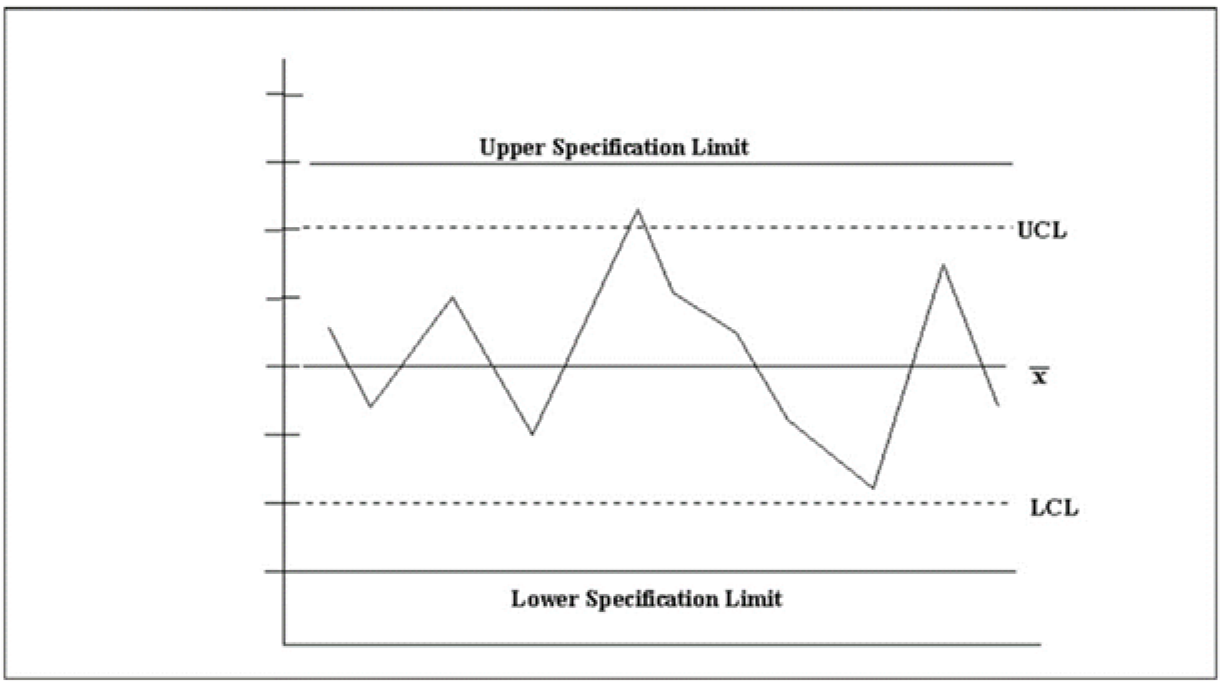
3.17.5.2. The cause-and-effect diagram allows the participants to visually focus on the various categories of causes that could impact a problem. This makes it easier for the group to focus on generating potential causes.

3.17.5.3. All personnel participating in the analysis gain from the interaction of ideas produced in the group. This interaction not only serves the purpose of generating ideas for solving a problem, but also aids in educating the participants about the various factors impacting the problem being addressed.

3.18. Control Chart General Concepts. A control chart is an effective tool for determining if samples come from the same population and if the variation between samples is sufficiently small to allow the use of the mean as the sole descriptive statistic of the population.

3.18.1. Control charts (See Figure 3.15) give important graphical information to help determine where variation in a process might be normal or abnormal with the latter case requiring further analysis. By plotting the sample points in time order (in sequence of occurrence), control charts can identify unusual changes in the process indicating the need for further analysis. There are several distinct data patterns indicating whether an ME analyst should explore data to include in analysis these patterns are shown in Figure 3.15.

Figure 3.15. Examples of a Control Chart.



3.18.2. There are two main types of control charts - for attributes data and for variables data. Attribute control charts are used to plot go or no-go factors such as an output being in or out of tolerance. Variable control charts plot specific measurements of a variable characteristic such as size, time, or weight of an output.

3.19. Description of Terms.

3.19.1. Assignable Cause. Any force and/or situation, not deemed part of the defined population that causes a sample to deviate significantly (exceeding established control limits) from the mean. For example, a certain population of proportions may be defined as being "the level of daily productivity associated with the production of 40 to 60 units. If one day’s productivity exceeded the Upper Control Limit (UCL) and the associated workload was 75 units, an ME analyst would know some force, not inherent to the defined population, was at work.

3.19.2. Common Cause. A host of small, independent, and elusive forces acting on events or measurements. Chance is normally responsible for the unassignable variation between elements of a population.

3.19.3. Observation. The selection of one element of a population.

3.19.4. Population. Any set of objects that an ME analyst may care to define. Each member of a population is called an element.

3.19.5. Range. The difference between the highest and lowest value of any set of elements or observations.

3.19.6. Sample. In this context, sample is assumed to be a random sample. A random sample is the selection of one or more elements of a population - each element having the same probability of being selected.

3.19.7. Sample Size (n). A sample may consist of one or more observations, i.e., the number of observations is the size of the sample. For example: 23 (sample size is 1); 23, 27, 22, 21 (sample size is 4); and 20, 22 (sample size is 2).

3.19.8. Standard Deviation. The square root of the variation. The formula is:

$$\boldsymbol{s} = \sqrt{\sum_{i=1}^{n} \frac{(x_i - x)^2}{n - 1}}$$

3.19.9. Variation (s2). The average of the squared deviation from the mean. It’s written as:

$$\frac{\Sigma(x - \bar{x})^2}{n} \; or \; \frac{\Sigma(x - \bar{x})^2}{n - 1}$$

3.19.10. Use n-1 when the sample size is 30 or less. The formula is:

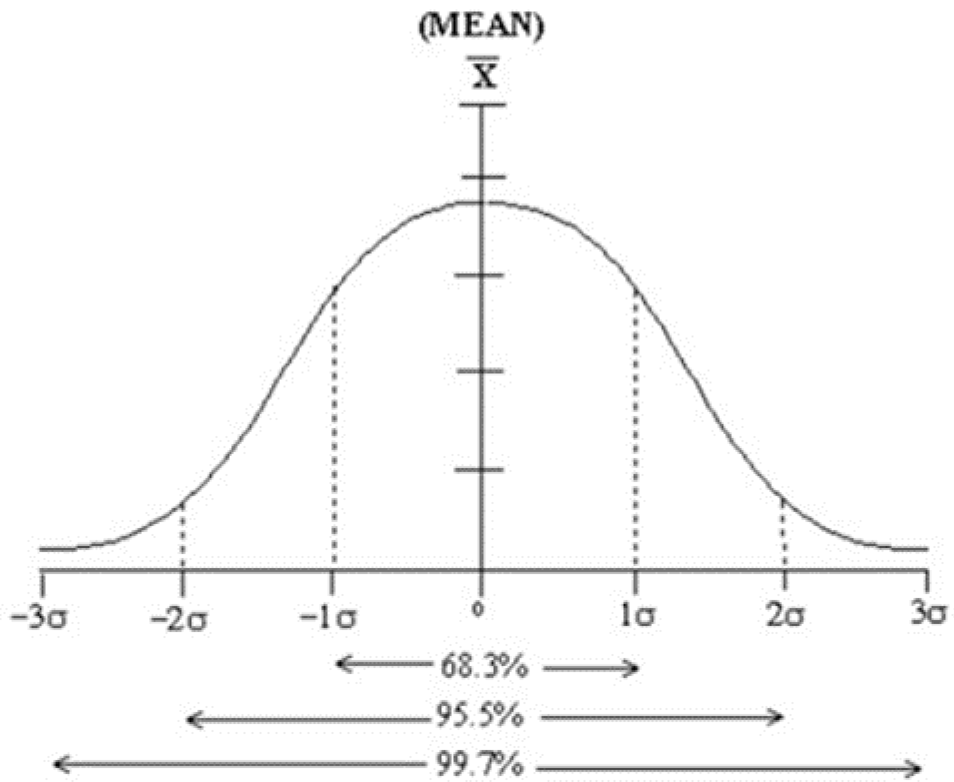
$$s^2 = \sum_{x-1}^{n} (x_i - \bar{x})^2 / n - 1$$

3.20. Control Chart Description. Descriptive statistics enable ME analysts to compile information in numerical form about populations. Two characteristics of populations lend themselves to numerical description - the central tendency and the dispersion of populations. By combining a visual representation of data with numerical descriptions, control charts enable ME analysts to make a visual and numerical analysis of the population.

3.20.1. A control chart is a graph with a centerline, upper and lower control limits (LCL), and sample points. The center line is usually the average (central tendency) of the samples. The control limits are the expected limits of the population based on the number of samples and dispersion. The most used measure of central tendency is the mean and the measure of dispersion is the standard deviation. Control limits are determined by adding and subtracting one or more standard deviations from the mean (See Figure 3.16). The limits are derived mathematically by sampling data from the process. In Figure 3.16, the process is within specifications, but it's not stable. To meet the customer's needs, all process samples should be within the UCL and LCL. The variation displayed in the chart can be decreased further by improving the process used to furnish the product or service to the customer. The normal curve (See Figure 3.9) has 68.3% of the data points falling within one standard deviation (plus or minus) from the mean; 95.5% of the data points fall within two standard deviations from the mean; and 99.7% of the data points fall within three standard deviations.

3.20.2. Construct a control chart to display data samples using the steps outlined below.

Figure 3.16. Standard Deviation Curve.



3.20.2.1. Get samples from the process being monitored.

3.20.2.2. Compute the mean by summing all data values together and then dividing that total by the number of counts.

3.20.2.3. Compute the Control Limits (UCL and LCL). The formula used varies depending on which chart you are using. Refer to Table 3.4 for the formulas.

Table 3.4. Control Chart Center Line and Control Limits.

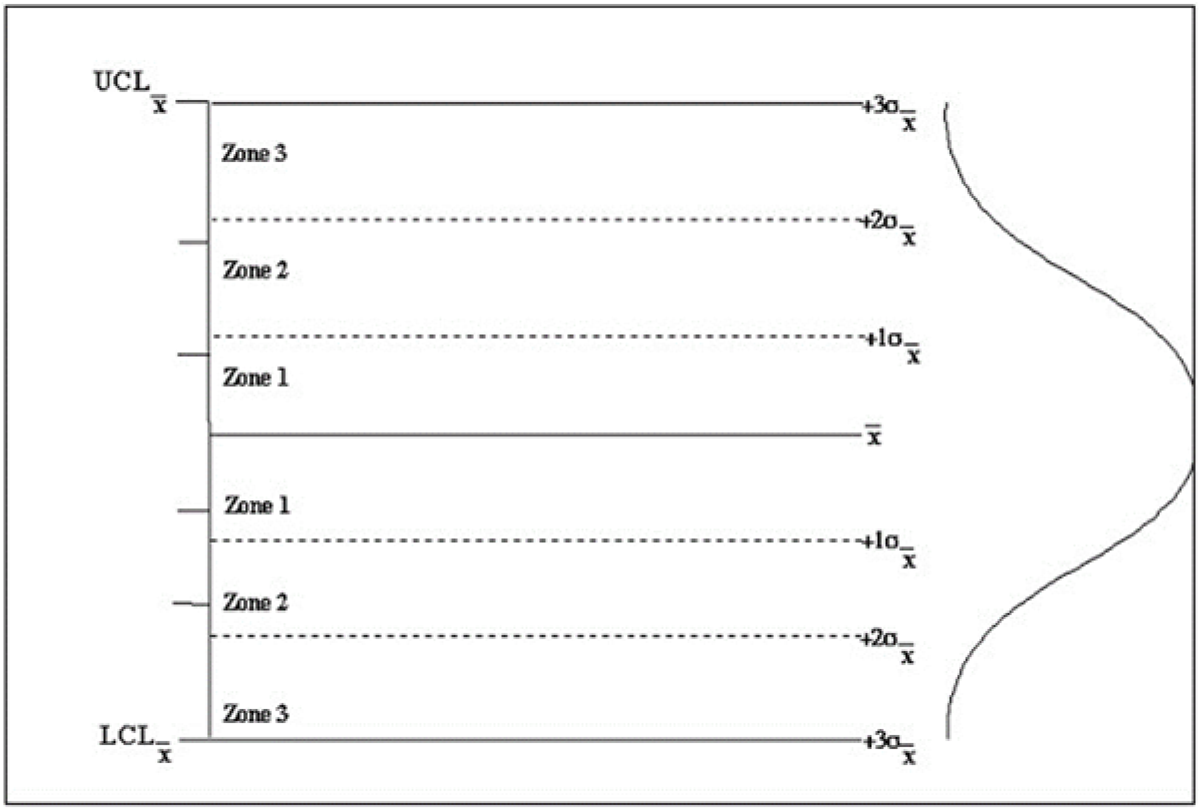
LINE	A	B	C	D	E	F
	For Control Chart	with center line	first compute SYX or mean using	Next compute control limits using UCL	LCL	Notes
1	p	$\bar{p}$	$s = \sqrt{\frac{\bar{p}(1-p)}{n}}$	$\bar{p} + 3s$	$\bar{p} - 3s$	$p = \frac{\#\ of\ rejects(subgroups)}{\#\ of\ inspected(subgroups)}$
2	np	$\overline{np}$	$s = \sqrt{n\bar{p}(1-p)}$	$n\bar{p} + 3s$	$n\bar{p} - 3s$	$\bar{p} = \frac{Total\ \#\ rejects}{Total\ \#\ inspected}$
3	C	$\bar{c}$	$s = \sqrt{\bar{c}}$	$\bar{c} + 3s$	$\bar{c} - 3s$	$\bar{c} = \frac{Total\ \#\ defects\ per\ sample}{Total\ \#\ sample\ days}$
4	U	$\bar{u}$	$s = \sqrt{\frac{\bar{u}}{n}}$	$\bar{u} + 3s$	$\bar{u} - 3s$	
5	X	x	$\bar{x} = \sqrt{\frac{x_1 + x_2 + \dots + x_n}{n}}$	$\bar{\bar{x}} + A_2\bar{R}$	$\bar{\bar{x}} - A_2\bar{R}$	$n = \#\ of\ samples$ $A_2 = \left(\frac{3}{d_2\sqrt{n}}\right)$
			$\bar{\bar{x}} = \sqrt{\frac{x_1 + x_2 + \dots + x_n}{k}}$			$k = \#\ of\ subgroups$ $(20 - 25\ groups)$
6	R	R	$R = x_{max} - x_{min}$	$\bar{R}D4$	$\bar{R}D3$	
			$\bar{\bar{R}} = \sqrt{\frac{R_1 + R_2 + \dots + R_n}{k}}$			$R = x_{max} - x_{min}$

3.20.2.4. Calculate the Standard Deviation. Each standard deviation is identified as a zone.

3.20.2.4.1. Add three standard deviations to the process average (mean) for the zone limits 1, 2, and 3 above the center line.

3.20.2.4.2. Subtract three standard deviations from the process average for the limits 1, 2, and 3 below the center line. Draw the X, and Y axis; process center line; UCL, LCL, and Zones (1, 2, and 3) on the control chart. See Figure 3.17.

Figure 3.17. Control Chart with Three Standard Deviations.



3.20.2.5. Plot and connect the sample data points.

3.20.2.6. Analyze the data by looking for out-of-control and unnatural conditions.

3.20.3. If samples are within three standard deviations, analyze variation to determine if the mean can be used as the sole descriptive statistic of the population. Some populations have such broad limits the mean alone has little value as a description of the population. Observe how the standard deviation compares to the size of the mean. If the standard deviation is small compared to the mean, the mean can be used as the sole descriptive statistic of the population.

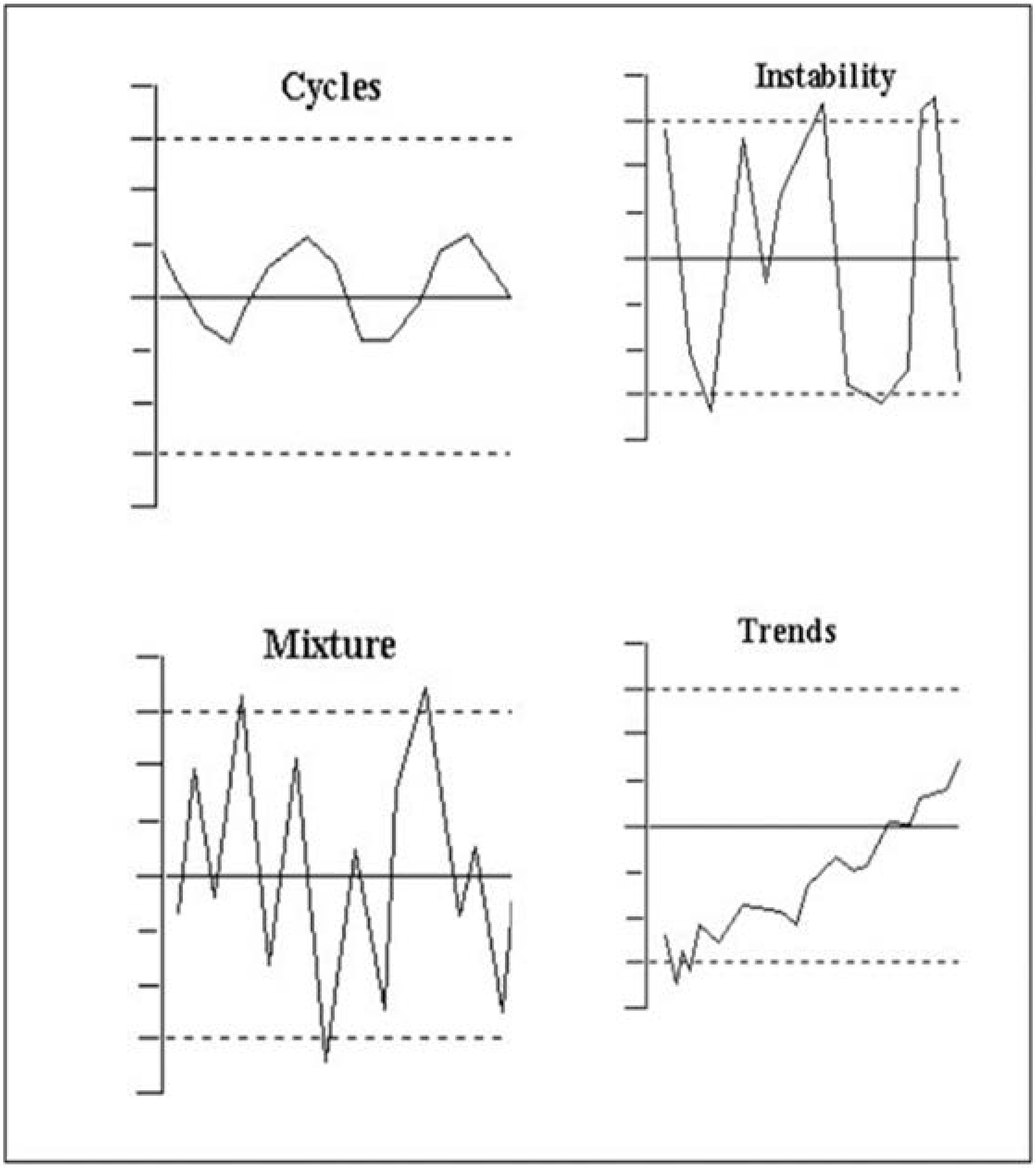
3.20.4. Analyzing Control Charts. After building a control chart and plotting the data on it, analyze what the data is saying about the process. As mentioned earlier, if the data on the control chart forms a normal curve (natural pattern), the points fluctuate at random and settle around the mean (center line). A few points may fall near the control limits (UCL, LCL), but none of the points should exceed the control limits. A normal curve shows there is a steady, stable process not being disturbed by assignable causes from outside the process.

3.20.4.1. If one of the data points exceeds the UCL or falls below the LCL, the process is "out-of-control. When this condition exists, investigate the process to identify the cause of the variation and correct it. Assignable causes of variation (e.g., machine out of alignment, fatigued worker, etc.) can be corrected bringing the process back into control.

3.20.4.2. When the correction or adjustment for assignable cause is made, the process variation should resume its normal distribution pattern between the UCL and LCL of the control chart. This normal amount of variation (normal distribution) is due to common causes of variation. Common causes of variation, unlike assignable causes, cannot be entirely eliminated from a process. However, management can take action to improve the overall process and reduce the amount of variation due to common causes by setting up process action teams, or providing training.

3.20.4.3. Having data points fall outside of the control limits is not the only indicator of an out-of-control condition. Data that fluctuates too widely or fails to fall around the mean can be classified as unnatural patterns of variation. An unnatural pattern usually shows an abnormal condition is occurring or beginning to occur in the process. It needs to be investigated as a problem source or area of concern. There are several types of unnatural patterns of variation (See Figure 3.18).

Figure 3.18. Examples of Unnatural Patterns of Variation.



3.20.4.4. Cycles. A short trend in the data that occurs in a repeated pattern where the pattern becomes predictable or systematic. This is an indication of an assignable cause because a characteristic of a normal (random) pattern is that it does not repeat. A cycle is caused by a process variable that comes and goes on a regular basis.

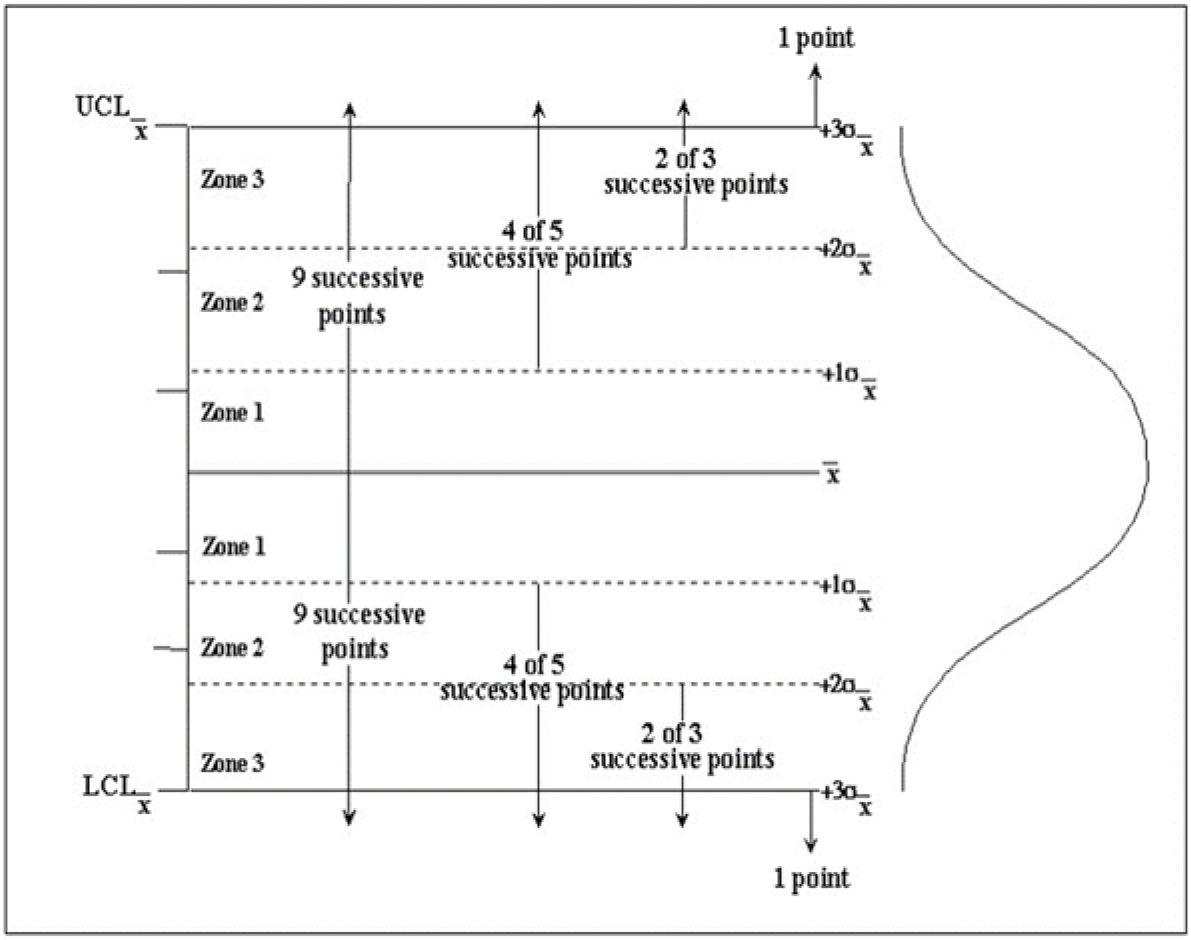
3.20.4.5. Instability. It is identified by wholly erratic fluctuations going beyond the control limits or showing erratic upward and downward movement.

3.20.4.6. Mixture. A pattern falling near the control limits with an absence of points near the center line. This pattern is more commonly known as the saw tooth effect. A mixture is actually a combination of two different populations on the same chart.

3.20.4.7. Trends. A series of points showing a steady change in one direction, either up or down the control chart. Even if there is up and down movement of successive points, if the general direction of the points exhibit either an upward or downward movement, it can also be considered a trend.

3.20.4.8. There are some other out-of-control or abnormal condition indicators. Each show something unusual is happening in the process needing to be investigated (See Figure 3.19).

Figure 3.19. Abnormal Data Point Occurrences.



3.20.4.9. Two out of three successive points in Zone 3, on the same side of the center line.

3.20.4.10. Four out of five successive points in Zone 2 or beyond, on the same side of the center line.

3.20.4.11. Nine successive points on one side of the center line.

3.20.5. After building the control chart, plotting the data points, and interpreting the results, if no out of control conditions are found, the process is considered in control and free of assignable causes of variation. Continue using control charts to monitor the process and make sure it stays in control. Concentrate your efforts on reducing the common (random) causes of variation. This is how to achieve continuous improvement in a process.

3.20.6. This brief introduction on control charts with respect to construction and use, gives enough information to allow ME analysts to look at some specific types of control charts. The number of samples used in each example shouldn't be considered to be a sufficient number for analysis. Strong analyses and conclusions depend on many more samples than used in the examples.

Chapter 4

CONTROL CHARTS FOR ATTRIBUTE DATA

4.1. Attribute Data. Attribute data are usually obtained by counting the number of items in one of two categories; e.g., go or no-go, pass or fail. For example, a light bulb either lights up or it doesn't light. In attributes data, the item either has the characteristic or it doesn't.

4.1.1. Attribute control charts are useful in analyzing factors such as effectiveness, efficiency, document errors, reducing backlog and other forms of manpower analysis. These charts are useful when there are many processes to monitor. There are basically four types of attribute control charts: two types count the number of nonconforming parts or items, and two types count the number of nonconformities on a particular part or item.

4.1.1.1. The two types of attribute control charts counting nonconforming parts or items are the NP and the P-Charts. The NP-Chart plots the number of nonconforming parts or items in a sample and is used when the sample size is constant (5 items repaired each day). The P-Chart plots the percentage of nonconforming parts or items and is used when the sample size varies (15 items on day 1, 20 items on day 2, 25 items on day 3, etc.).

4.1.1.2. The two types of attribute control charts counting the number of nonconformities on a particular part or item are the C-Chart and the U-Chart. The C-Chart plots the number of nonconformities per sample and is used when the sample size is constant. The U-Chart plots the number of nonconformities per individual unit and is used when the sample size varies such as comparing documents differing in size.

4.1.2. Using a P-Chart. The P-Chart may be used when it's necessary to determine if sample proportions come from the same population. For example, ME analyst may use the P-Chart in WS to analyze the stability of daily productivity (the daily ratio of productive time to available or assigned time); and ME analyst can use the P-Chart to determine what proportion of a given number of items expected to be effective. The latter use is valuable if a work center's output is produced by defective items; using the samples of the items, plot the sample proportions of defective items to total items, evaluate the P-Chart, and arrive at a reasonable conclusion about the stability of the mean and dispersion of the population. As an example, let's analyze the proportions of defective widgets produced at an Air Force base. There are 800 widgets produced each day of the study (n = 800). As an example, an ME analyst decided to analyze the proportions of defective widgets produced at an Air Force base and collects data over a 10-day sampling period as shown in Table 4.1.

Table 4.1. Example P-Chart Data.

SAMPLE (DAYS)	NO. OF DEFECTIVES (x)	p (x/800)
1	36	0.0450
2	42	0.0525
3	42	0.0525
4	40	0.0500
5	42	0.0525
6	40	0.0500
7	60	0.0750
8	40	0.0500
9	26	0.0325
10	66	0.0825
N = 10	x = 434	

4.1.2.1. Calculate the mean proportion.

$$\bar{p} = \frac{\sum x}{N_n} \xrightarrow{yields} \frac{434}{10(800)} = 0.0543$$

4.1.2.2. Calculate the standard deviation.

$$s^2 = \frac{\bar{p}(1-\bar{p})}{n} \xrightarrow{yields} \frac{0.0543\ (0.9458)}{800} = 0.000064$$

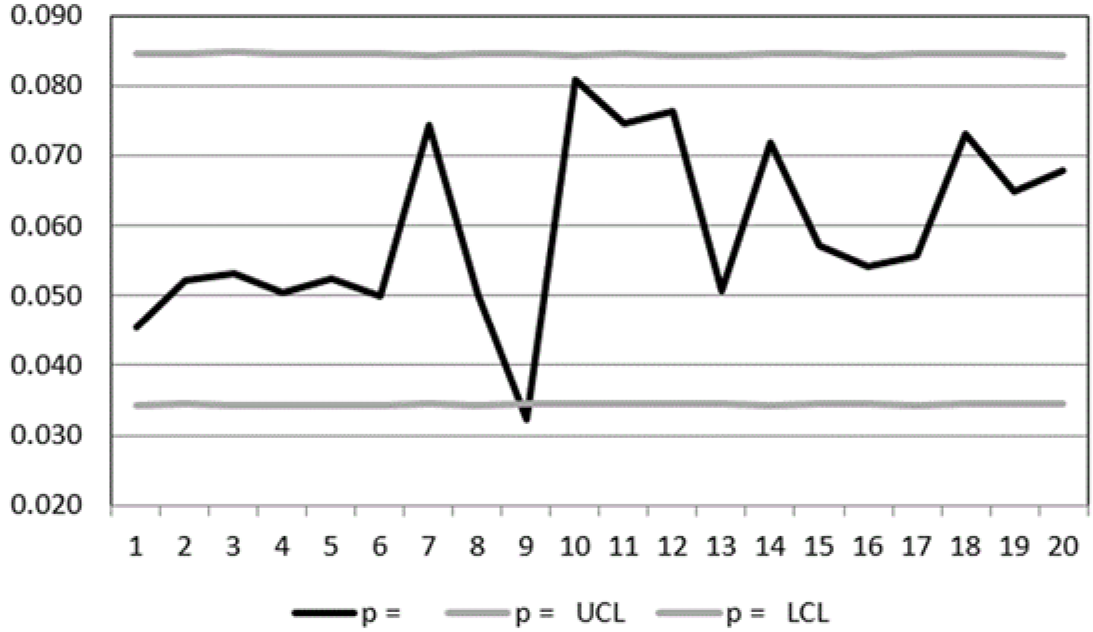
$$s = .0080$$

4.1.2.3. Calculate the control limits.

UCL	LCL
$UCL = p + 3s$	$LCL = p - 3s$
$UCL = 0.0543 + 3(0.0080)$	$LCL = 0.0543 - 3(0.0080)$
$UCL = 0.0783$	$LCL = 0.0303$

4.1.2.4. Plot the P control chart (Figure 4.1).

Figure 4.1. Example of a P-Control Chart.



4.1.3. Analyze the control chart.

4.1.3.1. Using a C-Chart. Another type of control chart for attribute data is the C-Chart. The letter c denotes the number of defects per item or group of items. The c symbol (c-bar) represents the mean number of defects. The standard deviation of the population is estimated by the square root of c.

4.1.3.2. Use the C-Chart when these two conditions are present: first, the average number of defects are far less than could occur if everything went wrong; and second, the area of opportunity for defects is the same. The latter condition means when you group elements, always use the same number of elements per group.

4.1.3.3. As an example, analyze the number of defects per group of five equipment benches checked by the personnel of a Communication Navigation work center. The conditions described above were met because each group of five equipment benches checked have considerably fewer defects than possible, if everything went wrong. Each group of five units gives a constant area of opportunity. Ten samples are taken as shown in Table 4.2.

Table 4.2. C-Control Chart Sample Data.

SAMPLE (DAYS)	NO. DEFECTS PER SAMPLE
1	3
2	0
3	4
4	1
5	6
6	8
7	3
8	2
9	1
10	4
n = 10	$\Sigma c = 32$

4.1.3.3.1. Compute the mean number of defects.

$$\bar{c} = \frac{\sum c}{n} \xrightarrow{yields} \bar{c} = \frac{32}{10n} \xrightarrow{yields} \bar{c} = 3.2$$

4.1.3.3.2. Compute the standard deviation.

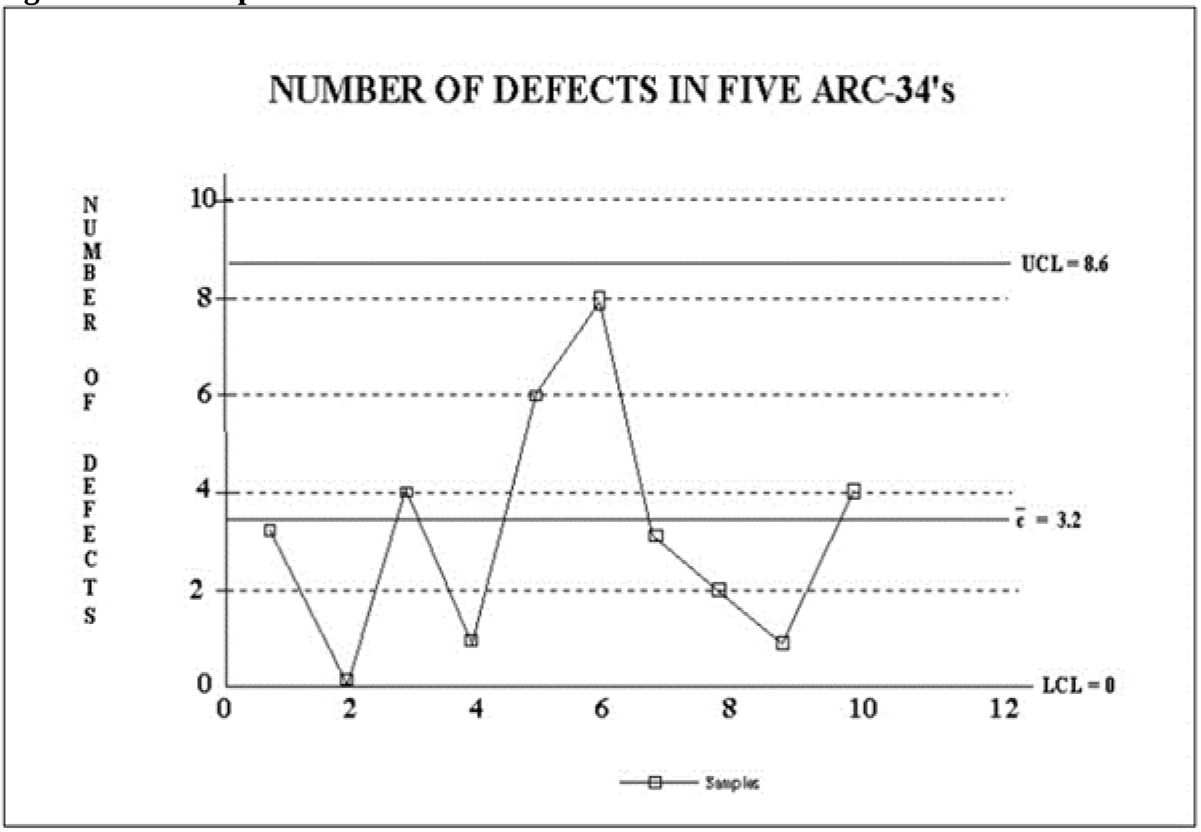
$$s^{2=}\bar{c} \xrightarrow{yields} s = 1.8$$

4.1.3.3.3. Compute the control limits.

UCL	LCL
$UCL = c + 3s$	$LCL = c - 3s$
$UCL = 3.2 + 3(1.8)$	$LCL = 3.2 - 3(1.8)$
$UCL = 8.6$	$LCL = -2.2$
	(For our purposes - LCL = 0)

4.1.3.3.4. Plot the C control chart. Finally, the ME analyst needs to plot c-bar, the UCL, LCL, and the count of defects for each sample as shown in Figure 4.2.

Figure 4.2. Example of a C Control Chart.

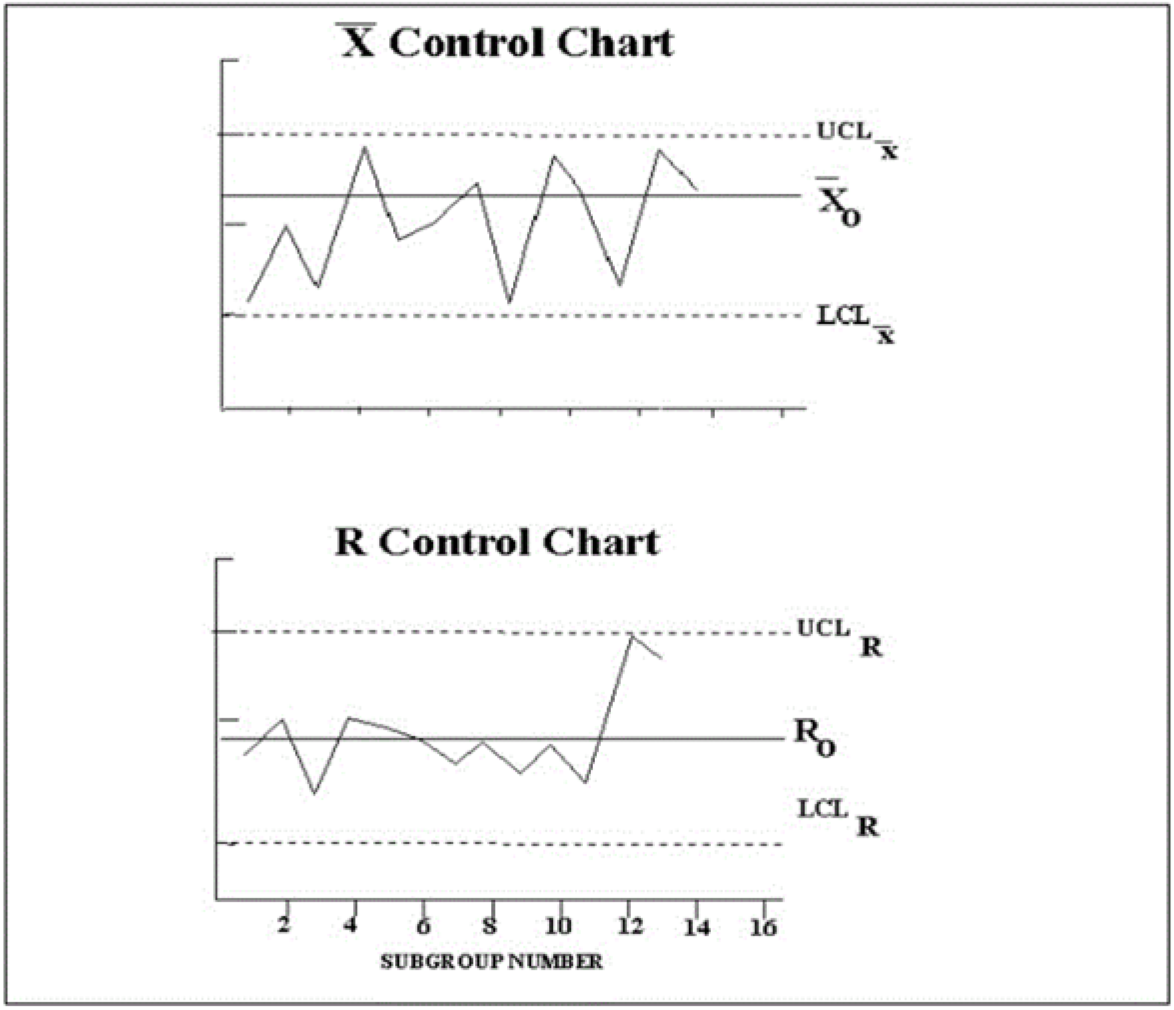


4.1.3.3.5. Analyze the control chart.

4.1.4. Control Charts for Measurement Data. Measurement data are recorded observations of the extent or amount of a characteristic associated with a given element or group of elements. Some fundamental characteristics are length, weight, and time. Workload data such as units produced, sorties flown, or items received can also be considered measurement data. The two types of variables control charts used in quality improvement are the X-bar and charts. The bar above the indicates an average is used and the chart is called an X-bar chart. The stands for range. The charts are created separately but are used together since each measure a different aspect of the process. The chart plots the average or mean of measurements in a sample. The chart plots the range or variation of measurements in the sample.

4.1.4.1. Typical X-bar and R charts are shown in Figure 4.3. These charts include basic elements common to all control charts; i.e., the mean (center line), UCL and LCL. The X-bar and R control charts are often used and give more information on the variation within a process than the charts that measure attributes. Figure 4.3 shows a fairly stable process. All the points are within the calculated control limits and move in a random pattern.

Figure 4.3. Typical *X-bar* and *R* Control Charts.



4.1.4.2. If the plotted values of X-bar and R fall on or above the UCL, or fall on or below the LCL, an unexpected event has occurred and should be investigated. It might be due to worn machine parts, deviating from accepted methods of processing, a change in material, or fatigue on the part of the worker.

4.1.4.3. Constructing an X-bar Chart. The steps in constructing an X-bar chart are:

4.1.4.3.1. Collect the data.

4.1.4.3.2. Compute the mean. Each mean is the sum of the measurements for the sampling period (i.e., daily, weekly, etc.) divided by the number of measurements taken during the sampling period.

4.1.4.3.3. Compute the range, or R for each data point. For each sample, the range is determined by subtracting the smallest value from the largest value.

4.1.4.3.4. Compute the center line (mean) for each chart. Add all the values of the X-bar data and divide by the number of X-bar data points. Each sample size should be the same size. Do the same for the R data points.

4.1.4.3.5. Compute the control limits (*UCL*, *LCL*) for each chart (X-bar and R) by using the formulas that apply. (See Figure 4.3)

4.1.4.3.6. Draw the x (horizontal) axis and y (vertical) axis for each chart. Mark the scale on the x-axis of each chart. (The distance between the control limits on the X-bar chart is roughly similar to the control limits of the R chart.)

4.1.4.3.7. Draw the X-bar and R center lines and draw the control limits for each chart.

4.1.4.3.8. Plot the X-bar and R values on the chart.

4.1.4.3.9. Analyze the control charts.

4.1.4.4. Using the X-bar and Range Charts. These steps show the development of an X-bar chart and R chart for 5 weeks of daily numbers of work orders completed. (See Table 4.3. for constant values A2, D3, & D4).

Table 4.3. Factors for *X-bar* and *R* Charts.

L I N E	A	B	C	D
	For Observations in Sample	Factors for	Factors for *R* Chart	
	n	X Chart A_2	Lower D_3	Upper D_4
1	2	1.88	0	3.267
2	3	1.023	0	2.574
3	4	0.729	0	2.282
4	5	0.577	0	2.114
5	6	0.483	0	2.004
6	7	0.419	0.076	1.924
7	8	0.373	0.136	1.864
8	9	0.337	0.148	1.816
9	10	0.308	0.223	1.777
10	11	0.285	0.256	1.744
11	12	0.266	0.283	1.717
12	13	0.249	0.307	1.693
13	14	0.235	0.328	1.672
14	15	0.223	0.347	1.653
15	16	0.212	0.363	1.637
16	17	0.203	0.378	1.622
17	18	0.194	0.391	1.608
18	19	0.187	0.403	1.597
19	20	0.18	0.415	1.585
20	21	0.173	0.425	1.575
21	22	0.167	0.434	1.566
22	23	0.162	0.443	1.557
23	24	0.157	0.451	1.548
24	25	0.153	0.459	1.541
Monthly Data				
WEEK 1 X1	WEEK 2 X2	WEEK 3 X3	WEEK 4 X4	WEEK 5 X5
11	17	15	19	15
17	18	12	11	14
16	12	13	20	14
13	20	21	11	15
18	17	16	15	12
Total = 75	Total = 84	Total = 77	Total = 76	Total = 70
$\bar{X}$ = 75/5 = 15.0	$\bar{X}$ = 84/5 = 16.8	$\bar{X}$ = 77/5 = 15.4	$\bar{X}$ = 76/5 = 15.2	$\bar{X}$ = 70/5 = 14.0

4.1.4.4.1. Calculate the mean of each sample.

$$X = \frac{\sum X}{n}$$

4.1.4.4.2. Calculate the average of the means.

$$\bar{\bar{x}} = \frac{\sum X}{Nn} \xrightarrow{yields} \frac{382}{5(5)} = 15.28$$

4.1.4.4.3. From Table 4.3 calculate the range of each sample (R = largest value – smallest value within the sample).

R1 = 18 – 11 = 7
R2 = 20 – 12 = 8
R3 = 21 – 12 = 9
R4 = 20 – 11 = 9
R5 = 15 – 12 = 3

4.1.4.4.4. Calculate the average of the ranges.

$$\overline{R} = \frac{\sum R}{N} \xrightarrow{yields} \frac{36}{5} = 7.2$$

4.1.4.4.5. Calculate control limits X-bar Chart.

$$UCL\bar{x} = \bar{\bar{X}} + A_2\bar{R}$$
$$A_2 = 0.577\ (for\ n = 5)$$
$$UCL\bar{x} = 15.28 + 0.577 * 7.2 = 19.43$$
$$UCL\bar{x} = \bar{\bar{X}} - A_2\bar{R}$$
$$UCL\bar{x} = 15.28 - 0.577 * 7.2 = 11.13$$

4.1.4.4.6. Calculate control limits R Chart:

$$UCL_R = D_4\bar{R}$$
$$D_4 = 2.114\ (for\ n = 5)$$
$$UCL_R = 2.114 * 7.2 = 15.2$$
$$LCL_R = D_3\bar{R}$$
$$D_3 = 0$$
$$LCL_R = 0 * 6.8 = 0$$

4.1.4.4.7. Plot the control charts. Plot the R Chart below, and in line with, the X-bar Chart. Each range is then in line with the mean of its respective sample (See Figure 4.4 and Figure 4.5).

Figure 4.4. Examples of *X-bar* and *R* Control Charts.

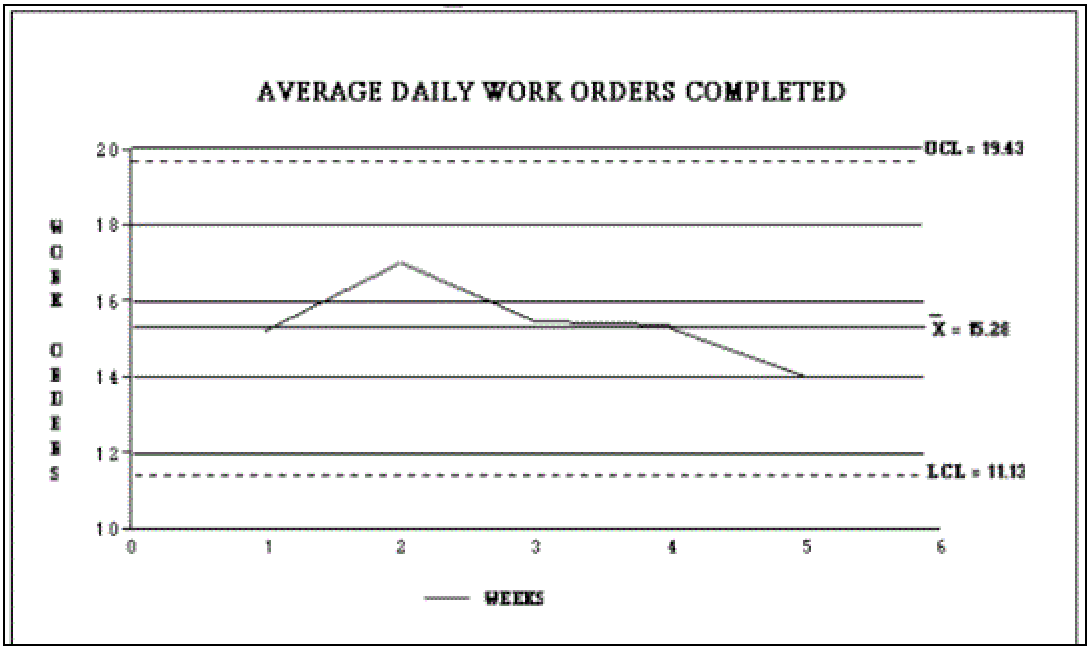
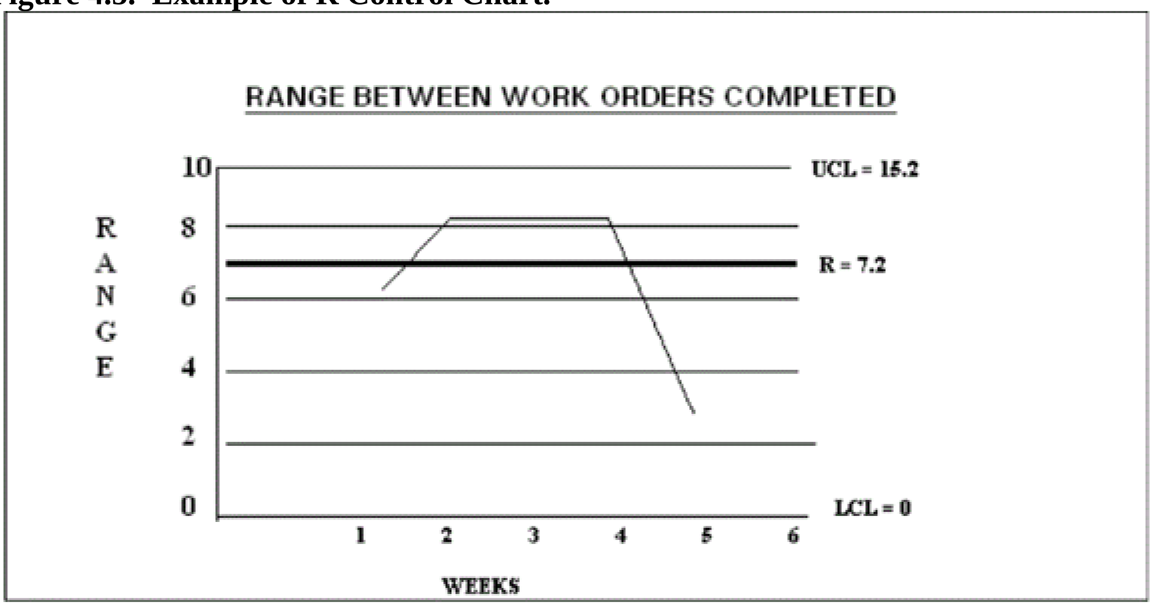


Figure 4.5. Example of R Control Chart.



4.1.4.4.8. Analyze the control charts. Each chart should be analyzed for data "in control" before the data is assumed to come from the same population.

4.1.5. Advantages and Disadvantages of X-bar & R Charts.

4.1.5.1. The main advantage of the X-bar and R chart is the chart gives specific data about a single characteristic of a product or process giving clues on how to isolate a particular problem.

4.1.5.2. A disadvantage of the X-bar and R chart is that, if used to measure products or processes having many variables, many charts are needed (One for each variable considered is important). This can be very costly, so the X-bar and R control charts are often used together with attribute control charts.

4.1.6. When To Use Control Charts. Deciding when to use control charts and which type to use isn't always easy. It’s not economical nor is there enough time to chart every variable for every process. Therefore, determine which key areas or characteristics of a process really need to be monitored and concentrate on them. Take these steps:

4.1.6.1. Flow chart the process.

4.1.6.2. Identify the key areas or elements.

4.1.6.3. Select the key areas or elements to monitor. Focus your efforts to prevent defects rather than just detecting them.

4.1.6.4. Select the pertinent control chart and determine the sample size. Then begin collecting data.

4.1.6.5. Construct a control chart and analyze the information.

4.1.6.6. Continue monitoring the process. Constantly seek ways to reduce assignable and random causes of variation.

4.1.6.7. Periodically reevaluate how closely you need to monitor the process using the control chart selected and the results being achieved. If there is too much variation in the process, work on improving it and eventually providing increased customer service and satisfaction.

Chapter 5

FLOW PROCEDURES CHARTING

5.1. General Concepts. In the past, obtaining concurrence on measurement data was difficult due to functional OPR uncertainty the level of detail of the measurement included all work being accomplished in the work center. Flow Procedures (FP) charting displays a level of detail so specific the customer or functional manager can determine what work is being performed, who's doing the work, how much time a process takes to perform, and where the delays in the process take place. This chapter provides an overview of the FP charting process and its use within the manpower or functional community.

5.1.1. FP charting may be used in practically any work center, but is particularly suited to process-oriented work centers. A process is a series of actions bringing about an end or result. For our purposes, a process consists of a definitive input and output product. Examples would be: TDY travel vouchers, supply requisitions, contract orders, etc.

5.1.2. FP charting is especially helpful in areas where extremely long work cycles would preclude WS.

5.1.3. If the study team is unable to get acceptable statistics from the measurement data, FP charting provides an alternate course of action. Since the data is already aligned procedurally, "b" coefficients are easily developed.

5.2. Benefits of FP Charting. The FP charting method is a good starting point for a most effective organization study. It provides a tool allowing both the functional customer and manpower community to depict and analyze a work center under the current mode of operation, identify problems and improve the current operation. It also provides a performance measures tool the function can use to monitor internal performance.

5.2.1. FP charting segregates technical, administrative, and supervisory duties within the measurement data. This is particularly helpful in the development of the skills and grades matrix.

5.2.2. Determinant maintenance is greatly simplified. Because of the measurement detail provided in FP charts, changes to existing processes are easily identified and quantified.

5.2.3. FP charts can be used as forecasting tools to price out or determine the manpower impact of policy changes levied on a work center in advance.

5.2.4. Specific Characteristics. As with the OA method of measurement, FP charting uses activity time values at the process, step, or even beyond to obtain measured man-hours. The primary difference between OA measurement and FP charting is in the arraying of the measurement data. Some of the similarities and differences are outlined as follows:

5.2.5. Measurement Data. FP charting arrays data both vertically and horizontally. Each process identified has its own set of charts. A process may begin at whatever level of detail the study requires. Break each step down to the level the study team has determined provides the best measurement data.

5.2.6. SAT Data. Obtain SAT data using the same procedures outlined in the chapter for OA Chapter 7.

5.2.7. Frequency Data. Although frequency data may be obtained using the same methods as OA measurement, this is where the similarity ends. By aligning the work center steps procedurally, only a single frequency count (excluding conditional factors) needs to be collected for each process charted.

5.2.8. Conditional Factors. Conditional factors relate to frequencies of a step and are those parts of a process not always occurring with each repetition of a given work cycle or occur more than once per repetition. In order to account for these factors within a process's total time, the factor percentage of occurrence is computed. The percentage of occurrence is obtained by dividing the number of times a given factor occurred within a process by the number of times it could have occurred. For example, if the work center frequency is service contracts processed for the service contract process, and if the second step in the process only occurs with 1 out of every 10 contracts, a percentage of occurrence would be determined as follows: 1 divided by 10 = 10%. This percentage or factor is then multiplied by the step time to obtain a constructed SAT. Thus, instead of giving full time for this step for only the cycles in which it would occur (something that might be difficult to measure), partial time is provided for the step in every cycle. This allows for a constructed time to be developed for even the most difficult or lengthy processes. Also, as most conditional factors are associated with rework, clearly identifying to functional management the areas on which to focus quality improvement efforts.

5.2.9. Format. Process Flowcharts are designed based on the needs of each study. Charts have a basic format for processes that are one page or chart an extension format for processes that are over one page. All processes should begin with the basic format chart. The following are specific chart characteristics:

5.2.9.1. The page number of the chart should be identified in the top right hand corner.

5.2.9.2. The upper left corner is general information about the process and should be completed by the study lead.

5.2.9.3. In the upper right corner are the chart symbols.

5.2.9.4. Next, determine how the positions or people involved in the process should be depicted on the chart.

5.3. Precharting Activities.

5.3.1. The guidelines for developing an FP chart are relatively simple as the technique provides maximum flexibility in allowing the study team to express its measurement needs concisely to the input locations in the field.

5.3.2. The first step in chart development is to become very familiar with the work center and to draft a step-by-step word description for those steps in the standard process list that are being considered for FP measurement. The study team should have full understanding of the work center processes, as well as the respective inputs and outputs.

5.3.3. The word description should depict the actions of work center personnel as interacting with the product or process being charted.

5.3.4. As with other measurement methods, each step should have easily recognizable beginning and ending points for ease of measurement.

5.3.5. Process flowchart items can be broken up into three types.

5.3.5.1. Measurable Items. These are the steps in the process requiring measurement. Identify the type of method to be used in quantifying this step by using an alpha character below the step number.

5.3.5.2. Nonmeasurable Items. Nonmeasurable items are steps not expending work center man-hours but are charted in order to maintain process continuity. Some examples of nonmeasurable items are origination and gap symbols. Another example would be when a measurable step is referenced elsewhere in another set of charts. This occurs when certain steps cross procedural boundaries. If this is the case and a separate work count for each process cannot be obtained, then develop another set of charts for each of the affected processes. Since the man-hours for that step are accounted for elsewhere, this step becomes nonmeasurable in the process.

5.3.5.3. Informational Items. The only items on an FP chart not having step numbers or symbols are informational items. These items are placed on the charts to clarify certain processes or supply specific information designed to aid the input craftsman during measurement. Besides the normal step descriptions, informational items supply an additional avenue for the study team to describe occurrences in the process that may not otherwise be evident. This provides the input craftsman with a greater understanding of the process and what the measurement needs are.

5.3.6. Once the word description has been finalized, the work is then broken out by position. Although the manner in which work center positions are broken out depends on the study team, the most common type of breakout is by craftsman, administration, and supervisor. Dividing the workload along these lines allows the study team to determine the impact of administrative and supervisory personnel on direct workload. Further breaking out the craftsman process by skill level provides for analysis of craftsman grade structures as well.

5.3.7. Once the position breakout has been done, process steps within those positions have been categorized, and process symbols have been assigned, the draft charts are then prepared.

5.4. FP Chart Preparation. The following steps are required to prepare a FP chart:

5.4.1. Determine the process to be charted and its input and output documents.

5.4.2. Determine how many people are involved in the process, the type of work and interactions among personnel.

5.4.3. Select the appropriate chart format in terms of the number of people needed in the process.

5.4.4. Complete the top left portion of the chart and fill in column headings for required personnel.

5.4.5. Start the process with an origination symbol under the appropriate column where the document is received.

5.4.6. Select a symbol to depict the next step or action taken in the process. Each symbol should be accompanied with a brief narrative statement.

5.4.7. Continue to identify and depict each step with a symbol and narrative. For all measurable steps, the narrative statement should match the narrative on the SWD. Only measurable steps are identified on the SWD; however, all measurable and nonmeasurable steps should have a step number.

5.4.8. Make sure all steps in the process are captured from start to finish.

5.4.9. After all processes in the work center have been captured, get together with the functional manager or other team members and review and analyze the current processes. Your major objective is to determine where inefficiencies exist in the current mode of operation. The functional manager can be of tremendous help while doing this analysis. You should look at ways of changing the process by reducing variation and step complexity. Things to consider are: multiple review levels, rework, scrap, avoidable delays, and nonvalue added steps.

5.4.10. After the process charts have been improved and streamlined, make the necessary changes and redo the charts. After the charts have been updated, go back and update the SWD to reflect the new improved mode of operation.

5.4.11. Begin measurement. Measure only the steps with an alpha character below the step number. The study team should decide the best type of measurement for each step. The alpha characters should show the type of OA measurement used. Place the measured time in the standard time (ST) block of the form. If a delay is involved in the activity, include the time in the delay time column of the form. Note: Delay time does not always add measurable man-hours to a process, but is important to consider for process improvement.

5.4.12. Identify steps having conditional factors. These are measurable steps not occurring in every cycle. Compute adjusted SAT as follows:

$$\text{Adjusted SAT} = \%\text{ of Original} * \text{Occurrence} \xrightarrow{\text{yields}} 10\% * 100\text{Min.} = 10\text{ Min.}$$

5.4.13. After measurement has been completed, always re-check your frequency, source of count, and accuracy.

5.4.14. Add the total step times for the process and transfer this total to the upper left corner of the first page of the FP charts.

5.4.15. You do not have to follow these steps exactly to successfully complete a FP chart. The type of work center under study determines if you can consolidate or eliminate certain steps.

5.4.16. Next, go through each process from a step standpoint and look at ways of changing the process by reducing variation and step complexity. For each step in the process, consider the following:

5.4.16.1. Why is it being performed?

5.4.16.2. What value does it add to the overall product?

5.4.16.3. Why is this person doing it?

5.4.16.4. Who should be doing it?

5.4.16.5. Are conditional factors built for rework or errors and does management know what the error rate is?

5.4.16.6. Why are errors taking place?

5.4.16.7. At what stage in the process do most of the errors occur?

5.4.16.8. Are too many people looking at the same document?

5.4.16.9. Can certain steps be automated?

5.4.16.10. Can certain steps be eliminated?

5.4.16.11. What are the governing publications for each step?

5.4.16.12. Can any steps be simplified?

5.4.17. After analyzing each step, determine what the real problems are within the processes and correct them. Then redo the FP charts under the new or proposed mode of operation.

5.5. Manpower Determinant Development Using FP Charting. You can develop a manpower determinant using FP charting in a manner very similar to the OA method of measurement. Two ways to do this are as follows:

5.5.1. Statistical manpower determinants using correlation and regression (C&R) analysis are developed by transferring FP chart process times to an OA Data Worksheet. The following steps should take place:

5.5.1.1. Determine the total time one complete process takes. This total time should be located on the first page of the FP charts for each process. For example, the total time for Process 2 (Processes Service Contract) is 300 man-hours. Normally, each separate process is a separate unit of work (output). For example, Process 2 on the Operational Contracting SWD is: Processes Service Contract.

5.5.1.2. Next determine how many service contracts were processed or awarded per month for the last 12 months. Assume there is an average of 10 service contracts awarded per month.

5.5.1.3. Prepare an Operation Audit Data Worksheet for each location, by completing the frequencies (10 per month), and SAT (300 man-hours), then computing total Process 2 man-hours (3000 man-hours). Do this for each process to determine the total work center man-hours.

5.5.1.4. At this point, regular C&R can be performed at the process level, step level, or for the total work center.

5.5.1.5. Determine indirect allowed man-hours by using the indirect allowance factor (IAF). These man-hours can then be added to the man-hour equation for total work center requirements.

5.5.2. Develop the "b" Coefficient. When data is accurate however satisfactory statistics cannot be achieved with C&R analysis, functional modeling as well as functional estimating equations (FEE) may be used. Simply use the average total FP chart time (or total process time) as the "b" coefficient. An example is provided below.

BASE	1	2	3	4	5	6	7	AVERAGE
Process 2 man-hours	315	320	280	275	290	305	300	297.86

Equation format: $Y = 297.86 * X_2$ (multiply Y by IAF to determine total man-hours)

5.5.3. The other phases of the determinant process remain the same.

5.5.4. Skill and Grade Matrix Development Using FP Charting. By identifying workload by position on the FP chart, you can determine the percentage of work performed by each position and specialty, then develop a skill and grade matrix. This is done by adding the total time per position from the FP chart for a process, and then determining the process's total impact on the work center. For example, the Operational Contracting work center process 2 would be presented as follows:

5.5.4.1. Step 1. Time to process one Service Contract is 300 man-hours broken down by the following positions:

POSITIONS	MAN-HOURS PER PROCESS	PERCENT OF PROCESS
Craft/6C0S1	200	67%
Supervisor/64PQ	70	23%
Admin/3A1S1	30	10%
TOTAL	300	100%

5.5.4.2. Step 2. Determine the overall man-hour impact Process 2 has on the work center. Let's assume the work center measured a total of 5,000 monthly man-hours and Process 2 takes a total of 3,000 monthly man-hours (10 service contracts awarded per month x 300 man-hours per contract). In this case, Process 2 impact on the overall work center man-hours would be: 3,000 divided by 5,000 = 60%.

5.5.4.3. Step 3. Now multiply Process 2 position percentages by its overall impact on the work center percentage to determine the overall percentage that should be allocated to each position.

POSITIONS	% OF PROCESS	SWD % IMPACT	% ALLOCATED
6C0S1	67%	60%	40%
64PQ	23%	60%	14%
3A1S1	10%	60%	6%

5.5.4.4. Step 4. Repeat this for each process in the work center that has been measured, making sure the percent allocated account for 100% of the work center requirements.

5.5.4.5. Step 5. There may be situations in which a position is comprised of 3, 5, and 7 level work. If this occurs, determine what percent is 3 level, 5 level, and 7 level prior to doing the calculations, and extrapolate this percent to the position percentages.

5.5.4.6. Step 6. Consider officer grade ceilings and career progression factors when preparing the skill and grade matrix.

5.6. Functional Measures Tracking.

5.6.1. Work center performance can be measured using the FP charts as the standard process and time to perform work center processes. Effectiveness and efficiency indices can be developed to track and measure performance. For example, the standard time to process a service contract is 300 man-hours. Suppose the work center is taking 330 man-hours to process a service contract, exceeding the standard allowed time by 10% (30 divided by 300 = 10%). Management should investigate this variation to determine the causes for exceeding the standard time.

Chapter 6

WORK MEASUREMENT

6.1. Work Measurement.

6.1.1. General Concepts. This chapter provides an overview of work measurement and techniques commonly used during the Measurement phase of ME development. It also outlines policies and procedures for collecting man-hour and workload data. Work measurement is defined as any method or technique used to accurately compute man-hours required to build a product or provide a service. The historical techniques used in the Air Force MEP include OA, time study, and WS. Each of these techniques, as well as other methods, are discussed in later chapters.

6.1.2. Classifying Work. When developing the SWD, the ME analyst analyzes the work center's activities to classify them as productive, nonavailable, or not allowed (assumed work or inferred work). Only productive "direct" work processes and activities are documented in the SWD. Use Table 6.1 to assist in conducting analysis. Proper accountability of special work requirements (flying requirements, travel, supervision, OJT, and cleanup) may be confusing or difficult. Refer to Table 6.2 for rules on how to handle these circumstances.

6.1.3. Productive Work. There are two categories of productive work activities: direct work and indirect work. Direct work is documented in the SWD, while indirect work is normally addressed by application of an IAF.

6.1.3.1. Direct work activities are required by MAJCOM or higher directives, are essential to and directly support the work center's mission, and can be identified with a particular service or end product accurately, logically, and without undue effort or expense.

6.1.3.2. Indirect work activities are considered productive work. However, indirect work is done in support of the function, does not add value to an end product, and may not be readily identifiable with a specific output or service. The IAF represents a portion of total productive work and is used to quantify productive, indirect work man-hours associated with the following nine standard indirect work activities: (1) Civilian Employee Administration; (2) Officer Administration; (3) Enlisted Administration; (4) Work Center Administration; (5) Administrative Support; (6) Prepares For, Conducts, or Attends Meeting; (7) Training Administration; (8) Supply Administration; (9) Inspects and Cleans Work Area. It is not usually necessary to measure indirect work. Rather, application of an IAF is accomplished to credit a work center for standard indirect man-hour requirements. The IAF is discussed in more detail in Paragraph 6.2.10.

6.1.4. Nonavailable Activities. There are activities directed, approved, or recognized by the Air Force making people unavailable to perform assigned primary duties. The major groupings of nonavailable activities are leave, permanent change of station (PCS)-related, medical, organizational duties, and education and training. Since these activities impact all functions and have been measured Air Force-wide, the associated man-hours have been subtracted from each person's assigned time. Therefore, this time should not be included in the SWD. For more information about nonavailable activities, refer to the military and civilian MAF reports located on the AFMAA SharePoint site.

Table 6.1. Classifying Work.

I. CLASSIFYING DIRECT WORK									
R	A	B	C	D	E	F	G	H	I
U			and the work is		then classify the work as				
L E	If work is required by a command or higher directive	and the directive identifies the work center to perform the work	performed at all locations where the work center exists	essential to the work center's mission	Productive (core for work center)	Productive (positive variance for work center)	NON AVAILABLE	NOT ALLOWED	and contact the responsible OPR to ensure the appropriate directive is changed to add or delete this requirement
1	Yes	Yes	Yes	Yes	X				
2				No				X	X
3			No	Yes		X			
4				No				X	X
5		No	Yes	Yes	X				X
6				No			X		
7			No	Yes		X			X
8	No							X	

Table 6.2. Special Work Requirements.

	A	B	C
Rule	**Work classified as**	**and includes**	**then**
1	Flying Requirements	Flying to accomplish the work center's mission and to satisfy the requirements of Aircrew Position Identifier (API) 1, 2, 5, 6, or 8.	Identify steps related to conducting flying mission, training, or evaluation in a direct process titled "(type Aircraft) Flying Activities." Include steps required to satisfy all currency requirements.
2		Currency requirements associated with API 3 and 4 coded positions.	Consider the steps credited in the IAF and the MAF.
3	Travel	Travel between work centers, travel from the work center to the job site, or temporary duty (TDY) travel with the purpose of doing official mission-oriented direct process work.	If travel is required to accomplish a direct process, establish a step in the process for travel. If travel is required to do two or more steps in the same direct process, establish a separate step for each time travel is performed (See **note 1**).
4	Supervision (See **note 2**)	Managing two or more subordinate functions.	Establish a process called "Management" that contains those steps necessary to support subordinate work centers.
5		Supervising only internal work center personnel.	Consider tasks credited in the IAF for OA efforts.
6	OJT	Accomplishing direct work while receiving OJT.	Credit this work to the direct process done.
7		Receiving in-house proficiency training or qualification training in a classroom environment in lieu of numerous individual OJT sessions on one subject.	Consider tasks credited in the IAF for OA efforts. In a minimum or position manning work center, where certification is maintained and personnel are attending training in addition to shift work, training would be considered direct work and position qualification time (PQT) would be calculated to provide required man-hours.
8		Receiving field training detachment or mission directed training instructions when the training is of a recurring nature similar to, or in lieu of, normal OJT or proficiency training.	
9		Study of career development course and professional military education materials during normal duty hours.	Consider as nonproductive unless used in conjunction with rule 6 or 7.
10	Cleanup	Performing cleanup services not authorized for custodial service.	Consider task as credited in the IAF for OA efforts.
11		Mowing grass (See **note 3**).	Considered assumed work.

Notes:
1. Ensure credit for travel is not double-counted in the steps or processes identified.
2. Indirect tasks can be reflected as both direct and indirect in management or overhead work centers. However, when documented as direct work, the processes reflect steps to support personnel in subordinate work centers while the indirect categories reflect steps to support people inside the overhead work center. Ensure direct processes are written clearly and do not duplicate indirect work included in the IAF.
3. There may be other duties performed by the work center's personnel (e.g., snow/ice removal) that may or may not be creditable to the work center. Use the decision logic **Table 6.1** to determine how this work should be classified.

6.1.5. Not Allowed. Inferred or assumed workloads are not included when developing a manpower determinant, so careful analysis of the work activity against Table 6.1 is required.

6.1.5.1. Inferred Work. Workload defined as the responsibility of a function other than the one under development. When MAJCOM and HQ USAF guidance or higher conflict, the higher HQ guidance prevails.

6.1.5.2. Assumed Work. Work being done not necessary to accomplish the Air Force mission and is not required by MAJCOM or higher directive.

6.1.6. Infrequent Work. A tenet of manpower determinants development is to document the minimum amount of man-hours needed to perform a given mission at various monthly average levels of workload (normally based on a 12-month period). Manpower or man-hours are not provided at peak workload nor reduced for sharp declines in workload levels that may be experienced by a work center. Rather, man-hours for peaks and valleys of workload are averaged throughout the year. Determinants attempting to set manpower at peak workload requirements inflate man-hour costs. The determinant development tenet here is manpower is set to the norm, and leadership manages to the exception (i.e., managing the peak workload when it happens).

6.1.6.1. Actions to reduce the impact of peak demand may include the transfer of work from one period to another or the revision of procedures to spread the workload over a longer cycle. The function may also opt to accommodate peak demand via management actions such as overtime or temporary over hire employment.

6.1.6.2. Infrequent tasks (i.e., those occurring less than once per year) should not be ignored or dismissed without looking at the bigger picture. Independently, these taskings may seem to cause minor spikes in needed man-hours however, these spikes may actually cause a higher and almost steady state of workload throughout the year. In conjunction with the functional manager, the ME analyst should analyze and address these peak demand situations.

6.1.6.3. The analysis results, decisions, and related actions concerning peak demands driven by infrequent work should be addressed in measurement design and documented in the AFMD development report.

6.2. Time Classification Considerations.

6.2.1. On-Call Time. On-call time is a period of time an off-duty worker is available at a prearranged off-duty location and can be reached by telephone or other means. When authorized work is required and cannot be held over to the next duty day, credit the work center with productive time expended and the travel time needed to get to the job site and return to the off-duty location. Off-duty time spent waiting for a call is not measured or included in manpower determinants.

6.2.2. Borrowed Time. Borrowed time is time provided by personnel authorized and assigned to another work center but used to do productive work within the work center that is part of the ME development.

6.2.3. Loaned Time. Loaned time is time expended by work center personnel to do work which is the responsibility of another work center.

6.2.4. Standby Time. This is time spent in a ready status awaiting work when work is unavailable (for example, the time a taxi driver waits to be dispatched). Include standby time only when it is essential to do the mission and when no other work (direct or indirect) can be accomplished.

6.2.5. Nonavailable Time. This is time work center personnel spend participating in activities directed, recognized, or approved by the Air Force which render them unavailable for assigned primary duties. Nonavailable time is accounted for through the MAF. The major groupings of nonavailable activities are: leave, PCS-related, medical, organizational duties, education and training, military equal opportunity, and miscellaneous. Refer to the military and civilian MAF reports on the AF/A1M SharePoint site.

6.2.6. Overtime. Uncompensated overtime is the productive time spent in excess of regularly scheduled duty hours. This time is used to do productive work and cannot be caused by nonproductive activities or offset by compensatory time. For civilians, include only overtime which is documented according to AFI 36-802, Pay Setting. For military personnel, document and thoroughly analyze the need for overtime. Ask the supervisor to validate overtime. If overtime is a normal occurrence, visit the work center during overtime periods and observe the work in progress. Identify the backlog driving the overtime work. Determine if the backlog is at unacceptable or growing levels.

6.2.7. Idle Time. This includes time spent by a worker in an avoidable delay status, doing unnecessary work, or doing work not job-related. Idle time is not included in a manpower determinant.

6.2.8. Avoidable Delay. Any unnecessary delay, regardless of source, that causes work stoppage. Time lost to avoidable delay is not included in the determinant. Note: When conducting simulation modeling, it may be necessary to measure and/or model avoidable delays to produce realistic scenario results; however man-hours are still not provided in final manpower determinant.

6.2.9. Unavoidable Delay. An occurrence that is essential and outside the worker's control or responsibility preventing the accomplishment of productive work. Time lost to an unavoidable delay is included in the determinant as part of the Personal, Fatigue, and Delay (PF&D) allowance depending on the work measurement method used. See **Chapter 11** on PF&D allowance quantification and application.

6.2.10. Quantifying Indirect Workload and the IAF General Concepts and Principles.

6.2.10.1. Standard indirect work activities include personnel administration; directing work center activity; administrative support; preparing for, conducting, and/or attending meetings; administering training; managing supplies; maintaining office or shop equipment; and performing cleanup. These standardized indirect duties are common to most Air Force work centers, and a Standard Indirect Description can be found on the AF/A1M SharePoint site.

6.2.10.2. The IAF is the monthly man-hour allowance factor to perform indirect duties. It is applied as a percentage, 6.19%, of total monthly direct man-hours to determine the total monthly allowed man-hours required by the work center. Refer to the IAF report for additional information located on the AFMAA SharePoint site.

6.2.11. The IAF defines allowed indirect work. This work is classified as indirect only when it is in support of the work center where it is done. Work accomplished in support of subordinate work centers is classified as direct work. In the latter case, these work centers are called "overhead" functions because of direct management responsibility for two or more subordinate work centers.

6.2.12. The duties of administering personnel, directing work center activity, and providing administrative support can be classified as indirect or direct. Duties performed for subordinate work centers are classified as direct work. This means for overhead functions, it is possible to have the same activity titles listed under both direct and indirect processes.

6.2.13. Application of the IAF. Indirect work is accounted for as a separate factor applied outside the model during the manpower requirements determination process. Directions are included in the manpower determinant's application instructions, addressing the applicable IAF and how to apply it. The base, MAJCOM, direct reporting unit, or forward operation agency manpower requirements analyst should first determine total direct man-hours by adjusting the results of the basic manpower equation with applicable variances. The analyst selects the IAF, per application instructions, and multiply the sum of direct man-hours by the IAF, 1.0619. This product reflects the total monthly man- hours required by the work center. Conversion to FTEs is accomplished by dividing total monthly man-hours by the applicable MAF and overload factor, when appropriate.

6.2.13.1. Coordinating Input Data with the Functional Representative. Close coordination between the measurement team and the functional representative during the measurement is necessary to ensure active functional participation in the effort. The functional also has the opportunity to clarify information collected during measurement. Building a relationship with the functional OPR is helpful for future coordination of the AFMD development report.

6.2.13.2. Using More than One Measurement Technique. Sometimes it is not possible to get an accurate and representative measurement of all work center activities with a single measurement method. For example, exclusively using WS may preclude measurement of certain tasks that do not occur during the measurement period. Abnormal times may also be recorded for some tasks that do occur. In these instances it may be necessary to supplement the WS results. OA can be used to capture man-hours for the tasks not measured.

6.2.13.3. Familiarizing Manpower and Functional Personnel with ME Development and Work Measurement. Work measurement can frequently cause some angst with both the functional community and the Study Lead. To mitigate friction between manpower and functional teams, ME analysts:

6.2.13.3.1. Become familiar with the work center mission, responsibilities, operating environment and organizational structure, regardless of the measurement method used.

6.2.13.3.2. Become familiar with the flow of work and work center layout.

6.2.13.3.3. Brief work center supervisor and personnel on the measurement methods and techniques to be used by the team.

6.2.13.3.4. Explain how the data are to be used in developing a manpower determinant, but avoid using technical ME terms.

6.2.14. Rounding Procedures. As a general rule, do all computations using the capability of your computing device. Round only the final result to the number of decimal places shown in Table 6.3.

Table 6.3. Rounding Rule.

RULE	If the number to be rounded is	then round it to
1	reported man-hour values	2 decimal places
2	average workload values	2 decimal places
3	leveling factor	2 decimal places
4	statistical measure such as: accuracy, mean and standard deviation, standard error of the estimate, coefficient of determination (R^2), coefficient of variation (V), or test statistics (F&t)	3 decimal places
5	FEE, percentage factors	3 decimal places
6	fractional manpower values	3 decimal places
7	coefficients for manpower models (including regression equations, single location equations, or simulation equations)	At least 4 significant digits. For example, 5.332, 0.5332, or 0.05332

6.2.14.1. Once the number of decimal places is decided, discard all of the digits to the right of that point. Do not change any digits to the left of that point. Round the last digit to be kept up only if the digit to the right of it is greater than or equal to 5.

6.2.15. Examples of rounding numbers to three decimal places are:

Example	Reason
$27.16346\ldots \xrightarrow{yields} 27.163$	Because 4 is less than 5.
$31.39461\ldots \xrightarrow{yields} 31.395$	Because 6 is greater than 5.
$16.48450\ldots \xrightarrow{yields} 16.485$	Because 5 is equal to 5.

Chapter 7

OPERATIONAL AUDIT

7.1. General Concepts. The OA measurement methods encompass several non-engineering work measurement techniques using activity time values at the process step-level to determine the man-hours for a particular activity.

7.1.1. Total man-hours for a process are determined by the mathematical model $T = f_i\, t_i$, where T is the man-hours for one activity; f_i is the activity frequency (FREQ) (converted to monthly), and t_i is the SAT.

7.1.1.1. The SAT is the time it takes to perform an activity for one single cycle as defined by the SWD step.

7.1.1.2. The activity FREQ is the naturally occurring FREQ that a work center performs an activity; e.g., once per day, three times per week, eight times per quarter.

7.1.1.3. To determine total monthly man-hours for the work center, sum all the individual activity FREQs multiplied by the corresponding SAT. This is represented by the following mathematical model:

Where:

$$T = Total\ monthly\ man - hours$$

$$f_i = activity\ FREQ\ (converted\ to\ monthly)$$

$$t_i = SAT$$

$$T = \sum (f_i\, t_i)$$

7.1.1.4. The activity FREQ is converted to a monthly count so eventually the total measured hours can be converted by the appropriate monthly man-hour availability and overload factors to determine full time equivalents. Refer to Table 7.1 for activity FREQ conversion factors. For example, given a process with six activities, assume the following breakdown for step FREQs, SATs, and computed monthly man-hours. Refer to Table 7.1.

Table 7.1. Example of Combining Steps with Different FREQs.

Activity Frequency A	Monthly Conversion Factor B	SAT (minutes(min)) C	Monthly Min =A x B x C
1/D1	20.91	20	418.2
1/W6	4.348	30	130.44
3/W6	4.348	15	195.66
1/MO	1.000	80	80
1/MO	1.000	30	30
1/QT	0.3333	60	19.998
		$TOTAL = \sum(f_i t_i)$	874.298

7.1.1.5. When the process is insufficiently defined, it may be difficult to estimate total process man-hours. In this case, break the process down into more detailed steps and sub-steps.

7.1.1.6. Use the most frequent activity as the natural frequency. In this example, the most frequent activity is daily. To find the associated process SAT, divide the total measured monthly min (874.298) by the daily conversion factor (20.91).

$$SAT = \frac{Total\ Measured\ Monthly\ Minutes}{Daily\ Conversion\ Factor} \xrightarrow{yields} \frac{874.298}{20.91}$$
$$= 41.81(daily\ PAT\ in\ Min.)$$

7.1.1.7. The entry on the OA worksheet for the process referred to in Table 7.1 is shown in Table 7.2.

Table 7.2. Example of Combined Steps to Obtain FREQ and SAT.

A	B	C	D
Sub-activity Frequency	Conversion Factor	SAT (min)	Monthly Man-Hours $\left(\frac{A*B*C}{60}\right)$
1/D1	20.91	41.81	14.57

7.1.1.8. Another approach may be used for activities of varying FREQs with no identifiable "natural frequency”. In order to credit the proper allowed man-hours, use a FREQ of 1/MO and enter the measured monthly time as the SAT.

7.1.1.9. For either approach, the ME analyst should be provided the details as to how the process times were captured in order to facilitate data analysis.

7.1.2. OA Versatility. OA is one of the Air Force MEP’s most flexible and widely utilized work measurement methods. It is used for setting activities times and FREQs when alternate methods are not appropriate. This method can be used to measure workload in practically any type of work center (production, administration, supervision, etc.).

7.1.3. OA Techniques. OA techniques are generally less accurate than engineered techniques, but OA can also use to supplement Time Study, **Chapter 9** or WS, **Chapter 12**, methods to:

7.1.3.1. Determine man-hours for work not accomplished during the sampling period.

7.1.3.2. Document requirements for specific activities not appropriate for time study due to low frequency or long duration, when time study is the primary measurement method.

7.1.3.3. OA integrates five primary techniques to obtain activity SATs and FREQs to systematically measure work: historical records, good operator timing, directed FREQ and/or SAT, technical estimate, and standard data. Each of these OA techniques is briefly defined below:

7.1.3.4. Historical Records. This technique draws on the work centers documented past performance to obtain historical FREQs and/or SATs. Many functions have automated computer systems capturing workload data. Examples of computer systems used in this technique are: Integrated Maintenance Data System and the Standard Base Supply System. SATs determined with this technique often need to be validated, using good operator timing or technical estimate due to the lack of a clear understanding of what that time includes (e.g., delays, standby time, worst case scenario, etc.).

7.1.3.5. Good Operator Timing. An OA technique used to determine SAT values through the measurement of the time a qualified individual expends on a given activity. Man-hours captured using the good operator technique are considered representative of the time that others need to do the same work. In addition, this technique instills confidence in the data since functional OPRs tend to trust the man-hours derived from actual timed observations more than those resulting from less objective means. This technique is similar to time study but is not as stringent; i.e., work does not need to be broken down into elements, nor does a specific number of samples have to be taken to meet statistical confidence and accuracy.

7.1.3.6. Directed FREQ or SAT. A technique used to determine FREQs or SATs based on Air Force-approved guidance (e.g., AFIs, technical orders, etc.). Examples of directed FREQs include monthly inspections or periodic maintenance of a standby electrical power generator. If the directed FREQ does not seem reasonable, the ME analyst should question what justifies the FREQ. An example of a directed SAT would be a contract statement of work.

7.1.3.7. Technical Estimate. The determination of the SAT or FREQ needed for a given process step is based on an estimate made by individuals technically and professionally competent to judge the FREQ and time needed to accomplish an activity. This technique should be used as a last resort.

7.1.3.8. Standard Data. A technique that uses a collection of standardized process, step definitions, and associated time values to accurately reflect the SAT for standardized units of PF&D work. One source for the creation of standard data is through the use of Pre-determined Time Systems Standards.

7.1.4. It is not uncommon for ME analysts to use one technique to figure activity FREQ and another to figure activity SATs. However the technical estimate should only be used when it is not practical or cost-effective to use historical records or good operator timing techniques.

7.1.5. To find each separate FREQ and SAT, use the technique supplying the most accurate and realistic data. Activity FREQs are converted to monthly equivalents via conversion factors.

7.1.6. Preparing for OA Measurement. The measuring ME analyst prepares in advance for OA to ensure the accuracy and validity of the data.

7.1.7. Check the SWD and statement of conditions with work center personnel. Make sure the work center supervisor and SMEs both understand the work to be measured, statement of conditions, and variations existing at the specific measurement sites.

7.1.8. Obtain all workload values for the period specified in the measurement plan. Work count procedures should call for a minimum of 6 months historical data, while 12 months of data are preferred. The ME analyst, in conjunction with the functional OPR establish data collection parameters to ensure complete work cycles are covered for all input locations to use in measurement efforts.

7.1.9. Identify all FREQs and SATs using historical records, directed FREQ, good operator timing (when reasonable and cost effective) before using technical estimates.

7.1.10. Identify activities directly related to other activities. For example, if activity B is always done as follow-on to activity A, the FREQs should relate.

7.1.11. Identify activities indirectly related to other activities. For example, in a maintenance work center, part replaced might relate to part transaction processed in a materiel management work center.

7.1.12. Obtain the number and skill of people assigned to the work center in the past 12 months. If 12 months of data are not available, use 6 months of data at the minimum.

7.1.13. Determine if the work center has borrowed or loaned manpower, scheduled or documented overtime, or has backlog. Twelve months data should be collected and used whenever possible.

7.1.14. Historical workload data and associated man-hours may not show the work center's true requirements. Over or under-manning impacts the level of effort and the historical workload production level. Contracted work, backlog, labor negotiations, or future production schedules might also be factors. Identify and document the impact of these conditions during measurement.

7.1.15. Activity FREQ (fi) Determination. Techniques used to establish activity FREQs are historical records, directed FREQ, or, as a last resort, technical estimate. Make every effort to get accurate FREQs of occurrence. Generally, the best source of FREQ data can be captured using the historical record technique. Determining activity FREQ (fi) using each technique is discussed below.

7.1.16. Historical Record. Research historical records such as functional workload, data systems, reports, letters, messages, rosters, etc., to determine activity FREQs. Verify data with work center personnel.

7.1.16.1. Evaluate work counts and workload cycles associated with specific processes to determine the natural FREQ period (e.g., normally occurs on a daily, weekly, monthly, quarterly, or yearly basis), as well as the historical FREQ counts.

7.1.16.2. In some cases, it is possible to relate unknown FREQs to reliable recorded data to find more objective estimates. For example, if there is no record in a work center to show the FREQ with which a particular part is replaced on a piece of equipment, a check of supply issue records may verify the FREQ. Investigate inconsistencies between work counts and directly related activity FREQs.

7.1.17. Directed FREQ. Use FREQs that are predetermined by directive or policy (e.g., weekly, monthly, or annual inspections). If applicable, the ME analyst documents directed FREQs in the measurement plan.

7.1.18. Technical Estimate. Use technical estimates for activity FREQ only when no alternative data source is available.

7.1.18.1. Evaluate estimates when determining average FREQ, if the estimates are suspect (e.g., based on lack of experience or isolated situations). Attempt to verify the estimate by cross-referencing it with other relatable step FREQs. Do not adjust FREQs without justification or coordination from the work center supervisor.

7.1.18.2. Base estimates on judgment and experience. Get a more confident estimate by sampling the judgment and experience of several people in the work center. Where two similar work centers exist at the same base in separate organizations, get estimates from both of them.

7.1.18.3. Use benchmark or expected FREQ values provided by the ME analyst, if applicable, as a guide for evaluating work center estimates. Reasonable variations in values are expected; however, large variations generated by differences in conditions or levels of service warrant investigation.

7.1.19. SAT (t_i) Determination. Determine required activity man-hours using good operator timing, directed SAT, historical records, technical estimates, or standard data. Each technique is discussed below.

7.1.20. Good Operator Timing. To use the good operator technique, consult with the work center supervisor to jointly select a qualified person who does the process at an average pace. Measure the time it takes the individual to do a given activity. If at all possible, measure several qualified individuals doing the same activity. Man-hours captured using the good operator technique are considered representative of the time that others need to do the same work.

7.1.20.1. Ensure sufficient samples or observations are taken to give accurate estimates of the activity time. The number of observations taken should be comparable with the number of Man-hours associated with the activity. Where the activity is infrequently done or the activity time is relatively small, fewer observations may be appropriate. However, where the activity is done often, or a large amount of the effort of the work center is spent in the activity, more observations are justified.

7.1.20.2. Observe good operator(s), measure the time needed to accomplish the activity, and record time. Apply the PF&D allowance factor and see paragraph 7.1.3.5 for values obtained with the good operator timing technique.

7.1.20.3. Besides being a primary measurement technique, this method is also useful for verifying suspect SATs collected via technical estimate during a workshop or field measurement.

7.1.20.4. An example of good operator timing (Table 7.3) shows the results of an activity observed five times. The mean SAT is computed (sum all SATs and divide by the number of observations). The mean SAT is then multiplied by the base PF&D (1.067) to determine the actual activity time: 3.79. This is the time recorded for the process measured.

Table 7.3. Deriving SAT using Good Operator Timing.

Observations	SAT (in min)
1	3.25
2	4.50
3	3.00
4	4.50
5	2.50
Mean SAT	= (17.75/5) = 3.55
Mean SAT x PF&D	= (3.55)x(1.067)
Recorded Time	= 3.79

7.1.20.5. Directed SAT. Use SATs that are predetermined by directive, policy, or other performance standards. If applicable, the ME analyst documents directed SATs in the measurement plan.

7.1.21. Historical Record. Use recorded historical SATs only if the method of recording and reporting has been thoroughly reviewed and validated.

7.1.21.1. Validate a reporting system by examining several recorded times for the same activity and comparing those to measured data.

7.1.21.2. Examine production and man-hour accounting records before using the data with historical record technique. Use 12 to 24 months of historical record data, if available, but use no less than a minimum of 6 months of data.

7.1.21.3. Discuss the work situation with the supervisor to find out whether changes were made in methods, product, or type of services during the period covered by the records. Also, find out what effect any changes may have had on the data. In some cases the effects of changes are not significant; in others, the records and data may no longer be valid and should not be used in the measurement. Use the average historical time based on all representative values.

7.1.21.4. Ensure the time recorded for work corresponds exactly to the associated activity in the SWD.

7.1.21.5. It is not necessary to apply the PF&D allowance factor to SATs determined by this technique. These SATs are averages derived from estimates, not based on timing of the event. Due to the lack of precision associated with these time estimates, time for these allowances is included in the estimated average SATs.

7.1.22. Technical Estimate. Use technical estimate to determine SAT values only as a last resort. Base time estimates on the judgment and experience of a representative number of work center personnel. Sample at least three individuals when possible (the more samples used to determine average time, the more credence given to the estimate). The significance of the activity man-hours to the total work center expenditure should determine how many sample estimates are needed. Where two similar work centers exist at the same location in separate organizations, get estimates from both. Evaluate extreme estimate values and determine whether corrections are appropriate. For example, use good operator technique to validate questionable technical estimates.

7.1.22.1. When the SAT is affected by varying levels of complexity, derive a weighted-average SAT based on percent of occurrence. In this approach, an optimistic, most likely, and pessimistic (OMP) time estimate is made. Since all calculations are based on these estimates, SATs need to be as accurate as possible. OMP is not intended to be used on every activity. Extreme values are evaluated before OMP is used.

7.1.22.1.1. The first time estimate, the optimistic time is the shortest time in which the activity can be performed if everything goes very well.

7.1.22.1.2. The second time estimate, "the most likely mode time, is the most realistic time it takes to perform the activity. The most likely time should occur more often than either of the other two estimates: optimistic and pessimistic.

7.1.22.1.3. The third time estimate, the pessimistic time, is an estimate of the average time to perform the activity under adverse conditions (i.e., when things go wrong).

7.1.22.1.4. These three estimates are converted to a weighted SAT by a simple approximation formula. Functional SMEs can provide an estimate of the occurrence of each activity (as a percentage, with most likely being the highest percentage). The SAT becomes a statistically weighted average of the three time estimates. Refer to the following example of a weighted SAT:

$$Weighted\ SAT\ =\ Optimistic\ \% * SAT\ +\ Most\ Likely\ \% * SAT\ +\ Pessimistic\ \% * SAT)$$

Complexity	Percent of Occurrence (Totals 100%)	SAT
Optimistic	10%	20 min
Most likely	70%	50 min
Pessimistic	20%	75 min

$$Weighted\ SAT\ =\ .10 * 20\ +\ .70 * 50\ +\ .2 * 75 \xrightarrow{yields} 2 + 35 + 15 = 52$$

7.1.23. Standard Data. If appropriate, the measurement plan should contain standard times or the source to be used for standard data. ME analysts documents the source of standard times used when the source is not included in the measurement plan.

7.1.24. Crew Size. Unless specified by Air Force, MAJCOM, DoD, Air Force Occupational Safety and Health, Occupational Safety and Health Administration, or other directive, crew size should always be quantified as "1".

7.1.24.1. Data Reporting. Document measurement results using the study team's prescribed format to report measurement data. An automated OA workbook is available on the AFMAA SharePoint site. An overview of the key internal computations is described in Table 7.4. Conversion factors used in OA worksheets for each activity FREQ and the related symbols are in Table 7.5.

Table 7.4. Data Reporting Overview.

Step	Data elements needed and computation of monthly man-hours.	Sample
1	Number of Occurrences: Whole number occurrence per time period.	2
	Activity Frequency. Natural rate of occurrence.	Per Week
2	Conversion Factor: Converts the expected natural rate of occurrence to a monthly figure. For example, the conversion factor for a weekly report is 4.348. Use the conversion factor from **Table 7.3**.	4.348
3	Crew Size: Use a crew size of "1" unless a directive dictates otherwise.	1
4	SAT or Weighted SAT: The time required to complete one occurrence of the activity. Express time in clock min.	40
5	Man-hours per Month Computation: Multiply each of the numbers in steps 1-4 and divide by 60. $MMH = \frac{2 * 4.348 * 1 * 40}{60} = 5.80$	= 5.80 MMH

Table 7.5. Conversion Factors.

Rule	Activity Frequency	Symbol	Conversion Factor
1	Per day (5 workdays/week excluding holidays)	D1	20.91 *
2	Per day (5.5 workdays/week excluding holidays	D2	23.08
3	Per day (6 workdays/week excluding holidays)	D3	25.26
4	Per day (6.5 workdays/week excluding holidays)	D4	27.43
5	Per day (7 workdays/week excluding holidays)	D5	29.60
6	Per day (5 workdays/week including holidays)	D6	21.74
7	Per day (5.5 workdays/week including holidays)	D7	23.92
8	Per day (6 workdays/week including holidays)	D8	26.09
9	Per day (6.5 workdays/week including holidays)	D9	28.26
10	Per day (7 workdays/week including holidays)	D10	30.44 *
11	Per week (5 workdays/week excluding holidays)	W1	4.182
12	Per week (5.5 workdays/week excluding holidays)	W2	4.197
13	Per week (6 workdays/week excluding holidays)	W3	4.209
14	Per week (6.5 workdays/week excluding holidays)	W4	4.220
15	Per week (7 workdays/week excluding holidays)	W5	4.229
16	Per week (Any of the above workweeks including holidays)	W6	4.348 *
17	Per month	MO	1.000 *
18	Per quarter	QT	0.3333 *
19	Per year	YR	0.08333 *
Note: "*" Primary Factors to be used. All others are to be used with extreme caution to ensure correct application. Derivation of conversion factors based on other than 12 months can be accomplished as follows. To compute a conversion factor of once per 9-month academic year, for example, the equation would be 1/9 or .1111 and the activity frequency would read (1/Academic Year).			

7.1.25. Data Examination. Each input is analyzed and compared with all other input measurements. As such, be sure to furnish supplemental OA worksheets and comments to aid the study team. Forward comments to explain any questionable measurement data, even when verified with the work center.

7.1.25.1. The ME analyst computes total measured manpower and compare to average assigned strength. If measured manpower is greater than average assigned strength then the delta should be supported by borrowed time, overtime, unacceptable backlog, or a reason to explain how the measured work is being accomplished with existing resources. If measured manpower is less than assigned ensure all valid work center workload has been documented and credited.

7.1.25.2. Ensure the measured data reflects the minimum amount of time to perform Air Force directed workload, not what personnel would like to do in excess of or to short-cut valid workload requirements. Also remember historical data reflects the mistakes and inefficiencies of past operations, and past performance does not mean the manpower was used to the best advantage, or that future work should be done under the same conditions.

7.1.25.3. As directed by the study team, obtain the work center supervisor's concurrence or documented reasons for non-concurrence with the measurement data. In the end, the quality of the manpower determinant is dependent upon the quality of the measurement data submitted by the ME analysts.

Chapter 8

WORKSHOP MEASUREMENT AND FACILITATION TECHNIQUES

8.1. General Concepts.

8.1.1. Workshop Measurement. A workshop is the preferred approach and environment to develop and finalize process flowcharts, conduct man-hour measurement of processes and activities required to produce an output, and to develop level-of-service options.

8.1.1.1. Benefits of Workshop Measurement. The major benefit of using workshop measurement is it reduces the measurement time. It also eliminates the need for an extensive measurement plan, data adjustments, and data errors which can be addressed and resolved during the workshop.

8.1.1.2. Drawbacks of Workshop Measurement. The major drawbacks are the TDY costs and scheduling difficulties associated with a workshop. This may impact the number of people available to attend. Caution, ensure the participants are representative of the locations to which the subsequent determinant applies.

8.1.2. Workshop Procedures.

8.1.2.1. Define Purpose of the Workshop. Know the purpose or ultimate goal before conducting and planning a workshop. Develop the workshop's objectives: how many processes need to be measured; do FREQs of occurrence and benchmark times need to be collected; how many functions are there; and what is the scope of the effort?

8.1.2.2. Determine Location of the Workshop. When selecting the workshop location, consider cost, availability of facilities, and the ME analysts location. Consider scheduling the workshop at a centralized location to reduce overall travel costs. However, conducting the workshop at the study team's location expedites the process.

8.1.2.3. Determine Who Should Attend. Consider the purpose, scope, and objectives when deciding who should attend the workshop. The functional representative select SMEs based on experience and knowledge. The study lead should advise the functional representative that it is imperative the right people are selected to ensure MAJCOM representation regarding the AFMD; reflect the different levels of work to be covered by the determinant; and have recent hands-on experience in the work center. Senior managers and supervisors no doubt have previous experience, but the people actually doing the work today are better able to identify ways to improve processes and to provide accurate technical estimates on the time and resources required to accomplish required activities. Presenting criteria for attendee selection may be helpful to reduce the risk of nonqualified participants attending based on simple availability. Always ensure complete representation while trying to minimize the number of participants.

8.1.2.4. Schedule the Workshop. Estimate how much time it should take to meet the objectives. Prepare a plan or schedule of those processes to flowchart and measure. Consider both the ME needs and the needs of the attendees when scheduling the workshop. If there are conflicts with other events (major exercises, inspections, etc.), the attendees may be forced to cancel or send a replacement who does not necessarily meet the needs of the workshop.

8.1.2.5. Prepare and Distribute Pre-workshop Information Package. Send an information package to each attendee. Include base and local area information, a workshop agenda, travel instructions (if appropriate), and any other information contributing to the success of the workshop. Identify information and/or data the participants are expected to bring to the workshop and provide information that can be read before the event, thus saving workshop time. If possible and appropriate, collect inputs from participants prior to the workshop on information to be addressed by the group.

8.1.2.6. Conduct the Workshop. There are many different ways to conduct a measurement workshop. The following suggestions being provided:

8.1.2.6.1. Prepare briefings or short lesson plans to teach participants the basic concepts of the tools and techniques to be used. When the workshop focus is to obtain SATs and FREQs of occurrence, consider the following issues:

8.1.2.6.1.1. Ensure each participant knows exactly what is included in each process or activity before determining a SAT. Solicit unbiased estimates and clarify any outstanding issues.

8.1.2.6.1.2. Give each participant an opportunity to submit SATs and FREQs of occurrence for a process. To the maximum extent possible, use FREQs of occurrence from validated workload collection systems. Decide how to record the data before the workshop. The ME analyst may decide to keep SATs and FREQs inputs confidential or may elect to obtain consensus in reaching the SATs and FREQs. Regardless of the method chosen, the intent is to have one SAT per activity.

8.1.2.6.1.3. Ensure the workshop participants are giving average SATs, not the worst case scenario or ideal scenario. Be prepared to calculate weighted averages.

8.1.2.7. Questions asked during a workshop. Identify the function's current state through analysis of "What do you produce?", "Who is it produced for?", "How do you produce it?", and "How well do you do it?". Data collection should be done at the highest possible level of analysis while still being able to answer the appropriate questions. The process of defining the current state identifies worthwhile target processes for improvements, uncover improvement opportunities within those processes and help focus on improvement opportunities. Without the baseline provided by the current state analysis, it becomes impossible to know if any organizational/process changes are truly better than the original state. Collection of current state data can be done using the measurement techniques outlined in proceeding chapters of this publication. Following are several specific considerations regarding each of the key current state question areas:

8.1.2.7.1. What do you produce? Regardless of the scope of the study, understanding the ultimate mission and outcome(s) of the target organization is a critical initial step in defining the current state. This serves as the anchor to help identify additional information (e.g., "What products/services provide these outcomes?", "Who are the customers of these products and services which deliver those outcomes?", "What processes create the products and services for these customers who needs these outcomes?" etc.).

8.1.2.7.1.1. The study lead identifies the appropriate sources of this initial information (e.g., published plans, guidance, interviews, and workshops). Outputs and processes performed are also useful details to capture with regard to the "What do you produce?" question. Often, current manpower determinants, specifically standard work, serve as a source for initial process lists. If a current determinant does not exist, or current processes are not defined in the determinant, then standard work needs to be developed.

8.1.2.7.1.2. An initial analysis of the process list considers whether it is truly directed by some guidance or higher level strategy. It is valuable to understand what the function under study is currently doing, but it is also insightful to compare that to what the function is required to do. The distinction may reflect directed versus inferred/assumed work, refer to para. 6.1.5 for additional information on inferred/assumed work. Any remaining non-directed work is challenged and may be an immediate source of work savings. The assumed work can be measured to reflect workload and man-hours associated with work not mandated by the DoD, Air Force, or MAJCOM. If assumed work processes are eliminated, the result would be the organization would have more time and possibly people to dedicate to doing the mandated job. Having some idea of the recuperated workload may be considered worth the effort of measuring the assumed workload.

8.1.2.7.2. Who is it produced for? Identifying the customer group(s) is valuable for several reasons. First, by distinguishing these groups, you identify the sources of information on gathering current process performance. Secondly, it establishes a baseline for current customers who can be compared to the future customers and the requirements for the products/services. Finally, by truly clarifying: Who uses this product/service? Or who demands this outcome? Certain perspectives/stakeholders may be included in the future design process that may have otherwise been ignored. This question identifies who currently has an opinion about your current performance and may dictate how good you need to be in the future. This is especially important when "level of service" is a major workload driver (e.g. requirements to serve a customer within one minute vs. 15 min at a commissary checkout would influence the manpower requirement).

8.1.2.7.3. How do you produce it? The process can be listed or flowed out at an appropriate level of detail to identify redundancy, wasted time, unnecessary steps, under/over-utilized people, etc. Process flow or process mapping diagramming techniques are discussed in **Chapter 3** and reflect just one of many ways to capture this information. In addition, organizational charts, physical layouts, etc. may be useful in painting a clear picture on how efficiently/ inefficiently the products/services are being produced for the customers. Ideally, this activity should be performed on processes after the processes have been prioritized and selected for improvement based on established criteria.

8.1.2.7.4. How well do you do it? This is the effectiveness dimension, which cannot be ignored. Very few Air Force organizations have a formal approach to capture this information, but this performance information identifies improvement opportunities and ultimately provides insight into effectiveness of the improvement effort. Current process performance may be available in inspection reports, cycle time data, customer complaints, rework, on-time work, and other performance measures. In addition, since the customer defines what is and is not good performance, collecting performance information from the customer is ideal. Surveys, focus group interviews, individual interviews, field measurement or workshops are some methods for capturing such data. Current performance may be a useful criterion to use when prioritizing and selecting processes to improve. For example, a high resource cost, and high value (to the Air Force or the organization) process may initially not appear to be a worthwhile target for improvement. Only by understanding the current performance level is below par does this process become a necessary target for improvement. Likewise, if performance is outstanding, then the opportunity for improvement might be considered less beneficial.

8.1.2.7.5. Attempt to gain consensus and agreement on inputs before the end of the workshop. Reconcile the measurement data with the functional representative to increase the chance of buy-in and coordination through the remainder of the effort.

8.2. Techniques for Facilitation.

8.2.1. The Nominal Group Technique. The facilitator works with the work center representatives and management, in a workshop environment, to identify work center customers, performance measures, efficiency and effectiveness indicators, and mission effectiveness charts. These elements can be identified using a proven approach called the Nominal Group Technique. This technique is a useful problem-solving and idea-generating strategy. The process begins with the workshop facilitator discussing each step of the process to the workshop participants. The nominal group technique is controlled by the facilitator and includes these steps: silent generation, round robin listing, clarification, and voting and ranking. These steps are described below for identifying the performance measures. These same steps may be used to identify work center customers and functional measures indicators.

8.2.1.1. Silent Generation. The silent generation step typically takes about 10 min. During this step, the facilitator writes a carefully worded task statement:

8.2.1.1.1. What is the primary service or product of this work center?

8.2.1.1.2. Each participant responds to this task statement during the structured group session. It is perhaps the most critical element of the nominal group technique. The task statement is simple, direct, and addresses the subject being pursued. Tell workshop participants to write the responses to the task statement on a sheet of paper. Good opening task statements when developing effectiveness indicators are: Our task is to develop an indicator allowing ME analysts to decide if the work center is achieving the performance level desired, to determine what quantitative indicators the work center personnel should track on a monthly basis, and to tell if the work center's mission is being effectively accomplished.

8.2.1.1.2.1. The facilitator is asked what is meant by the task statement, it is best to avoid introducing bias by giving examples. Instead, the facilitator might ask several of the participants to give an interpretation of the task statement. If the responses appear to meet the objective and the remainder of the participants grasp the task, it is all right to proceed.

8.2.1.1.2.2. Even if most participants appear to stop writing before 10 min are up, do not shorten the period. If some talking occurs, the facilitator should tactfully ask for cooperation in letting others think through and record their ideas.

8.2.1.1.2.3. Like each of the steps in the nominal group technique, silence is an important element. Research has shown for generating ideas, individuals are more effective than groups. Silent generation focuses attention on a specific task, frees participants from distractions, and gives them an opportunity to think through ideas rather than to simply react, thus yielding inputs of greater quality and variety. Participants are motivated by the tension of seeing those around them working hard at the group task and are forced to pay attention to the task longer, rather than considering the first input suggested to the group. Participants are freed from all of the inhibiting effects of the usual face-to-face interaction of unstructured groups.

8.2.1.1.2.4. When the 10 min are up, the facilitator interrupts the silent generation process. (Note: Additional ideas may also be produced for use following silent generation.)

8.2.1.2. Round Robin Listing.

8.2.1.2.1. The facilitator calls on participants, in turn, to read one of their written responses. Participants may pass at any time and may also join in on any later round. A participant may propose only one item at a time, and either the facilitator or an assistant records each item as it is offered. The only discussion allowed is between the facilitator and the participant who proposed the item. The discussion is limited to seeking a concise rephrasing for recording. As each participant responds, the facilitator repeats exactly what has been said, and the assistant records the concise phrase on a sheet. The facilitator may help rephrasing to maintain consistency and achieve session goals as long as the basic idea or concept is not altered. This phase goes on until all the ideas produced by the group are listed and displayed. Judgment of ideas should not take place during this early and crucial portion of the group process.

8.2.1.2.2. This round robin listing step allows the leader to establish an atmosphere of acceptance and trust. He or she does not unduly rephrase or evaluate the contributions. All responses are equally and prominently displayed before the group. Leader openness and non-evaluative behavior are essential here. Make sure each idea and each participant receives equal attention and acceptance. The process separates ideas from other authors and lets conflicting and incompatible ideas be considered. This step furnishes a written record of the group's efforts and makes later documentation easier.

Chapter 9

TIME STUDY

9.1. General Concepts. Time study is a work measurement method where the manpower ME analyst uses a stopwatch to record the time a worker takes to do each element of an operation in a specified way. This technique is used to measure operations that are repetitive, of relatively short duration (less than 20 min per element is a good rule of thumb), and accomplished at one work station. Leveled time is an average time adjusted to reflect differentiating factors in operator performance, such as effort, skill and work conditions. Leveled time is computed by applying a leveling factor (reference **Chapter 10**, paragraph 10.1.6.) to the productive time. The leveled time is multiplied by an allowance factor to determine the elemental allowed time. The total of the elemental allowed times then gives the standard time for the operation. The cost of performing a time study is higher than other work measurement techniques; however, it is the most accurate means to determine standard times.

9.1.1. The purposes of time study are:

9.1.1.1. To analyze the operations and job conditions to improve existing methods.

9.1.1.2. To increase the effectiveness of worker effort by using only necessary motions.

9.1.1.3. To establish standard conditions for an efficient operation.

9.1.1.4. To establish consistent and fair standards of performance.

9.1.1.5. To furnish reliable data for use in constructing man-hour equations.

9.1.2. Time study is also used to develop elemental standard data for use in synthesizing time standards for operations containing the same elements in different combinations. This eliminates the need for re-measurement.

9.1.3. Not all situations in the Air Force meet the time study prerequisites of being both highly standardized and repetitive. If these prerequisites are not met, then this method is not to be used.

9.1.4. Verification of the SWD. Time study, in most cases, is neither a practical nor an economical method to use to develop an entire manpower determinant within most Air Force functions. However, when this measurement method is selected (generally for some portions of the SWD) the following procedures are necessary:

9.1.4.1. Verify the portion of the SWD to be time studied is properly designed. Each process activity is identified in the sequence of performance with definite beginning and ending points.

9.1.4.2. Ensure all processes are in-line with current governing directives and local performance procedures. Significant differences from location-to-location may cause variation in timing and result in inaccurate values. Resolve any differences prior to beginning timing operations.

9.1.5. Procedures for Conducting a Time Study. Establish a system to record daily work counts. If the work center activities do not allow this to be done, record the WU count as the work is finished. Production reports may be used, but collect sufficient data to make valid comparisons and to set an average workload level.

9.1.5.1. Find the time study method that best fits the work situation to accurately measure the various steps. Snapback and continuous are two basic methods of reading a watch when doing a time study. Each of these basic methods is addressed separately below.

9.1.5.2. In the snapback (repetitive) method, record a reading after timing each element, and then reset the watch back to zero.

9.1.5.2.1. Advantages of this method are: (1) it eliminates the need for making subtractions to find element time and (2) it also facilitates rapid analysis of variations in readings for each element per cycle.

9.1.5.2.2. Disadvantages of this method are: (1) it does not present a clear picture of the sequence in which the elements were done and (2) the extent and nature of foreign elements upon occurrence are not always recorded. In addition, unavoidable errors occur due to the time needed to reset the watch back to zero.

9.1.5.3. In the continuous method, the watch runs continuously from the beginning to the end of the process being measured. Record the time at the end of each element.

9.1.5.3.1. An advantage of this method is every event that occurs is recorded and is traceable back to the actual sequence of occurrence. This makes it easy to handle elements occurring out of normal sequence.

9.1.5.3.2. The disadvantage of this method is additional time is needed to develop the elemental time.

9.1.5.4. The use of either the snapback or continuous method is at the discretion of the ME analyst. The various characteristics contributing to the use of each method are displayed in Table 9.1 and should be taken into account when selecting a particular timing method. For example, when checking a job situation to be timed, use Table 9.1 to select a timing method. If at least six job situation attributes are identified in a timing method, then that method should be favorably considered for use.

Table 9.1. Timing Method Attributes.

The suggested timing method to be used is	When the available time study equipment is	and the elements to be timed are	and the ME development environment
Snapback (Repetitive) Method	easy to use decimal minute watch	few in number long in duration easy to time relatively constant occurrence	is semi-quiet has good lighting elements are usually performed in one location is climate controlled does not require workers to wear additional apparel or safety equipment
Continuous Method	difficult or cumbersome decimal hour watch	many in number short in duration hard to time somewhat variable with only minor interruptions	is crowded or noisy has uneven lighting and/or darkness elements are performed in several locations in sequence has a climate variable in nature requires workers to wear additional apparel or safety equipment

9.1.5.5. When conducting the ME development identify elements to be timed to ensure the elements are recognizable and have obvious beginning and ending points. Clear beginning and ending points make the time study process easier. Make a sketch showing the equipment used, flow of work, significant distances traveled by the operator, and unusual working conditions.

9.1.5.6. Take readings for 5 to 20 cycles to find the number of good readings needed. Pace rate each timed element. The ME analyst compares the observed pace (speed) of work done to the normal time (NT). See **Chapter 10** for more details.

9.1.6. Determining Sample Size. Find the required number of readings after measuring a relatively small number of cycles. The initial cycle readings may be included as part of the required total needed. Observe complete cycles of an operation and take readings on all elements of the cycle. The number of cycle readings needed is the highest number necessary for any one element. Table 9.2 provides instructions and an example of how to compute the number of samples needed. For this particular example shown in Table 9.2, a 95% statistical confidence with a +/-5% relative accuracy is desired with 25 time study samples given. Study teams determines statistical confidence and accuracy by weighing ME development schedule and cost.

Table 9.2. Determining Necessary Time Study Sample Size for Given Statistical Confidence and Accuracy Requirements.

Step	Action	Variable/Equation/Computation	Example
1	Take time readings for 25 cycles	n=number of samples X_i = individual time reading (in decimal min)	n =25
2	Compute summary statistics.	$\sum X$	$\sum X$ = 270.2 mins (See Note)
3	Compute sample mean	$\bar{X}$ = sample mean, where $\bar{X} = \frac{\sum X}{n}$	$\frac{270.2}{25}$ = 10.81 mins
4	Compute sample standard deviation.	s_x = sample standard deviation $s_x = \sqrt{\frac{\sum (Xi-\bar{X})^2}{n-1}}$	s_x =.981 (See Note)
5	Calculate desired accuracy	d = desired accuracy d=.05 $\bar{X}$	.05(10.81) =.540
6	Determine confidence factor using a t-Table and the number of readings (n) where $Z^* = t\left(\frac{1-\alpha}{2}\right), n-1$	$Z^* = t_{(.975,24)}$ = From t table value at 95% confidence ($\alpha = 0.05$) and 25 samples (n =25 samples; therefore n-1 = 24 degrees of freedom)	z* = 2.0694
7	Compute the precision obtained with this sample.	E = precision $E = \frac{Z^*s}{\sqrt{n}}$	$E = \frac{2.0694^*.981}{\sqrt{25}}$ $= 0.4060$
8	Make decision: If the precision obtained (E) is less than or equal to the desired accuracy (d), then this sample is good and you can Stop here. If not, additional samples are needed. Go to step 9.	If E < d, then no further samples needed, else, if E > d go to Step 9	.4060 < .5400; therefore, E < d, thus no further samples required.
9	Calculate estimated sample size needed (n') using values just calculated (z*, s_x, and d). Obtain additional samples to meet this new sample size and repeat the procedures in this table until E<d.	n' = n prime = new sample size needed n' = $\left[\frac{Z*s}{d}\right]^2$	
Note: Actual summation of data values and calculation of standard deviation are not shown here.			

9.1.6.1. Recording the ME Development Data

9.1.6.1.1. The Work Measurement Time Study. Use this method for short-element, short-cycle operations, and for multi-person activities. Run the stopwatch continuously, recording readings. The manpower ME analyst records the methods description by listing each element as it occurs and uses the continuous watch reading method. Document good operator SATs for supplementing time study and WS measurement methods. Record the derived times on the OA Workbook located on the

AFMAA SharePoint site contains instructions to complete the Work Measurement study (Non-Repetitive) Time Study.

Chapter 10

THE PACE (PERFORMANCE) RATING SYSTEM

10.1. General Concepts. In pace rating, the ME analyst compares the observed pace, or speed, of work performance to a predetermined value of normal pace.

10.1.1. The ME analyst considers the difficulty of each step and adjusts to allow for inherent job difficulties. Use unity (1.00) as the numerical value for the normal pace, and give all ratings a value in relation to 1 or 100% of normal pace.

10.1.2. Observed (or measured time) is adjusted by the pace rating to determine NT. Normal hand speed used in the Air Force MEP is determined as the hand speed required to deal a deck of cards in four even piles in 30 seconds (See **Chapter 10** paragraph 10.1.11.) Normal walking speed used in the Air Force MEP is three miles per hour walking across a flat surface. (See **Chapter 10**, paragraph 10.1.13.)

10.1.3. Using Performance (or Pace) Rating.

10.1.4. The manpower determinants process utilizes the practice of figuring the pace at which work is accomplished. The terms pace rating and performance rating are used interchangeably in the Air Force MEP. Using the average pace ratings for individual workers results in a leveling factor that is applied to productive time. Leveling is limited to the observed activity.

10.1.5. In the Air Force MEP, pace rating is used only in WS, time study, or good operator timing. Time values coming from the directed frequency, historical records, or technical estimate methods are not pace-rated (or leveled).

10.1.6. The leveling factor is used to adjust productive time to a norm. Some processes do not lend themselves to pace rating, for example, supervision and mental work. For these activities, use a pace rating or leveling factor of 1.

10.1.7. ME analysts should be proficient with rating and familiar with the job to effectively pace rate. Periodic training is needed especially prior to a ME Development where pace rating is required. The ME analyst should avoid using pre-established ranges for average leveling factors because these ranges bias the value of leveling.

10.1.8. The number of ratings needed varies with the work measurement method used.

10.1.8.1. Time study and good operator timing (OA) technique: rate each timed element.

10.1.8.2. WS: rate a minimum of 25% of the observations of each worker.

10.1.9. Computing an Average Pace Rating. Pace rating results in a number of separate ratings used to figure the overall leveling factor. At the end of the study, find the average of these ratings (leveling factor) and use this average to compute leveled time. The example below (Table 10.1) shows the computation of a leveling factor from six separate pace rating values.

Table 10.1. Leveling Factor Computation Example.

Rating No.(N)	Pace Rating (R)
1	.95
2	.90
3	.95
4	1.05
5	.90
6	.95
	$\Sigma R = 5.70$
Average Pace Rating (R) $= \frac{\Sigma R}{N} \xrightarrow{yields} 5.70 \div 6$ Leveling Factor = .95	

10.1.10. Creating Pace Rater Proficiency. Training an ME analyst to develop a "mental image" of a normal pace and how to rate in a consistent manner is critical. The ME analyst needs to have many images of normal since a wide variety of jobs are studied. This makes the need for training greater and the training more difficult. While it is just about impossible to give the ME analyst every possible "norm" that may be found, there are some point-of-departure norms that can be used. The following exercise is suggested for this purpose:

10.1.11. Hand Speed Pace Rating Practice. Deal 52 playing cards in 4 piles in 30 seconds (.50 min). To deal the cards, hold the deck in the left hand and with the thumb, take off and move the top card each time; with the right hand, grasp the pre-positioned corner of the top card between the thumb and first finger, carry it to the correct pile, release it, and bring the hand back to the pack. Form the four piles in front of the dealer and the other three corners of a one-foot square. This training method needs at least three people; the trainee, the card dealer, and a person with a stopwatch. The dealer deals the cards, the person with the stopwatch times the operation, and the trainee rates the operation. The true rating is found by dividing the known NT (.50 min) by the stopwatch reading. For example:

$$\frac{\text{NT}}{\text{Stopwatch Time}} = \frac{0.50}{0.40} = 1.25\ (125\%)$$

10.1.12. Comparing the true rating with those given by the trainee is a good way to show where the trainee is rating in relation to the actual pace of the dealer.

10.1.13. Walking Speed Pace Rating Practice. The Air Force MEP standard for walking speed is 3 miles per hour on a flat surface. To become proficient at pace rating walking speeds, ME analysts may view pace rating tapes or pace rate fellow workers across a known distance. This training routine, like hand speed, also takes three ME analysts to perform: one to perform the practice pace rating, one to act as the walker, and another to time the walker using a time device. As the practice pace rating is taken of the walker across a known distance, the timer records the time from start to crossing the line. With the time known, the actual rate (in miles per hour) can be determined and a comparison of pace rating and actual calculated pace can be determined.

10.1.14. Determining NT. Once an ME analyst has measured a process and performed the pace rating, NT can now be computed. For example, if a process has a measured time of 10 min with a pace rating of 125% of normal pace, then the NT is calculated as:

10.1.14.1. NT = Measured Time *

10.1.14.2. For the example:

10.1.14.3. NT = 10 * = 12.5 min of NT.

10.1.14.4. Likewise, if the pace rating had been determined to be 80%, then the calculations would be:

10.1.14.5. NT = 10 * = 8 min of NT.

10.1.14.6. Thus, both above and below average normal pace observations can be estimated to determine the NT.

Chapter 11

DETERMINING PERSONAL, FATIGUE AND DELAY ALLOWANCES

11.1. General Concepts. PF&D allowances are added to NTs to create standard time when time study, good operator timing, or WS are the measurement techniques. Allowances add time to account for personal human needs, the external and operational environment, and the nature of the work.

11.1.1. Do not add PF&D allowances to the OA techniques of technical estimate and historical record. When directed requirements technique is used for SAT, PF&D allowances may be added; but do not add PF&D allowances for directed requirements when whole manpower positions are directed, e.g., First Sergeant position in a squadron. Do add PF&D allowances for SATs determined via good operator timing.

11.1.2. Personal allowances take into account time given for personal breaks e.g., rest room breaks, personal phone calls. Do not confuse personal time with annual or sick leave or any other factor already taken into account in the nonavailable time of the monthly MAF.

11.1.3. Fatigue allowances recognize the limitation of the human condition and take into account time a worker needs to rest and recuperate due to the physical and mental demands of the job.

11.1.4. Delays that are unavoidable and cause the worker to stop immediate operations but also prevents the worker from doing other productive work, should also be considered and added to NT. Do not credit idle time that is truly avoidable, i.e., the worker may have been stopped at the immediate activity, but he or she can begin working on other productive work in the meantime.

11.1.5. At the discretion of the ME analyst, a standard PF&D allowance can be used for the entire work center or each activity in a SWD. However, when specific activities within a single SWD represent considerably different nature of the work or under significantly different work conditions, then PF&D allowances should be determined and applied at the activity level.

11.1.6. The Air Force MEP treats time for work center clean-up as part of a standard indirect labor standard or factor. Therefore, do not add work center clean-up time to the PF&D allowance.

11.1.7. Determining ST.

11.1.8. The computing PF&D allowances are expressed as the allowance factor multiplied by an activities NT to create a standard time such that:

11.1.9. NT x Allowance Factor = ST.

11.1.10. Note: Recall NT is the measured (i.e., observed) time that has been adjusted by a pace rating or leveling factor.

11.1.11. To compute the allowance factor for PF&D factor, use the following equation:

11.1.12. Allowance Factor = $\frac{100\%}{00\% - PF\&D\%}$

11.1.13. Where the PF&D allowances as depicted are expressed as a percentage of the total workday.

11.1.14. For example, to compute the allowance factor for 30 min per 8-hour duty day for PF&D:

11.1.15. PF&D (as a percentage) = $\frac{0}{30} = 6.25\%$

11.1.16. Where 480 equals the number of min in an 8-hour duty day. Thus the allowance factor would equal:

11.1.17. Allowance Factor = $\frac{100}{)0-6.25} = 1.067$

11.1.18. Continuing, if the NT of an activity was measured at 12 min, then to determine the standard time (i.e., the final manpower credit the USAF would pay for this activity) for an allowed PF&D time of 30 min per duty day as in the example above, then:

11.1.19. NT x Allowance Factor = ST

11.1.20. 12 x 1.067 = 12.80 min of standard time credited to the work center for this activity

11.1.21. Determining PF&D Allowances. At the discretion of the ME analyst, PF&D allowances can be determined either by:

11.1.21.1. Measuring the allowances via a work measurement technique, e.g., WS.

11.1.21.2. A combination of measured and predetermined allowance factors.

11.1.22. Using predetermined allowance factors (as discussed below). Base Personal Allowance: Predetermined PF&D Allowances. The base personal (i.e., minimum) allowance factor is 1.067 (i.e., 30 min per 8-hour duty day). If USAF policy for a given work center directs longer base PF&D allowance, annotate the authority source, and the ME analyst recomputes the base PF&D allowance. Use Table 11.1 to add to the base personal allowance factor (as a percentage) if applicable:

Table 11.1. Allowed Adjustments for Base Personal Allowance.

Conditions	Percent Added to Base Allowance
Normal office conditions	0
Normal shop with central heat and/or air but slightly dirty or greasy	1
Slightly disagreeable conditions. Personnel are exposed to inclement weather part of time, poor heating, or poor cooling	3
Adjunctive allowance-allowed for work performed in "super" clean rooms. Required when operators routinely don and doff special personnel protective equipment, e.g., caps, boots, etc.	4
Work center personnel are exposed to extremely disagreeable conditions most of time, e.g., proximity to hot objects, continuous exposure to disagreeable odors and fumes, or to excessive temperature fluctuations.	6

11.1.23. Calculating Allowances for Fatigue. Fatigue allowance can be categorized as physical or mental fatigue.

11.1.24. Physical Fatigue for Lifting Objects. When a work center's activities involve the lifting of objects, the ME analyst considers the following conditions:

11.1.24.1. The average weight handled per worker.

11.1.24.2. Percent of time for the defined activity actually under load.

11.1.24.3. The height the load is manually lifted (for the most likely situation).

11.1.24.4. The basic percentages for fatigue allowances in Table 11.2 are based on the effective net weight of the object(s) that are placed at a height somewhere between the worker's chest and the floor. Table 11.2 also applies when sliding or rolling the work objects along a flat surface.

Table 11.2. Predetermined Fatigue Percentages.

When the Effective Net Weight Lifted Is Between: (In Pounds)	And the percent of time the worker is under load is:				
	1-12%	13-25%	26-50%	51-75%	76-100%
1-10	0	1	2	3	4
11-20	1	3	5	7	10
21-30	2	4	9	13	17
31-40	3	6	13	19	25
41-50	5	9	17	25	34
51-60	6	11	22	X*	X*
61-70	7	14	28	X*	X*
71-80	8	17	34	X*	X*
Table values are multiplied by the following factors as dictated by conditions: When the worker places load above chest-height, multiply basic allowance by: 1.20 When the worker places the load from above chest-height, multiply basic allowance by: .50 * X= Exceeds ergonomic safety—redesign activity to lower weight or time spent lifting.					

11.1.24.5. Physical Fatigue Allowance for Worker Positions. The ME analyst should consider the position(s) the worker normally assumes to perform the operation. The ME analyst chooses the mostly likely scenario from Table 11.3.

Table 11.3. Fatigue Delay for Worker Position.

When the normal worker position is:	Then added percentage for worker position is
Approximate equal amounts of sitting or standing	0
Constant Sitting	1
Constant Walking	1
Constant Standing	2
Climbs and/or descends ramps, stairs or ladder	4
Working in close, cramped position	7

11.1.24.6. Mental Fatigue Allowance Nature of the Work. The ME analyst also considers the concentration necessary to perform the activity and the amount of variety in the activities as shown in Table 11.4.

Table 11.4. Consideration for Mental Fatigue Allowance Nature of the Work.

When the activity is/or involves:	Then the percentage to add for mental fatigue is:
Mostly routine known by habit Simple calculations on paper Reading easily understood material, e.g., routine or familiar instructions Counting and recording numbers Simple inspection requiring attention but little worker discretion is required Arranging papers by letter or number	0
Full worker attention such as copying numbers, addresses or instructions Memory of part number or name while checking stock or parts list Attention between work at hand and other worker activities Simple mental calculations Filing papers by subject of familiar nature	2
Requires concentrated attention such as reading of non-routine instructions Checking numbers, e.g., parts, papers, etc., that requires cross reference or double check Division of attention between three components such as accounting, inspecting, and grading Navigating unfamiliar routes, watching vehicle traffic and route signs	4
Work requires deep concentration Swift mental calculations or calculations on paper Inspection where work requires interpretation and discretion Routinely involved handling work of an unfamiliar nature, e.g., working against non-routine specifications Highly divided attention between phases of work, the operations of others, or specific work hazards	8

11.1.24.7. Mental Fatigue for Lighting. In addition to mental fatigue due to nature of the work, the ME analyst should also consider typical lighting in terms of the amount of light on the work surface and the fineness of details and the amount of glare on the work surface, and rapid changing or "hypnotic" effect of the work. Use Table 11.5 as a reference.

Table 11.5. Consideration for Mental Fatigue Allowance Lighting.

If the work involves either	Then the percent to add to Mental Fatigue for Lighting is:
Continual glare on work areas Work requiring constant change in light on work area Less than 75 foot candle power on work surface for normal job Less than 125 foot candle power on work surface for detailed work	2

11.1.24.8. Mental Fatigue for Noise. The ME analyst should also consider the general noise of the work areas as well as any annoying, sharp, staccato, or intermittent noises occurring during more than 50% of the work day. If ear plugs or ear muffs are required to be worn, the protective sound device's noise reduction effect is considered when using the allowance in Table 11.6

Table 11.6. Consideration for Mental Fatigue Allowance Monotony.

When the work environments noise level is	Then the percent to add for Mental Fatigue for Noise is:
Constant, rather loud noises such as in machine shops, etc. (over 60 decibels)	1
Average constant noise level but with loud, sharp, intermittent, or staccato noise such as nearby riveters, punch presses, aircraft engine starts, auxiliary power units, e.g., flight line or machine shop	2

11.1.24.9. Mental Fatigue for Monotony. The ME analyst should also consider the mental fatigue resulting from work that is fast and highly repetitive. Here, the ME analyst considers the cycle is time elapsed from the start of one complete cycle and the next repeat of that cycle as

11.1.24.9. Mental Fatigue for Monotony. The ME analyst should also consider the mental fatigue resulting from work that is fast and highly repetitive. Here, the ME analyst considers the cycle is time elapsed from the start of one complete cycle and the next repeat of that cycle as depicted in Table 11.7.

Table 11.7. Consideration for Fatigue Allowance Wear of PPE.

When the PPE involves a	Then the percent to add for Mental Fatigue for Wear of PPE is:
Safety glasses	0
Face shield	2
Rubber boots	2
Goggles or welding mask	3
Tight, heavy protective clothing	4
Filter Mask	5

11.2. Allowances for Unavoidable Delay.

11.2.1. The ME analyst finally considers unavoidable delay. Recall an unavoidable delay is just that, unavoidable. If a worker can be doing any other productive work instead of waiting for the task at hand, the reason for delay cannot be considered unavoidable.

11.2.1.1. Base Allowance for Unavoidable Delay, Table 11.8. A predetermined base allowance for delay can be estimated based upon the need for close coordination between defined activities. Note: The ME analyst should consult the SWD(s) to ensure understanding of the process flow and the inter-related nature of specific activities.

Table 11.8. Base Allowance for Unavoidable Delay.

When the activities in a process are:	Then the base allowance for Unavoidable Delay is
Isolated, but requires some coordination with adjacent activities	1
Fairly close coordination with adjacent activities	2

11.2.2. Other unavoidable delay situations can be included once measured and computed by the ME analyst.

11.3. Application of the Allowance Factors. These tables normally provide realistic PF&D allowances. However, in some situations, using these predetermined factors results in a total allowance ≥ 100 which yield a zero or negative denominator in the allowance factor formula. Assuming the PF&D allowances have been correctly characterized and computed correctly, when this situation occurs, the ME analyst should reshape SWD activities so realistic PF&D allowances are obtained. Realistic is defined as an allowance acceptable to the ME analyst and the functional work center; if the PF&D allowance is in dispute, the ME analyst's judgment as the work measurement expert prevails.

11.3.1. Example of Computing an Allowance Factor. Suppose a work center has the following PF&D allowances as determined by the ME analyst:

11.3.1.1. Allows two, 15-minute personal breaks.

11.3.1.2. Works under slightly disagreeable working conditions.

11.3.1.3. For this specific activity, requires grasping an 8-pound object 30% of total activity time and placing it above chest level.

11.3.1.4. Lighting is considered adequate without glare and noise levels are under 60 decibels.

11.3.1.5. Requires cross checking part number with a shipped document.

11.3.1.6. Require the wear of rubber boots personal protective equipment (PPE).

11.3.1.7. Require some coordination with adjacent activities.

Note: Table 11.9 shows the calculations to determine the PF&D allowance on the activity described above.

Table 11.9. Example of PF&D Computations.

Basic Allowance Category	Percentage	Multiplier (if applicable)	Final Allowed Percentage
Personal Allowance-Basic	6.25	N/A	6.25
Personal Allowance Adjustment for Environment	1.00	N/A	1.00
Fatigue Adjustment For Lifting	2.00	1.2	2.40
Mental Fatigue—Nature of work	4.00	N/A	4.00
Fatigue for PPE—Rubber Boots	2.00	N/A	2.00
Delay Allowance for some coordination with adjacent activity			1.00
Total PF&D Allowance (as %)			16.65

Chapter 12

WORK SAMPLING (WS)

12.1. General Concepts. WS is considered by the Air Force MEP as an engineered work measurement method based on the principle that random samples taken from a large group tend to keep the same distribution characteristics as the group. Conclusions are drawn about the population based on the sample recorded. The WS method relies heavily on the ME analysts to visually observe the work and collect accurate samples and workload information.

12.1.1. The WS method defines processes, makes observations, computes percentage of occurrence for each process, and applies these percentages to man-hours sampled.

12.1.2. The WS method has limited application in a wartime environment area of responsibility (AOR) because of the time needed to successfully do a measurement of this type. Another drawback is if home station data, measured by WS, is converted to AOR values, consistency between home station and AOR policy and procedures is assumed. Conversion in this instance is limited to workload and the MAF only. The most likely arena for WS in an AOR operation is a realistic and representative exercise or operational readiness inspection.

12.2. Applying WS. WS is commonly used to determine equipment utilization, analyze work distribution, conduct methods improvement efforts, and compute and verify PF&D allowances.

12.2.1. WS is very effective and an appropriate work measurement technique when a work center's workload is:

12.2.1.1. Repetitive, non-repetitive, or irregular work.

12.2.1.2. Accomplished in a general manner.

12.2.1.3. Performed by many workers in a relatively small area.

12.2.2. Take care when identifying work centers to be sampled. Historically, work centers requiring product analysis, closed-session counseling, or creative thinking have been difficult-to-nearly impossible to sample. For these work centers, consider using productive and nonproductive sampling (reference **Chapter 12**, paragraph 12.3). Some office work is difficult to quantify by WS because the work is not cyclical or is completed over a long period of time. Also, work cycles may be variable because of the many different products.

12.3. Types of WS Efforts. WS efforts can be designed to be either productive or nonproductive (Level I) or at the process level (Level II).

12.3.1. Level I. In Level I, samples are broadly classified as productive, nonproductive, nonavailable, and lunch. Sample nonproductive categories, such as PF&D and idle time, at the category level since these categories are easily distinguishable. This provides information to support the allowance factor and to brief the OPR.

12.3.1.1. If an ME analyst wishes to convert a Level I to a breakout by process category, use percentage estimates to distribute productive time (direct and indirect) into processes. However, when this approach is accomplished, the effort's work measurement data can no longer be considered to be derived via an engineered work measurement technique.

12.3.1.2. Derive these percentage estimates through consultation with key personnel and the work center supervisor. Get estimates from several work center personnel to improve the reliability of process distribution. Percentage estimates need to equal 100%.

12.3.1.3. Table 12.1 shows an example of estimated process distribution percentages. It assumes estimates were obtained from the work center supervisor (estimate A) and the foreman (estimate B). The percent of total column (column five) is used to distribute the productive direct time into processes.

Table 12.1. Percentage Distribution of Productive Processes.

(1) Process Number	(2) Percent Estimate by A	(3) Percent Estimate by B	(4) Total of (2) + (3)	(5) Percent of Total (4)/200%
1	9%	7%	16%	.08
2	30%	26%	56%	.28
3	15%	13%	28%	.14
4	8%	8%	16%	.08
5	25%	21%	46%	.23
I1	8%	4%	12%	.06
I2	4%	4%	8%	.04
I3	4%	2%	6%	.03
I4	3%	3%	6%	.03
I5	1%	1%	2%	.01
I6	1%	1%	2%	.01
I7	1%	1%	2%	.01
TOTAL			200%	1.00

12.3.2. Level II. Level II WS efforts are measured at the process level. In most WS efforts, it is easy to distinguish between productive and nonproductive samples. The distinction between productive direct and productive indirect is more difficult. For example, the productive direct process of management is similar to the productive indirect processes of supervision and administration when observed at the activity level of accomplishment. If a sample is misclassified as direct when it is really indirect, there is no change to total productive time.

12.3.2.1. Because measured indirect time is based on actual observations, do not use an IAF with Level II WS efforts (application of an IAF in this case double counts indirect time). Do not compromise determinant efforts based on observation by comparing Level II economics with the economics for determinants based on non-measurement methods.

12.3.2.2. Productive direct time is sampled at Level I and prorated by percentages to get direct process and indirect category time.

12.3.3. Productive indirect time is sampled at Level II (process level).

12.3.4. Economic Desirability of WS. The economic desirability of WS increases with the number of people being sampled. Each ME analyst should measure a minimum of five workers where possible; however, those being sampled may be assigned to more than one work center, for example, family of determinants.

12.3.5. The measurement work force should consist of personnel who spend most available time in a place allowing for observation of work. Account for work done away from the immediate work center for extended periods of time as follows:

12.3.5.1. Arrange for a ME analyst to observe the worker at the out-of-area location.

12.3.5.2. Sample this time as "out-of-area" and OA this time if it is not feasible to observe the worker. Account for out-of-area samples by applicable process. For multipoint determinants, study teams furnish guidance in the measurement plan for treatment of these samples if applicable.

12.3.5.3. Do not plan for more observations than a ME analyst can accomplish in a reasonable period. Assigning the measuring ME analyst too many personnel or too many work centers may not allow timely observations and may bias the sampling data. Conversely, assigning the measuring ME analyst too few personnel is not economically feasible.

12.3.6. Generally, measure a work center with two or less people by OA unless it is necessary to observe standby time or the need for an assistant. When several input points have four or less people to be measured, it is not economical to conduct a WS effort.

12.4. Briefings for WS.

12.4.1. In-briefing. Make sure the work center supervisor and workers fully understand the principle of WS during the in-briefing. Because its statistical basis makes WS difficult to understand, use illustrations without technical terms. Use simple explanations to eliminate confusion and allow work center personnel to understand the WS principle. Some examples of situations similar in principle to WS are: testing antifreeze in a car radiator, taking blood samples, or trying one package of cigarettes before buying a carton. Since all of these actions represent the original source, the opinions formed from the samples are valid for the whole product. Explain during in-briefing that WS daily observation sheets are to be treated confidentially and not shown to supervisors or managers. Sampling data is never used by superiors to evaluate individuals.

12.4.2. Out-briefing. Summarize process percentages of occurrence for presentation during out- briefings. A pie chart is a convenient way to graphically present this information. Brief local OPRs on measured man-hours and WLF values. Cover the treatment of assumed and inferred work. Inform local OPRs measurement results do not represent the final determinant. The ME analyst does C&R analysis and computes the final determinant using data from the measurement locations.

12.4.3. WS Process Development. Develop the SWD for WS at the same level as for OA (Level II), or if appropriate, at the broader process level (Level I). ME analysts may derive activity or step times by using the percentage estimates described in paragraph 12.3. In either case, write the SWD to facilitate observation during sampling. Make sure processes in the SWD cover all required work, are clearly defined, and mutually exclusive.

12.4.3.1. Select processes for both direct and indirect work. Further define the process by using steps. Each step is discrete and understandable to the observer. Failure to clearly define processes distorts process percentages and later makes analysis and determinant maintenance difficult.

12.4.3.2. WS efforts identify time spent in available and nonavailable activities. Available time is broadly classified as productive (direct and indirect) and nonproductive. Examples of nonavailable activities are: leave, medical absences, TDY for training, etc. Additional processes for management's information such as additional duties may be described and measured during WS.

12.4.3.3. Nonproductive categories, for sampling purposes, are personal fatigue, idle (extended lunch) and unavoidable delay. Other nonproductive categories may be added when needed, for example, assumed and inferred. Do not use other and miscellaneous for nonproductive category titles as other and miscellaneous become catchalls during WS efforts. Usually, productive indirect and nonproductive activities are sampled at the process level. Data collected for these processes is useful when out-briefing WS results. Treatment of lunch time is described in the following paragraphs.

12.4.3.4. Sample lunch to account for productive time expended during the lunch period and to account for nonproductive time taken for an extended lunch. Sampling of lunch eases the accounting of samples at the end of each sampling day. Be cautious when selecting random times and making observations during the lunch period. Incorrect accounting of lunch samples affects other process percentages. Study teams give specific guidance on treatment of lunch observations in the measurement plan, when applicable. This example illustrates the need for caution: assume three observations per hour are being taken and the lunch period for half the work center is 1100 to 1200. Assume the other half takes lunch from 1200 to 1300. Select random times so three observations occur between 1100 and 1200 and three occur between 1200 and 1300. The sampling ME analyst normally records three samples for lunch for each worker. However, if worker A (from the first group) was working at 1145 (observation time) and did not take his or her full lunch hour, then one productive sample and two lunch samples would be recorded. On the other hand, if worker B (from the second group) left for lunch at his or her regular time and was still on lunch break at 1310 (observation time), then three lunch samples and one idle or extended lunch sample would be recorded for worker B.

12.4.3.5. If lunch periods are staggered or workers do not take scheduled lunch breaks, this example is inappropriate. In this case, sample lunch cautiously and check the percentage of lunch samples daily and at the end of the ME effort to verify representativeness.

12.4.4. An unscheduled (U) category is useful for keeping accountability of samples. Use this category when:

12.4.4.1. Shift changes are staggered during a multi-shift operation.

12.4.4.2. Workers are doing required work before the beginning or after the end of a scheduled shift.

12.4.4.3. SWD Verification. As part of the verification process, accomplish the following:

12.4.5. Investigate the operation of the work center thoroughly before beginning the effort. Check organizational structure, mission requirements, directives, and other pertinent factors, such as backlogs, work cycles, and historical production.

12.4.6. Review the SWD. Contact the study team for guidance if steps are found not in the approved SWD. Measure such steps separately. The study team, in cooperation with the OPR during data analysis, makes the final decision to include or exclude these steps in the manpower determinant. The study team updates the SWD if it is determined the added steps apply to all locations.

12.4.7. Work Counts (WUC and Potential WLFs). Man-hours collected during WS efforts represent only one portion of the data needed to compute an equation. The other important part is workload data. Set up a work count system to record workload on a daily basis. If work counts are not completed daily, then record them as frequently as the work is completed. Use a production report if it is available, but make periodic checks to validate its accuracy. Ensure the period of the production report corresponds with the ME development period. Pay particular attention to recording correct values for work started before the ME development and work continuing after ME development. Do not include WUCs for days sampled but dropped from computations for non-representativeness. Adjust the average daily work counts to an average monthly figure. Use this figure as the independent variable for the determinant man-hour equation. Use total monthly-allowed man-hours as the dependent variable. An exception to this procedure is allowed when the potential WLF is nonproduction oriented. For example, population serviced may be relatively constant on a daily, weekly, or monthly basis. In this case, use population serviced as reported for the time frame closest to the WS period for the dependent variable.

12.4.8. Determining Sampling Period. Sample at least one complete cycle during the measurement period. The normal sampling period is 21 days (minimum of 15 usable duty days). When necessary, extend the sampling period to ensure it covers a complete cycle.

12.4.9. Conduct WS over a representative period or work cycle. Ideally, use WS when a normal period of productivity is to be measured and when relatable WUs are available. When a work cycle is longer than a month, the study team decides the feasibility of using WS. In a 7-day work center, ensure a representative proportion between weekend days and weekdays is maintained during the sampling period. For example, when 21 usable duty days are needed, 6 of those days should be weekend days. Each day's sampling results is evaluated for representativeness. If a day is not considered representative, the sampling period is extended.

12.4.10. Use the experience of work center personnel to set up an average work cycle and to pinpoint recurring periods of heavy productivity. Plotting these cycles against a time scale may reveal a pattern and its composite effect on the work center.

12.4.11. Supplementing WS with OA. During a WS effort, samples may be taken for a process previously identified for measurement by OA. When this occurs, maintain sample accountability on the Daily WS Observation Sheet, but do not record samples on the WS Record. Measure the process by OA and transfer this time to the Standard Input Data Computation Worksheet along with the monthly-allowed man-hours from WS.

12.4.12. The study team evaluates the supplemental OA for non-routine work based on total review of OA work. No adjustment is needed for non-routine work if the sampling period is considered representative. Project teams provide special instructions to identify and report cyclical work that occurs less frequently than monthly (for example, quarterly or annually). A representative sample period reduces the need for OA.

12.4.13. ME analysts should be cautious and realize there is a difference between work not occurring during the sampling period and work not observed. If a particular step was done but was not observed due to the randomness of the observation schedule, do not add OA time for the step. OA only those non-routine required steps that occur less frequently than monthly. Be particularly careful when supplementing WS data for indirect tasks. For example, preparing annual reports may be a wash item since daily or monthly reports normally feed into annual reports and the samples may have captured a normal amount of time for report preparations. Project teams identify reports and meetings along with sampling instructions in the measurement plan. When Level I sampling is being used (productive and nonproductive), a supplemental OA for indirect tasks is not required.

12.4.14. Man-Hour Population. The man-hour population (sampled man-hours) for accounting purposes consists of man-hours for available, nonavailable, borrowed, lunch, and overtime. It excludes loaned man-hours and for computational purposes, the man-hour population excludes nonavailable time. This allows for the complete accounting of time with no degradation of accuracy and percentage of occurrences.

12.4.15. Observation Schedule Development. When scheduling the time between observation samples, use a random process. The purpose of sampling is to supply information about the population. Characteristics discovered in the sample are expected to exist in the population from which the sample is taken. The key to unbiased sampling is the randomness of the sample. Several methods are available to ensure randomness; two are discussed below.

12.4.16. Random Number Tables. Randomly pick a starting point in a random number table. Proceed horizontally, diagonally, or vertically and record the one-digit, two-digit, or three-digit numbers upon appearance. Disregard numbers outside the needed range. For example, if you need two-digit random numbers ranging from 00 through 59, then disregard the two-digit numbers greater than 59. If a number appears again after it has previously been recorded for use within a particular strata (hour or day), ignore its later appearance. This ensures consistency with sampling without replacement. If it takes 5 min to make an observation round, disregard numbers within five-minute increments of each other. Continue selecting numbers until you reach the desired sample size.

12.4.17. Random Number Tables. Randomly pick a starting point in a random number table. Proceed horizontally, diagonally, or vertically and record the one-digit, two-digit, or three-digit numbers upon appearance. Disregard numbers outside the needed range. For example, if you need two-digit random numbers ranging from 00 through 59, then disregard the two-digit numbers greater than 59. If a number appears again after it has previously been recorded for use within a particular strata (hour or day), ignore its later appearance. This ensures consistency with sampling without replacement. If it takes 5 min to make an observation round, disregard numbers within five-minute increments of each other. Continue selecting numbers until you reach the desired sample size.

12.4.18. Random numbers from computers. When a computer is available, get a series of numbers with the needed number of digits. Treat this series the same as with the random numbers table.

12.4.19. Sampling period, work center operating hours, desired accuracy, and the number of people assigned determine the number of observation rounds needed for each work center during a WS effort. A sample is a single recorded status of one person during an observation of a work center. An observation yields a number of samples equal to the number of people observed. For example, an observation made at 10:15 am in a seven-man work center yields seven samples. Develop the observation schedule to get no fewer than 1111 available samples (excluding lunch) in each work center. This number ensures accuracy in all available processes and eliminates the need to estimate the number of samples needed when conducting a mini-effort. Prior to sampling, consult the work center supervisor regarding scheduled nonavailable activities, such as leave, medical absences, or TDY.

12.4.20. ME analysts determine the observation schedule. Project teams determine the cycle, which days to sample, and the strata to use (e.g., stratified hourly or stratified daily random sampling). Take care when setting up the observation schedule. Taking less than 1111 samples might cause the effort to fail statistical accuracy. If this happens, extend the measurement period through the next cycle. Taking too many samples may cause an excessive number of ME analysts to be used for measurement, thereby increasing the cost of the effort.

12.4.21. ME analysts select observation times so the number of samples taken per individual per day remains constant. An exception to this rule may occur when an individual is borrowed or loaned, works overtime, is newly assigned, or departs the work center for PCS during the duty day.

12.4.22. When an observation schedule cannot be met because locations are widely dispersed, develop a randomized location schedule. A randomized location schedule is similar to a randomized time schedule; however, instead of listing observation times on tickets or cards, write the title of each location on tickets or cards. Draw cards randomly from a hat or box, record locations in the order drawn, replace the cards in the box, and then repeat the draw a second time, third time, etc. Next, visit each location in the order recorded. Begin sampling at the start of the normal duty day and continue until the end of the normal duty day. Move from one location to another in the order previously recorded, but on no prescribed schedule. Sample the location on arrival. Follow the recorded order until you have enough samples to achieve accuracy, a complete cycle is sampled, and the minimum sampling period is covered. Operationally audit overtime when this method is used.

12.4.22.1. Often it is desirable to ensure each hour of the day has equal representation in the sample. In work centers where activity fluctuates hourly, use stratified sampling. In this procedure, determine the number of observations needed per hour and randomly select observations within the hour. Once sampling begins, input ME analysts consistently follow the predetermined schedule per hour until completion of the sampling period. Ensure the number of observation times for lunch is representative before sampling. The following example illustrates how to determine the number of observations needed per hour:

12.4.22.2. Assume a work center size of seven people and a sampling period of 21 work days.

12.4.22.3. One observation of 7 people per hour, assigned for an 8-hour day over a 21-day period, yields 1176 samples (1 x 7 x 8 x 21 = 1176). This meets the minimum requirement of 1111 available samples. However, if normal non-availability for military personnel (e.g., 10.6%) occurs during the effort, then only 89.4% of 1176 (or 1051 available samples) would be obtained. Therefore, increase the minimum number of observations per hour to two. Increasing the number of observations per hour above the minimum improves the ME development accuracy and reduces the ME analyst's slack time. Make allowances for loaned time when setting up observation schedules.

12.4.22.4. Man-Hour Shift Profile Sampling. The purpose of the man-hour shift profile chart is to reduce standby. When minimum manpower is not clearly defined and it is not possible to accurately sample standby, construct a present and proposed man-hour shift profile chart.

12.4.22.5. When collecting WS data to build the man-hour shift profile chart:

12.4.22.6. Use stratified hourly sampling.

12.4.22.7. Designate each productive process as transferable or nontransferable.

12.4.22.8. Construct the present man-hour shift profile chart directly from information on the daily observation and recapitulation sheets.

12.4.22.9. Construct the proposed chart by analyzing and improving the present chart (reference Chapter 11 for more information on constructing man-hour shift profile charts).

12.4.22.10. Use the proposed chart to support the standby time allowed in the determinant. Also, use the chart to graphically support reduced standby to the OPR.

12.4.23. WS Procedures. Make observations at scheduled times without distracting workers. Enter the work center as inconspicuously as possible. Sometimes it is best to remain in the work center between closely spaced observations because distractions caused by entering could bias samples.

12.4.23.1. Classify the sample instantaneously so each sample is the result of an immediate observation. When it is not possible to identify the proper process, classify the sample as productive or nonproductive and reconcile it later. The workers' activity immediately before or after the scheduled observation may give a clue to proper classification.

12.4.23.2. Conduct Familiarization or trial sampling to reduce the number of questions during observation rounds. When possible, wear apparel similar to that of personnel in the work center being sampled. Likeness in clothing causes the sampling ME analyst to blend with work center personnel and helps reduce apprehension. Avoid unnecessary conversation, but be friendly and answer questions regarding the ME development process.

12.4.23.3. Properly classify personal, fatigue, unavoidable delay, standby, and idle time. Accurate identification provides rationale for using the allowance factor or for proving a larger factor that includes additional fatigue or delay. The ME analyst should also be alert to assumed work (make work) or inferred work (responsibility of a different function) during sampling. Although the measurement plan should identify potential areas for assumed and inferred work, the key to proper identification is the ME analyst's familiarity with the work center. Identify inferred and assumed work separately on the daily observation sheet. Later, credit inferred work to the proper work center, or remove it from allowed man-hours. Always remove assumed work from allowed man-hours.

12.4.24. Sample pre-duty and post-duty periods. The ME analyst should be in the work center when the first worker arrives and stay until the last worker departs. When a worker is present during pre-duty or post-duty periods, but is not productive, sample the worker as (U) and exclude from sample man-hour computation. A productive sample during this period increases the number of samples per person per day and is equivalent to sampled overtime.

12.4.25. Follow the same measurement technique for all determinant input locations. For example, when WS is the primary measurement method, all inputs use WS. An exception is allowed when the work center has two or less people (See paragraph 11.3.7.). When OA is specified for one process, all inputs OA that process. Also, when stratified sampling is specified, all inputs stratify. When work center personnel stagger lunch periods, use stratified, hourly sampling to ensure lunch samples are representative.

12.4.26. Avoid sampling at the lower task levels unless these tasks are easily identifiable by observation. Sampling a large number of tasks increases the time needed to make an observation round and results in a need for more sampling ME analysts. Sampling at the task level disrupts work center personnel because questions need to be asked to properly classify samples.

12.4.27. Between samples, ME analysts accomplish daily accumulations, compute control chart limits, collect WUs or potential WLFs, conduct OAs, observe personnel who might be working out-of-area, and investigate process improvement opportunities.

12.4.28. Treat standby time during sampling according to **Chapter 17**, paragraph 17.3.3.1.

12.4.29. ME analysts should be able to recognize all the workers, their duty schedule and lunch period, and the work accomplished. ME analysts should also be familiar with the layout and boundaries of the work center. Devise coding systems to expedite sampling and facilitate recall. Use mutually agreed-on codes when more than one ME analyst is involved in the effort.

12.4.29.1. Confidentiality of WS Data. Daily WS observation data are considered sensitive information and is not releasable by name. These practices are followed to maintain confidentiality. Cut out personnel names and identification after the samples have been totaled. As an alternative, black out names and make a copy.

12.4.29.2. Use codes for identification in lieu of names.

12.4.29.3. Devise a code for idle and sensitive processes. Use codes familiar to other ME analysts. Memorize codes for productive indirect and nonproductive categories and omit the legend on the form, however a legend for all omitted entries is part of the study plan.

12.4.29.4. WS Data Leveling. Pace rating is used to determine a leveling factor. The leveling factor is used to adjust productive time to a norm. Many processes do not lend themselves to rating (for example, supervision and mental work). Also, the ME analyst needs to be proficient with rating and familiar with the job to rate effectively. The nature of selecting inputs from a cross section of installations, coupled with the determinant development process of using least squares regression, helps ensure the norm.

12.4.29.5. Pace rating for WS efforts is a study team option. If pace rating is used, the study team specifies the pace rating range in the measurement plan. If pace rating is not used, the leveling factor is 1.00. (Refer to Chapter 10 for information on pace rating).

12.4.29.6. Allowance Factor Computation in WS. Allowances are computed to recognize PF&D. Allowances are applied at the process level for WS efforts. When the base personal allowance factor is used for the work center, apply it to all productive, and leveled processes. When a larger allowance factor is computed, apply it only to the affected process. Use the base personal allowance factor for the remaining productive processes.

The study team determines whether the base personal allowance factor is pertinent. If it isn't, the study team computes the allowance factor to be used according to **Chapter 10.**

12.4.29.6.1. The allowance factor, fixed or computed, is evaluated during test measurement and then coordinated with the functional OPR. The coordinated allowance factor is then put in the measurement plan for all input locations to use.

12.4.30. WS Data Control Charting. The two types of control charts used with WS data are productivity charts and WLF control charts. Each of these control charts are addressed separately below.

12.4.30.1. Productivity Charting. Productivity charts are effective for determining representativeness of daily productivity. By comparing productivity control charts with the WLF control chart more information is apparent to the ME analyst. A productivity chart is a graph that has a center line, UCL and LCL and the daily productivity to be analyzed.

12.4.30.1.1. The center line is the average productivity for the period the chart represents.

12.4.30.1.2. Set UCL and LCL by adding and subtracting three standard errors of proportion from the center line.

12.4.30.1.3. Exercise caution in discarding data. Do not declare data unusable simply because a point falls beyond established limits. Clearly state a reason for not using each day's data.

12.4.30.1.4. Frequently in the first few days (possibly a week) of sampling, a greater percentage of productivity is observed than in the remaining days of the effort. This situation is usually caused by the ME analyst's presence in the work center. After personnel in the work center become accustomed to the ME analyst, the data are usually more representative of the normal situation. When this situation causes high productivity followed by low productivity, include both in the effort.

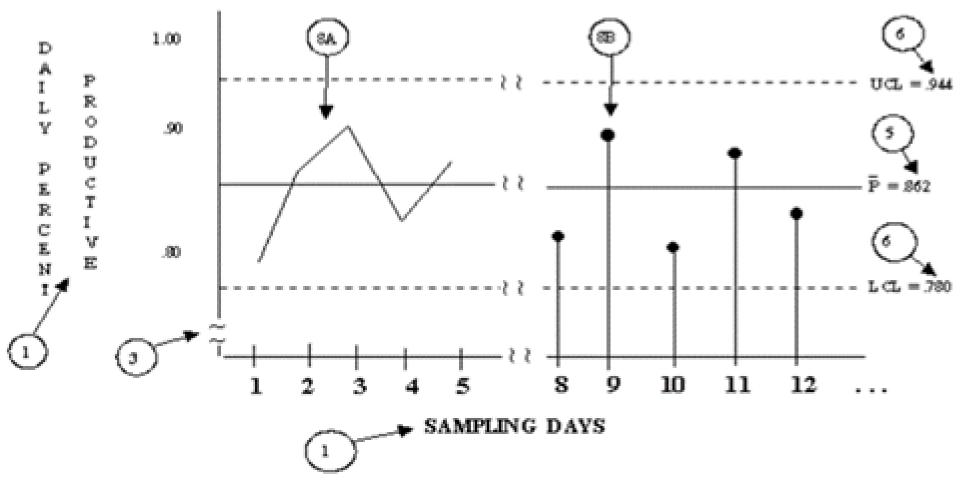
12.4.30.1.5. Consider alternating ME analysts daily and compare odd and even days. This helps identify any observer bias.

12.4.30.1.6. The same general procedures for preparing control charts (Table 12.2) apply to all types of control charts. However, the computations of the needed values differ for variable data (measurements of time, length, etc.) and attribute data (percent or proportions). WS uses attribute data.

Table 12.2. Preparation of a Control Chart.

Step	Action
1	Clearly label both vertical and horizontal axes to indicate what is being charted.
2	Scale the vertical axis to include the range of values to be charted.
3	Indicate with a broken line when an axis does not go all the way to zero.
4	Extend the horizontal axis to allow all of the data to be charted (both current data and data to be obtained in the future).
5	Draw a solid line to indicate the center line. Identify the value.
6	Place dotted lines for the UCL and LCL control limits. Indicate the value of each.
7	Plot the points to be evaluated on the control chart.
8	Connect all of the points to aid the visual analysis by using a solid line between each of the points or by using a vertical line between each point on the X-axis.

Example:



12.4.30.1.7. Attribute data are suitable for a P-chart that evaluates changes in the percent of proportion. The P-chart is based on the binomial distribution. This distribution uses the average quantity incomputing its variation. The instructions for the needed values are in Table 12.3.

Table 12.3. Preparation of a P-Chart for Attribute Data.

<table>
<tr><th>STEP</th><th>ACTION</th><th colspan="4">EXAMPLE</th></tr>
<tr><td>1</td><td>List total number of available samples and the number of samples that were productive (direct, indirect, or total) by the consecutive days sampled.</td><td>Productive Day</td><td>Daily Available Samples (n)</td><td>Productive Samples (X)</td><td>Productive Percent (p)</td></tr>
<tr><td rowspan="6">2</td><td rowspan="6">Compute the percent productive for each day:
$\bar{p} = \frac{X}{n}$
Carry one or two extra decimal places during computations.</td><td>1</td><td>162</td><td>137</td><td>0.8457</td></tr>
<tr><td>2</td><td>180</td><td>158</td><td>0.8778</td></tr>
<tr><td>3</td><td>184</td><td>157</td><td>0.8533</td></tr>
<tr><td>4</td><td>188</td><td>159</td><td>0.8457</td></tr>
<tr><td>5</td><td>190</td><td>156</td><td>0.8211</td></tr>
<tr><td></td><td>$\sum n = 904$</td><td>$\sum X = 767$</td><td></td></tr>
<tr><td>3</td><td>Calculate the average value, where:
$\bar{p} = \frac{\sum X}{\sum n}$
$\bar{n} = \frac{\sum n}{\sum K}$
K = number of sampling days</td><td colspan="4">$\bar{p} = \frac{\sum X}{\sum n} \xrightarrow{yields} \frac{767}{904} = 0.8485$
$\bar{n} = \frac{\sum n}{\sum K} \xrightarrow{yields} \frac{904}{5} = 180.80$</td></tr>
<tr><td>4</td><td>Compute the standard error of proportion:
$\sigma_{\bar{p}} = \sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}}$</td><td colspan="4">$\sigma_{\bar{p}} = \sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}} \xrightarrow{yields}$
$\sqrt{\frac{(0.8485)(0.1515)}{180.8}} = 0.0267$</td></tr>
<tr><td>5</td><td>Determine control limits:
$UCL = \bar{p} + 3\sigma\bar{p}$
$LCL = \bar{p} - 3\sigma\bar{p}$</td><td colspan="4">$UCL = 0.8485 + 3(0.0267) = 0.929$
$LCL = 0.8485 - 3(0.0267) = 0.768$</td></tr>
<tr><td>6</td><td>Prepare a P-control chart either manually or using an automated program using these values. Label all values and each axis clearly.</td><td colspan="4"></td></tr>
</table>

12.4.30.2. WLF Control Charting. A WLF control chart often helps determine the representativeness of the ME development period, verify the accuracy of the work count, and identify normal workloads. The WLF control chart is used in combination with productivity control charts. Make a WLF control chart when the WLF count is available on a daily basis. Development of a work center determinant during other-than-normal workload periods might result in a distortion of the determinant.

12.4.30.2.1. Get the historical workload (minimum of 6 months of data) and create a U-control chart (dividing monthly totals by the number of working days per month) to determine the normal expected average and control limits.

12.4.30.2.2. As the effort develops, plot each day's WLF count cumulatively. Valuable questions in analyzing points that deviate from the historical line include:

12.4.30.2.2.1. Are the daily and historical counts based on the same WLF? Check the definition of the WLF.

12.4.30.2.2.2. Is a regular cycle appearing? Plan to stop sampling as close as possible to the completion of a cycle.

12.4.30.2.2.3. Is productivity commensurate with high or low current workload compared to historical workload? Check rating factors for indications of high or low ratings.

12.4.30.2.2.4. Is the unit experiencing an activity (exercise or operational test) that affects the workload count? Is it affecting productivity? Check the P-chart to determine whether days should be excluded.

Chapter 13

QUEUEING

13.1. General Concepts. The primary intent of this chapter is to relate queuing analysis to the Air Force MEP. General procedures are presented to give direction to the analysis and a feel for queuing situations. Due to the complexity of the subject matter, additional textbooks and information are available in libraries and on the Internet to aid in continued professional development of the ME analyst. The following are basic queuing principles:

13.1.1. Queues are the waiting lines of customers; customers can represent anything, animate or inanimate, awaiting service.

13.1.2. During minimum manpower situations in particular, queuing analysis can be an ideal tool to determine the total number of positions needed to meet varying levels of service.

13.1.3. Defining the queuing system is critical to ensure the application of the correct queuing formulas.

13.1.4. Queuing analysis results in a deterministic result, i.e., using process averages always ends in the same mathematical result.

13.1.5. Queuing and simulation modeling hold much in common. If you have simulation software, refer to **Chapter 14**.

13.1.5.1. For simple solutions with Poisson (reference **Chapter 13** paragraph 13.1.14.6) distributed arrivals and an exponentially distributed service time, choose queuing analysis.

13.1.5.2. As the model becomes more detailed, or the system is inherently complex, choose simulation modeling.

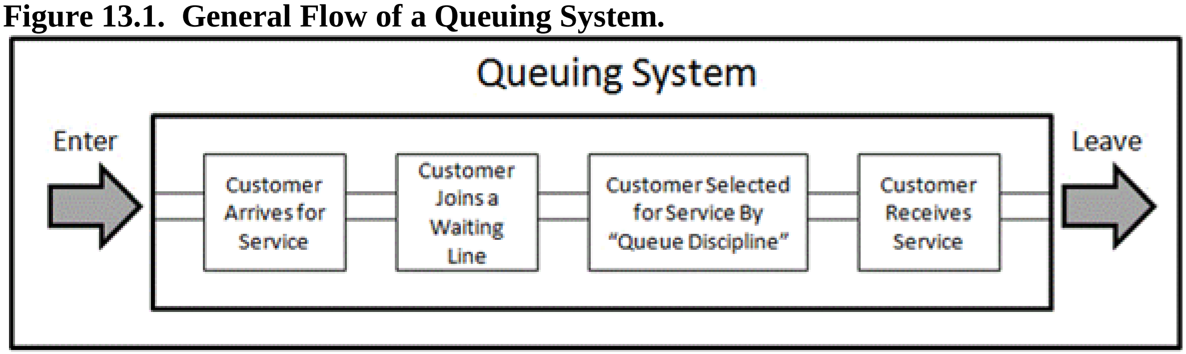
13.1.6. A queuing system refers to the entire process of a customer arriving, being served, and leaving the system. Figure 13.1 illustrates the basic steps of a queuing system. A specific definition is needed to understand the term customer. In queuing, customer is used in a general sense and does not necessarily refer to a human customer. A customer could be:

13.1.6.1. A vehicle waiting to enter a US Air Force base's main gate.

13.1.6.2. A morale call waiting to be answered by a telephone operator.

13.1.6.3. A patron waiting in line at checkout in the commissary.

Figure 13.1. General Flow of a Queuing System.



13.1.7. Queuing analysis can be a powerful addition to data analysis when conducting a manpower determinant. Although traditional work measurement techniques apply to a situation where the next item to be processed is available when the worker is ready to start, in systems where the workload develops (arrives) randomly, queuing theory applies. For example, and in keeping with examples above, queuing analysis could provide considerable insight when:

13.1.7.1. A minimum manpower situation is the appropriate tool and an analysis of the appropriate number of posts or positions is in question. For example, the number of Security Force posts required to maintain a specified wait time or average number of vehicles in the queue at a base entry control point.

13.1.7.2. There are differing levels of service, particularly when a function's performance measures deal with customer wait time, and the resultant manpower impact is being explored. For example, the manpower ME analyst could analyze various scenarios regarding the number of telephone operators required to answer a customer phone call within 10, 20, or 30 seconds.

13.1.8. Thus, as the ME analyst completes the mathematical analysis of a queue, he or she creates a queuing model. Upon completion of the queuing model (or models in the case of analyzing various scenarios), the ME analyst is able to predict the following queuing system metrics:

13.1.8.1. The probability of a customer(s) waiting or not waiting.

13.1.8.2. The average number of units waiting to be served.

13.1.8.3. The average time spent in the queue.

13.1.8.4. The average time spent in the system.

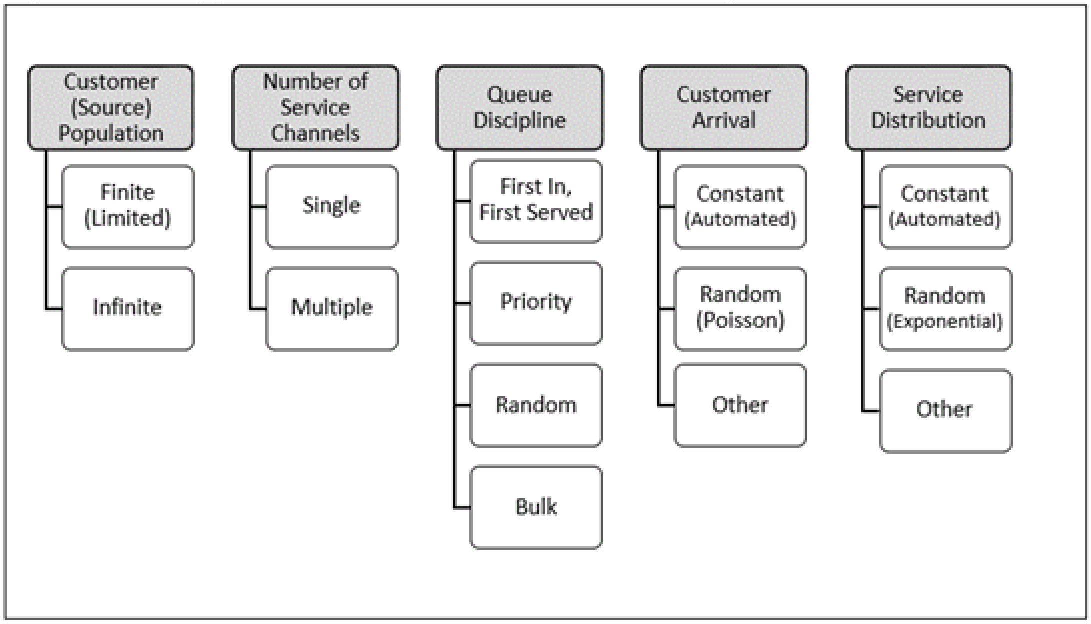
13.1.9. Given any of the aforementioned metrics as part of the function's performance criteria, the ME analyst can decide what level of service is acceptable and determine the resulting manpower impact. For example, the ME analyst can determine the number of cashiers needed to make sure a customer's desired average waiting time is not exceeded.

13.1.10. In the final analysis, a queuing model does not result in the final decisions. Rather, the model provides important information to base decisions upon. Thus, it becomes important for the ME analyst to objectively apply the tools of work measurement and analysis to ensure the best information is provided to the USAF leadership for its final decision.

13.1.11. Defining a System for a Queuing Analysis and Queuing Formulas. Information needed for a queuing analysis: before doing a queuing analysis, the ME analyst should carefully research and define the entire queuing system. Figure 13.2 presents the type of information needed (customer population, number of service channels, queue discipline, arrival distribution, and service distribution) and further delineations of that information needed (e.g., customer populations are either finite or infinite) to perform a queuing analysis. It is critical the ME analyst correctly defines the system in terms of these information categories as specific queuing formulas are needed to correctly compute the accurate solution for a specific type of queuing system.

13.1.12. Customer (Source) Population. The size of the customer population, also known as source, is basically a count of the actual system user population and is classified as either finite or infinite.

Figure 13.2. Types of Information Needed in Queuing.



13.1.12.1. Finite Customer Populations. A customer population that is fixed in size is finite. The key here is once a customer has arrived and been serviced, the total customer population to be serviced is reduced by one and directly affects the probability of arrival of the remaining customers. Thus, unless the population is infinite (or can be assumed to be infinite), the probability of a customer arriving for service is based on the number of customers already in the system. For example, consider repairing lathes. A machine shop has five lathes (i.e., customer population equals five) that are serviced by a single repairman. These machines break down occasionally (arrive for service). When this occurs, the down machine is repaired and put back in service. While the one machine is down for repair, the customer population is not the same as now only four remain in service affecting the probability of occurrence of the next arrival; this case is considered a finite source population.

13.1.12.2. Infinite Customer Populations. When a finite customer population is so relatively large such that it is not affected by the service capacity of the system, the population is essentially infinite. Most queuing systems may truly have finite customer populations, but these populations can correctly be assumed to be infinite.

13.1.12.2.1. Case in point, assume the aforementioned machine shop has now been equipped with a sufficient number of spare lathes. When one machine is down, a spare lathe is immediately substituted. Hence, the customer population to be serviced remains constant at five, even if one lathe is down for repair. Since a machine down no longer affects the customer population, the population in this case can be correctly termed infinite.

13.1.12.2.2. For another example, consider a commissary's customer population. Here, the commissary's customer population is finite because only people with commissary privileges are customers. However, this customer population is so large when compared to the service capacity of the commissary, the population becomes relatively infinite as the customer population is considered inexhaustible (i.e., infinitely large).

13.1.12.3. Service Channels. Service channels can be considered single (one server) or multiple (more than one server). A single service channel has only one queue or waiting line. Multiple service channels can have one queue, such as a barbershop with multiple barbers and a general waiting area where customers are served on a first-come, first-served basis. Multiple service channels can also each be served by different queues, such as a commissary with several checkers.

13.1.12.4. Queue Capacity. A queue's capacity is characterized by the maximum number of customers it can hold and can be characterized as either finite or infinite. A queue is considered finite when a given number of customers are already waiting in a queue and customers are denied entry into the queue until others are served. An infinite queue does not have such restrictions and can handle an unlimited number of customers.

13.1.12.5. Queue Discipline. A queue's discipline refers to the method used to select customers to be served from the queue. Some of the common queue disciplines are:

13.1.12.6. First In, First Served. The next available server services the first customer in the queue line.

13.1.12.7. Priority. A customer is given some sort of priority on entering the queue. Those customers with higher priorities are served before those with lower priorities. Two types of priority are preemptive and head-of-line. Preemptive priority is when a customer with high priority is allowed to enter the service channel immediately even if a customer with a lower priority is being serviced. Head-of-line priority puts a higher priority customer at the head of the line, but does not preempt any ongoing service.

13.1.12.8. Random Selection. With random selection, the order of customers being served is independent of arrival time and customers are selected to be serviced with no particular pattern.

13.1.12.9. Bulk Selection. In a bulk selection, a group of customers are selected for service at one time. Importantly, queue disciplines may alter when customers do not behave as expected. For instance, a customer may jump from one service channel to another. A customer may also balk, i.e., turns around and leaves instead of actually entering the waiting line for service; or customer may renege and leave the queue after becoming impatient and deciding to no longer wait in line.

13.1.13. Customer Arrivals and Inter-arrival Time. The arrival pattern of customers to a queuing system can be described as either:

13.1.13.1. Customer Arrival Rate. The average number of customer arrivals to the system per some unit of time (i.e., the mean arrival rate). For example, four commissary customers per minute arrive in the system.

13.1.13.2. Customer Inter-arrival Time. The average time between successive customer arrivals (i.e., the mean inter-arrival time). For example, a commissary customer arrives to the system on average every 15 seconds.

13.1.13.3. Note the customer arrival rate is measured in customers per unit of time, and the inter-arrival rate is measured in time between customer arrivals. Thus, for the same system and data, one measure is the reciprocal of the other.

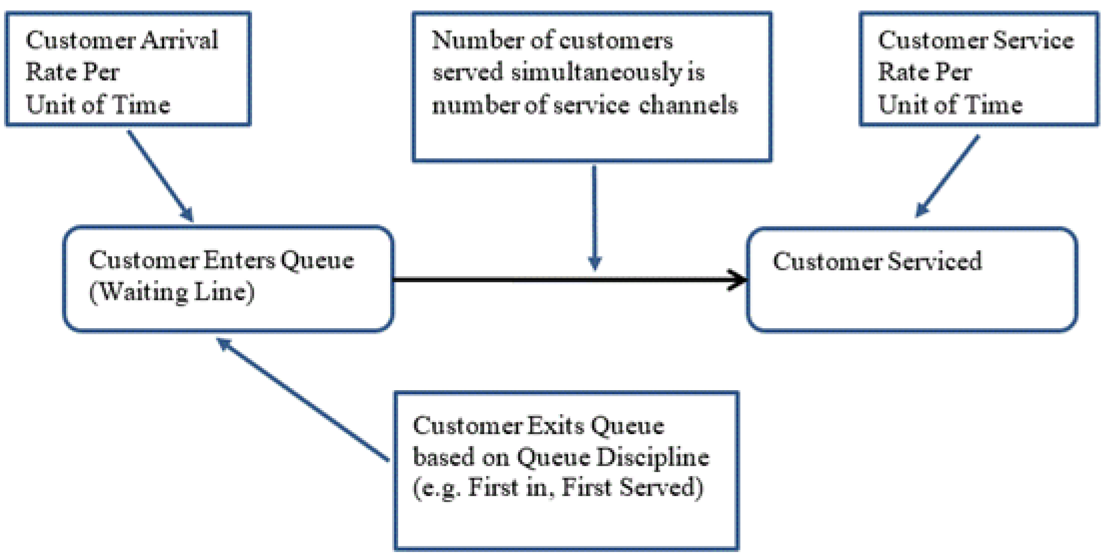
13.1.14. Service Patterns. The service pattern of customers within a non-empty queuing system can be described by its:

13.1.14.1. Customer Service Rate. The average number of customers served per some unit of time (i.e., mean service rate). For example, four hundred customers are served per day.

13.1.14.2. Average SAT. The average time to service a customer (mean service time). For example, it takes two hours per aircraft inspection.

13.1.14.3. Note again, akin to customer arrival and inter-arrival times, the relationship between customer service rate and average SATs are simply the reciprocal of the other measure. Figure 13.3 depicts the simplified relationship between the queuing system and definitions.

Figure 13.3. Simplified Relationship Between Queuing System and Definitions.



13.1.14.4. Queuing Symbols and Equations. Once the ME analyst has correctly identified the queuing system, the correct formula can be chosen. Table 13.1 depicts the various symbols and definitions commonly used in queuing analysis. Figure 13.4 contains the equations for the various systems an ME analyst may encounter. Pay close attention to all the assumptions when choosing the correct formulas. Finally, Table 13.2 provides a quick reference table for estimating the average expected number of customers in line for multiple server queuing systems.

Table 13.1. Queuing Symbols and Definitions.

Symbol	DEFINITION FOR INFINITE CUSTOMER POPULATION QUEUING MODELS.
λ	The Greek letter "Lambda"--average customer arrival rate per unit of time to the queuing system (e.g., six per hour*)
μ	The Greek letter "Mu"—average customers serviced rate per unit of time at which each service channel provided service (e.g., one customer per minute, or 60 per hour*)
ρ	The Greek letter "Rho"—the utilization factor defined as: $\rho = \frac{\lambda}{M\mu}$
n	Number of customers arriving the queue system
$\frac{1}{\lambda}$	Average customer inter-arrival time (i.e., the reciprocal of the customer arrival rate)
$\frac{1}{\mu}$	Average SAT (i.e., the reciprocal of average customer serviced rate)
M	Number of servers; M=1 for single server
W_s	Mean customer time in system; average amount of time one customer spends in the queuing system (waiting and being served)
W_q	Mean customer time in queue; average amount of time one customer spends in the queue (waiting only)
L_s	Average number of customers in the queuing system (waiting and being served).
L_q	Average queue length, i.e., average number of customers in the queue (waiting only)
P_n	Probability of exactly n number of customers in the system at any given point in time (to be used in computations)
P_w	Probability of waiting in line
J	Population Source less those in system, i.e., (N-n)
T	Average SAT
X	Proportion of total service time required
H	Mean number of customers being served
N	Number of customers in source population
* **Remember:** Units of time are the same for all final computations.	

Figure 13.4. Queuing Assumptions and Formulas.

MAJOR ASSUMPTIONS FOR ALL QUEUING MODELS:

1. The customer arrival rate follows a Poisson Distribution.
2. The queue discipline is "first-come-first-served."
3. The system is considered to be a "steady state" system; e.g., an ongoing system instead of one that is just starting up (in transition).

Probability of P_n or less customers in the system*: $P_{(n \text{ or less})} = P_0 + P_1 + \ldots P_n$

Probability of more than P_n in the system: $P_{(\text{greater than } n)} = 1 - P_{(n \text{ or less})}$

Rule	When the Customer Population is:	And the Service Channel is:	And the Service Distribution Is:	Then the following equations are to be used:
1	Infinite	Single	Exponential	$P_n = (1 - \frac{\lambda}{\mu})(\frac{\lambda}{\mu})^n$ $W_q = \frac{\lambda}{\mu(\mu-\lambda)}$ $W_s = W_q + 1/\mu$ $L_q = \frac{\lambda^2}{\mu(u-\lambda)}$ $L_s = \frac{\lambda}{\mu-\lambda}$
2	Infinite	Multichannel	Exponential	$W_q = \dfrac{\frac{\rho^M}{(M!)(1-\frac{\rho}{M})} \cdot \frac{1}{(\sum_{J=0}^{M-1} \rho^J/J!) + \frac{\rho^M}{(M!)(1-\frac{\rho}{M})}}}{\mu M-\lambda}$ $L_q = \lambda W_q$ (or use **Table 12.3.**) $L_s = L_q + \frac{\lambda}{\mu}$ $W_s = W_q + \frac{1}{\mu}$
3	Infinite	Single	Constant (Automated)	$P_n = (1 - \frac{\lambda}{\mu})(\frac{\lambda}{\mu})^n$ $W_q = \frac{\lambda}{2\mu(\mu-\lambda)}$ $W_s = W_q + \frac{1}{Wq}$ $L_q = \frac{\lambda^2}{2\mu(\mu-\lambda)}$ $L_s = L_q + \frac{\lambda}{\mu}$
4	Finite	Single	Exponential	$P_n = \frac{N!}{(N-n)!} X^n P_0$ $W_q = \frac{L_q}{H} T$ $n = L_q + H$ $J = NF(1-X)$

Table 13.2. Expected Number of Customers in Queue (Lq), Multiple Servers.

λ/μ (or ρ)	Servers					
	1	2	3	4	5	6
0.1	0.01111	0.00025	0.00001	0.00000	0.00000	0.00000
0.2	0.05000	0.00202	0.00008	0.00000	0.00000	0.00000
0.3	0.12857	0.00691	0.00041	0.00002	0.00000	0.00000
0.4	0.26667	0.01667	0.00127	0.00009	0.00001	0.00000
0.5	0.50000	0.03333	0.00303	0.00026	0.00002	0.00000
0.6	0.90000	0.05934	0.00616	0.00062	0.00006	0.00000
0.7	1.63333	0.09772	0.01124	0.00128	0.00013	0.00001
0.8	3.20000	0.15238	0.01892	0.00240	0.00028	0.00003
0.9	8.10000	0.22853	0.03001	0.00416	0.00054	0.00006
1	Infinite queue	0.33333	0.04545	0.00680	0.00096	0.00012
1.1		0.47706	0.06637	0.01060	0.00161	0.00023
1.2		0.67500	0.09412	0.01588	0.00259	0.00039
1.3		0.95108	0.13034	0.02302	0.00400	0.00065
1.4		1.3451	0.17706	0.03247	0.00596	0.00102
1.5		1.92857	0.23684	0.04475	0.00863	0.00157
1.6		2.84444	0.31291	0.06047	0.01218	0.00233
1.7		4.42613	0.40948	0.08033	0.01682	0.00338
1.8		7.67368	0.53212	0.10516	0.02278	0.00478
1.9		17.5872	0.68840	0.13597	0.03034	0.00662
2		Infinite queue	0.88889	0.17391	0.03980	0.00901
2.1			1.14880	0.22042	0.05153	0.01206
2.2			1.49094	0.27720	0.06594	0.01591
2.3			1.95106	0.34637	0.08351	0.02071
2.4			2.58876	0.43056	0.10477	0.02664
2.5			3.51124	0.53309	0.13037	0.03389
2.6			4.93282	0.65821	0.16104	0.04270
2.7			7.35355	0.81145	0.19765	0.05331
2.8			12.27348	1.00019	0.24120	0.06603
2.9			27.19266	1.23447	0.29292	0.08118
3			Infinite queue	1.52830	0.35423	0.09914
3.1				1.90194	0.42688	0.12034
3.2				2.38573	0.51299	0.14526
3.3				3.02732	0.61517	0.17447
3.4				3.90613	0.73667	0.20862
3.5				5.16503	0.88162	0.24845
3.6				7.08978	1.05530	0.29485
3.7				10.34708	1.26460	0.34883
3.8				16.93696	1.51871	0.41160
3.9				36.85945	1.83016	0.48459
4				Infinite queue	2.21645	0.56952
4.1					2.70286	0.66846
4.2					3.32731	0.78395
4.3					4.14934	0.91909
4.4					5.26818	1.07778
4.5					6.86244	1.26496
4.6					9.28928	1.48693
4.7					13.38206	1.75197
4.8					21.64080	2.07109
4.9					46.56553	2.45929
5					Infinite queue	2.93758
5.1						3.53628
5.2						4.30087
5.3						5.30280
5.4						6.66113
5.5						8.59017

13.1.14.5. Addressing Randomness and Distributions for Arrivals and Service Times. The random occurrences within each of these patterns (arrival and service) often follow a particular statistical distribution. However, the identification of the distribution may or may not be straightforward. In favorable situations, when the customer arrival rates follow a Poisson Distribution, and the service time follows an exponential distribution, straightforward queuing formulas can be used. Knowing, recognizing, and using these distributions are discussed below.

13.1.14.6. The Poisson distribution is a discrete (versus continuous) distribution, serves as an approximation of the Normal distribution, and can be used when customers are expected to arrive in a random fashion. The Poisson Distribution is given by the following formula:

Where,

$$P_{T(n)} = \frac{(\lambda T)^n \, e^{-\lambda T}}{n!}$$

$P_{T(n)}$ = the probability of (exactly) n customer arrivals
n= the exact number of customer arrivals in T time period
λ= (the Greek letter lambda) average customer arrival rate into the system T= some time period of interest (e.g., 1 minute)
Note: *n! = is termed "n-factorial'*, and is represented mathematically as *n x (n-1) x (n-2) x...(n-n)*. For example, where *n = 5*, thus *5! = 5 x 4 x 3 x 2 x 1 x 0! =120*.
(Further note that 0! [i.e., '0 factorial'] is understood to equal 1.) and e = the natural log, or approximately (≅) 2.7183

13.1.14.7. For the aforementioned customer arrival rate for the commissary example (paragraph 12.1.13.1.), assuming a Poisson Distribution with an average arrival rate of four customers per minute (λ =4), then the probability of six commissary customer arrivals in any minute (in this example, one minute is the time period (T)) would be shown as:

$$\text{P1 minute }(6) = \frac{(\lambda T)^n \, e^{-\lambda T}}{n!} \xrightarrow{yields} \frac{(4*1)^6 e^{-(4*1)}}{6!} = \frac{4^6 * 2.7183^{-4}}{6*5*4*3*2*1} = \frac{4096 * .0183}{720} = 10.42\%$$

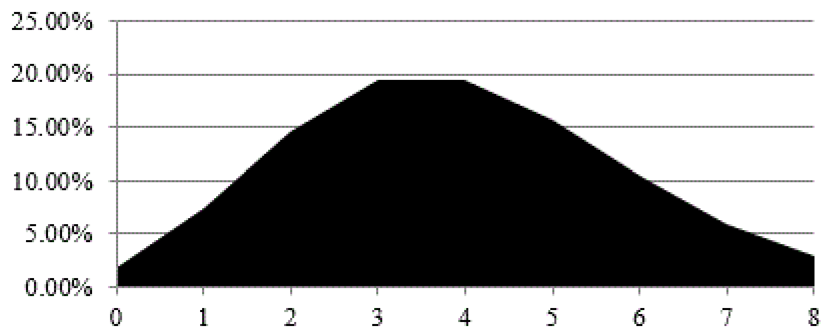
chance of six arrivals in any one minute.

13.1.14.8. With the aforementioned scenario (x= 4 customers per minute), plotting 0 through 8 customer arrivals (calculations shown in Table 13.3), ME analyst get the following shape of the arrival distribution shown in Figure 13.5. (**Note:** Keep in mind that the Poisson Distribution is still a discrete function even if Figure 13.5 makes it seem continuous here to better display the overall shape of the distribution in question.)

Table 13.3. Customer Arrival Calculations.

With Mean Customer Arrival Rate (with λ =4 per minute)		
For x number of Customer Arrivals per 1 minute interval	Probability	Percentage
0	0.0183	1.83%
1	0.0733	7.33%
2	0.1465	14.65%
3	0.1954	19.54%
4	0.1954	19.54%
5	0.1563	15.63%
6	0.1042	10.42%
7	0.0595	5.95%
8	0.0298	2.98%

Figure 13.5. Shape of Customer Arrival Assuming Poisson Distribution with Mean Customer Arrival Rate at 4 per minute.



13.1.14.9. For exponential distribution, on the other hand, an ME analyst might be interested in the inter-arrival time of customers. Again, assuming customers arrive in a random fashion, the analyst might assume an Exponential distribution, a continuous distribution, to determine the time between customer arrivals. The formula for the exponential distribution is:

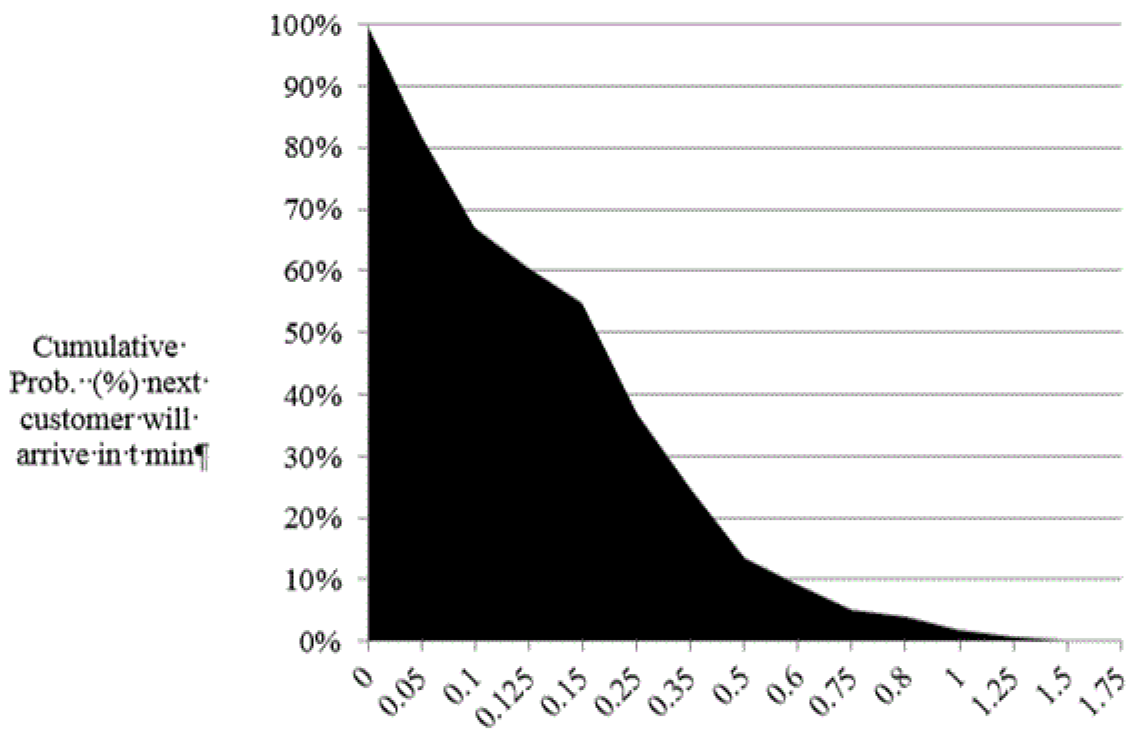
f(t) = λe-λt
Where:
f(t) = the probability of the next customer arriving in the specified t time period or more "= average customer arrival rate into the system"
t= time till the next arrival

13.1.14.10. Continuing with our commissary example, with four customers per minute, the ME analyst would get the following calculations, as shown in Table 13.4 Placed on a graph, the information in Table 13.4 is shown in Figure 13.6.

Table 13.4. Determining Probability of Customer Inter-arrival Time Assuming the Exponential Distribution.

With Mean Customer Arrival Rate (λ =4 customers per minute)	
Inter-arrival time (*t*) (in min)	**Cumulative Probability (%) the next customer arrives in *t* time or more**
0	100.0%
0.15	54.9%
0.25	36.8%
0.5	13.5%
0.75	5.0%
1	1.8%
1.25	0.7%
1.5	0.2%
1.75	0.1%

Figure 13.6. Shape of Exponential Distribution of Customer Inter-arrival Rate with λ = 4 customers per minute.



13.1.15. Inter-Arrival Time (in min)

13.1.16. Collecting System Information and Queuing Data. In queuing analysis, the information collected can be categorized in two broad categories - system information and queuing (numerical) data.

13.1.17. Characterizing the System Under Study. System information comes from an in-depth review of the queuing system under study that includes evaluating the customer population limit (i.e., infinite or finite), the queue discipline used (e.g., first in, first out), and the number of parallel service channels. This type of information appears easy to obtain, but a careful study of the situation may uncover some subtle yet very important differences inherent to the system. Document how the system was characterized in any final written report.

13.1.17.1. Methods for Collecting Queuing Data. Obtaining queuing data includes collecting and analyzing the distribution of service times and customer arrival data. This needed numerical data are the times customers arrive at the system for service and the actual customer service SATs. The method of collecting this data (either through measurement or from historical files) depends on the availability of data coupled with the need to meet an express statistical confidence and accuracy. Regardless of the measurement technique(s) used to collect queuing data, the ME analyst should ensure pertinent functional performance standards, e.g., the time a functional's customer waits in line, have been met and any additional levels of service explored as requested.

13.1.17.1.1. Using Historical Data. Sources for historical data (such as: Dispatch logs, automated management information systems, and job-supervisor records) may provide the needed information to capture customer arrival and service SAT data. It is incumbent upon the ME analyst to verify any historical data for accuracy and representativeness. For example, does the historically recorded service time include standby time? (Note: If the historical data did contain standby time, the study team would need to remove that time to determine the true SAT.)

13.1.17.1.2. Performing Measurement. Measurement is the most common source for collecting queuing data. Design a procedure for gathering this data for recording both the service SAT, using work measurement techniques described in this manual, and the customer arrival rate (or inter-arrival time) for the particular work center being studied. One of several methods or a combination of measurement methods may be used.

13.1.17.1.2.1. Measuring Service Time. Performing a time study or good operator timing to measure the amount of SAT needed to give customers service is an excellent approach. Ensure to collect enough samples to meet any predetermined statistical confidence and precision requirements. Time only the actual time spent giving service, from the second the service process starts to the second it finishes. For time study or good operator timing, PF&D allowances should be added to the SAT to reasonably predict queuing results. Do not add PF&D allowances if OA techniques were used to determine the SAT.

13.1.17.1.2.2. Measuring Customer Arrival Rate and Inter-arrival Times. Use a log or automated system to show the exact time a customer arrives to the system for service. Be consistent when making this recording determine by express definition of when a customer is said to have entered the system.

13.1.17.1.2.3. Recording Customer Arrival Rates. Record the customer arrival rates from a historical log or by counting the number of customers arriving in a given block of time (e.g., customer arrivals per each 10 minute increment).

13.1.17.1.2.4. Recording Customer Inter-arrival Rates. By recording the exact time the customers enter the system, the ME analyst can later compute the average inter-arrival time between successive customer entries.

13.1.18. Remember, the quality of this queuing data is extremely important because it forms the basis for the follow-on queuing analysis. Evaluating the collected queuing data thus becomes paramount for an accurate representation of the system.

13.1.19. Evaluating Queuing Data. For example assume an ME analyst has been asked by the local Security Forces commander to perform a MAS for its installation's main gate. The commander wants to know what the average wait time is for a vehicle to get on base. The ME analyst decides a queuing analysis is the best approach to adequately answer the commander's initial request.

13.1.20. Analyze information about customer arrival and service SAT data separately, but the general procedures are the same in both cases.

13.1.21. Arrange And Organize the Queuing Data in a Frequency Table. The ME analyst first designs data frequency tables to ensure the number of categories in the frequency table reflects the situation (for example, when talking about the number of customer arrivals per block of time, begin with 0 arrivals, l arrival, etc.) Usually between eight and 20 categories are sufficient.

13.1.22. Table 13.5 provides an example of a frequency table that synopsizes the number of customer (i.e., vehicle) arrivals per .5-minute increment for vehicles (i.e., customers entering a base gate on a mid (late night) shift. Note: Per Table 13.5, Method of Count, the actual customer inter-arrival times were recorded initially elsewhere. Column 3 actually fits the inter-arrival rates into one-minute increments-in effect determining the customer arrival rate (per minute). This approach prepares the data for the chi square Goodness-of-Fit test (discussed later).

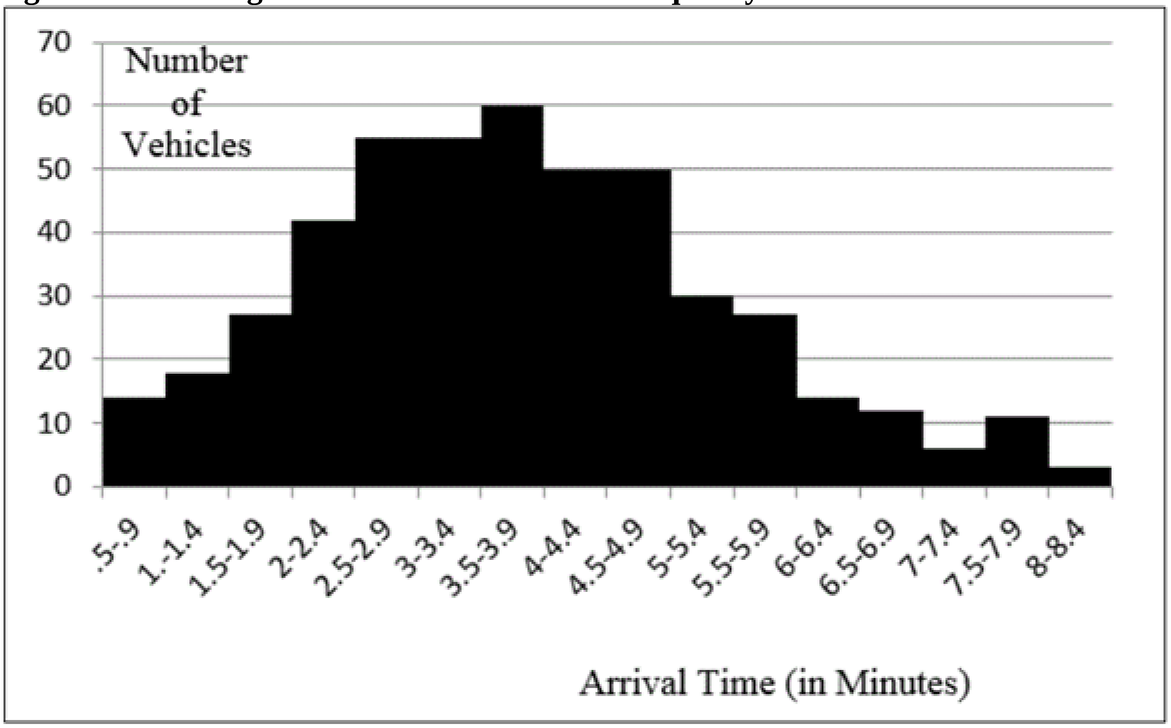
Table 13.5. Frequency Table of Observed Customer Arrival Data.

Management Analyst: R. Smith
Date: April 17, 20XX Location: Gate 16B
System Entry Definition: When the vehicle initially turns into the gate lane and the vehicle has come to a complete stop either in the waiting line or at the post and the vehicle's wheels have come to a complete stop.
Method of Count: On the separately provided spreadsheet, record the actual clock time of the each vehicle as each enters the system. Determine the inter-arrival time by subtracting the entry time of one vehicle from the entry time of the immediately preceding vehicle. For example, if a vehicle entered at exactly at 20:02:15, and the previous vehicle had entered the system at exactly 20:00:00 hours, then an inter-arrival time of two min, 15 seconds should be computed and then recorded as single frequency count (hash mark) to the Observed Frequency column for the 2-2.4 minute interval (Row 4).

Column		
1	**2**	**3**
Row	Inter-arrival Rate (In Min)	Observed Frequency Count— Summary Count of Customer Within Specified Time Increment (I= 10 count, ~~IIII~~= 50 count, X = 100 count)
1	0.5-0.9	14
2	1.0-1.4	18
3	1.5-1.9	27
4	2.0-2.4	42
5	2.5-2.9	55
6	3.0-3.4	55
7	3.5-3.9	60
8	4.0-4.4	50
9	4.5-4.9	50
10	5.0-5.4	30
11	5.5-5.9	27
12	6.0-6.4	14
13	6.5-6.9	12
14	7.0-7.4	6
15	7.5-7.9	11
16	8.0-8.4	3

13.1.23. Construct a histogram of the data to provide a visual tool for determining the shape of the arrival distribution data to visually inspect how well this data are exhibiting the properties of the desired (Poisson) distribution. Figure 13.7 represents a histogram that tallies the data from Table 13.4. **Note:** The ME analyst should experiment with several different numbers of data classes to ascertain a view of the potential resulting shape of the data. To perform this suggested approach, ensure to record the exact arrival time so you can place the data in any new histogram arrivals.

Figure 13.7. Histogram of Customer Arrival Frequency Data.



13.1.23.1. Similar to evaluating the customer arrival time, the ME analyst also evaluates the service SAT data. Depending on data collection methods and the amount of data, the ME analyst should consider similar tools to make the case for the final mean service SAT determined.

13.1.23.2. Performing the Chi Square (2) Goodness-of-Fit Test. Even though the shape of the data as shown in Figure 13.6 is encouraging and seems like a Poisson arrival distribution, the ME analyst should perform the Chi Square test to determine whether the arrival data can be considered from the desired probability distribution (here the Poisson). The key concept here is our observed frequency should be close to the expected (Poisson Distribution) frequency. To do this comparison, the ME analyst needs to create a test statistic and compare it to either prove or disprove our hypothesis.

13.1.23.3. Chi Square Test Sensitivities. The Chi Square Test is sensitive to the number of bins (classes) created when the ME analyst placed data in the histogram. Importantly and as a minimum, ensure each histogram bin (again, class) has an observed and expected frequency in each cell of at least five. Returning to our earlier Security Forces gate example, the ME analyst suspects with so many data classes initially chosen, some of the vehicle arrival expected frequencies may end up with less than five in a class. However, by combining two adjacent bins, the ME analyst gets the revised observed frequencies as shown in Table 13.6.

Table 13.6. Number of Customer Arrivals Data.

Number of Customer Arrivals (Inter-Arrival Time In Min)	Observed Frequency o_i
0.5-1.4	32
1.5-2.4	69
2.5-3.4	110
3.5-4.4	110
4.5-5.4	80
5.5-6.4	41
6.5-7.4	18
7.5-8.4	14

13.1.23.4. The Chi Square Test Statistic. The formula for determining the Chi Square Test statistic is as follows:

Where:

$$X^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i}$$

o_i = the observed frequency for bin *i* (i.e., your data count *ei* = the expected frequency for bin *i*)
k= the number of classes in your histogram
But, before the ME analyst can calculate all the requisite data to apply this formula, there are required steps to take to prepare the data to complete the test statistic computation and final hypothesis test.

13.1.23.5. Determining the Sample Mean () of the Grouped Data. Since the ME analyst has grouped the data into classes, be very specific about how the sample mean of that grouped data is now calculated as a straightforward mean of the originally recorded data would be inappropriate. In effect, (1) determine the midpoint of each class, and (2) determine the weighted average to determine the sample mean. Thus, the formula for grouped data would be, as follows:

Where

$$\bar{x} = \frac{\sum o_i M_i}{n}$$

o_i = the observed frequency for bin *i* (i.e., your data count e_i = the expected frequency for bin *i*)
M_i = midpoint of each cell
$n = o_i$ = (the summation of the total observed frequency count)

13.1.23.6. Modifying Table 13.6 to get Table 13.7 as follows:

Table 13.7. Determining the Sample Mean of Grouped Data.

Number of Customer Arrivals (Inter-Arrival Time In Min)	Observed Frequency o_i	Class Midpoint M_i	$o_i M_i$
0.5-1.4	32	1	32
1.5-2.4	69	2	138
2.5-3.4	110	3	330
3.5-4.4	110	4	440
4.5-5.4	80	5	400
5.5-6.4	41	6	246
6.5-7.4	18	7	126
7.5-8.4	14	8	112
n =	474		1824

13.1.23.7. Thus, $\bar{x} = \frac{\sum o_i M_i}{n} \xrightarrow{\text{yields}} \frac{1824}{474}$ = 39 customers (vehicles) per time interval (here, one minute)

13.1.23.8. Determining the Expected Frequency. At this point, the ME analyst now needs to determine the expected frequency of the data. Since the ME analyst is testing the data with relation to the Poisson Distribution, the ME analyst can use the Poisson formula to determine the expected probability and subsequently the expected frequency of the customer arrival data. To facilitate the continued computations, the ME analyst expands and modifies Table 13.7 now displayed as Table 13.8. Using the class midpoint as the specific customer arrival and the average arrival rate (3.9 customers per time interval) as λ, the ME analyst can determine the Poisson probability using the formula shown in **Chapter 13** paragraph 13.1.14.6.

Table 13.8. Determining Expected Customer Arrival Frequency.

Number of Customer Arrivals					
Class (Bin) i	Inter-Arrival Time In Min	Observed Frequency o_i	Class Midpoint M_i	Poisson Probability $P(M_i)$	Expected Frequency e_i
1	0.5-1.4	32	1	0.082042	38.9
2	1.5-2.4	69	2	0.157853	74.8
3	2.5-3.4	110	3	0.202479	96.0
4	3.5-4.4	110	4	0.194790	92.3
5	4.5-5.4	80	5	0.149914	71.1
6	5.5-6.4	41	6	0.096147	45.6
7	6.5-7.4	18	7	0.052855	25.1
8	7.5-8.4	14	8	0.025424	12.1

13.1.23.9. Determining the Chi Square Test Statistic. The ME analyst is now ready to compute its Chi Square Test statistic. Recalling the Chi Square Test statistic formula from **Chapter 12** paragraph 12.2.21.6.

$$X^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i}$$

Where *k* is the number of classes in the modified histogram (here, *k* =8)

13.1.23.10. The ME analyst can modify and expand the former table one last time to ease and display computations as shown in Table 13.9.

Table 13.9. Computing the Final χ2 Statistic.

Inter-Arrival Time (In Min)	Observed Frequency	Expected Frequency	Absolute difference	Squared Difference	Final Computation for the i^{th} category
	o_i	e_i	$o_i - e_i$	$(o_i-e_i)^2$	$(o_i-e_i)^2/e_i$
.5-1.4	32	38.9	-6.9	47.4	1.2
1.5-2.4	69	74.8	-5.8	33.9	0.5
2.5-3.4	110	96.0	14.0	196.7	2.0
3.5-4.4	110	92.3	17.7	312.2	3.4
4.5-5.4	80	71.1	8.9	79.9	1.1
5.5-6.4	41	45.6	-4.6	20.9	0.5
6.5-7.4	18	25.1	-7.1	49.7	2.0
7.5-8.4	14	12.1	1.9	3.8	0.3
			$X^2 = \sum_{i=1}^{k} \frac{(o_i-e_i)^2}{e_i}$ =		11.0

13.1.23.11. Testing the Final Hypothesis. Finally, the ME analyst is ready to test the hypothesis. Write the hypothesis as follows:

H0: the data does follow the Poisson Distribution
Ha: the observed distribution does not belong to the Poisson Distribution

13.1.23.12. The ME analyst now performs a p-test to determine whether or not to accept the null hypothesis (H0) and reject the alternative hypothesis (Ha).

13.1.23.13. Determining the Significance Level. At the beginning of the effort, the ME analyst, working with the functional customer, established that a 90% confidence level would be used to determine the acceptable level of risk. This risk means the ME analyst accepts a risk or significance level value of .10 (i.e., 1-confidence level, or in this example: 1-.9 = .10). In the final analysis, if the ME analyst's p-value is greater than .10, the ME analyst can accept the H0 that the difference between the observed distribution and the Poisson is within acceptable limits. Thus, accept the H0 when the p-test yields:

P(2) > significance level, then accept H0

13.1.23.14. For this example, the ME analyst evaluates: P(11.0) > .10

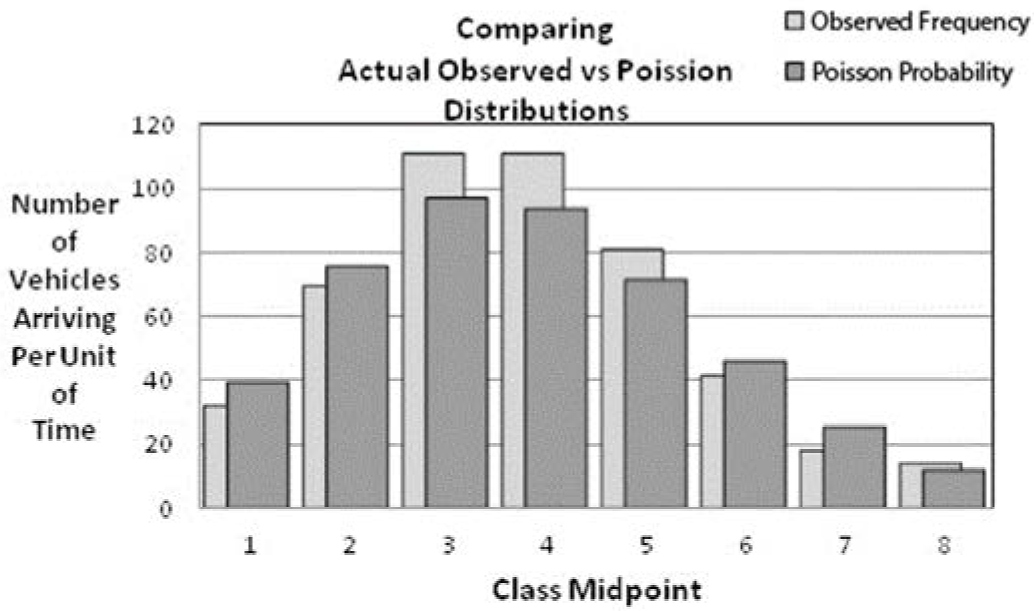
13.1.23.15. Determining the P-value. Chi-square calculators are available in many statistical software packages. (Note: In Microsoft Excel the function is CHIDIST(2, degrees of freedom)). The two pieces of data needed are the test statistic (2) (already calculated) and the degrees of freedom. Recall the degrees of freedom are k-1, where k is the number of classes. The ME analyst's data are arranged (grouped) into eight (8) classes; therefore there are seven (7) degrees of freedom in this example.

13.1.23.16. Using Microsoft Excel, the cell function = CHIDIST(11,7) = .139

13.1.23.17. Since .139 >.10, the ME analyst can accept the null hypothesis that the customer arrival rate does follow a Poisson Distribution. Importantly, the ME analyst can now use the sample mean of 3.9 cars (per minute) as the customer arrival rate for further queuing computations.

13.1.24. Performing a Final Visual Check. Recall solid data analysis contains a visual as well as a computational component. Displaying the observed and expected values as overlapping histograms, the ME analyst can see in Figure 13.8 the two distributions follow each other quite closely.

Figure 13.8. Comparing the Shape of the Observed versus Poisson Distribution.



13.1.25. Alternative Approaches When Queuing Data Does Not Pass The Goodness-of-Fit Test. If the data does not pass the Chi Square Test, do one of the following steps:

13.1.26. Reevaluate the data (collection method, accuracy, and representativeness of the data) to discover possible data collection or computational errors.

13.1.27. Resort to more complex modeling of this queuing system. The system may require both more theoretical knowledge and/or extensive computer support for simulation of the problem.

13.1.28. Computing Queuing Information and Cost Analysis. If the USAF's leadership decides key performance measures are not being met in a queuing system, e.g., vehicles are waiting too long outside the gate to get on base and this situation represents both a security and safety hazard, then an analysis of various alternative solutions can be performed and a cost-benefit analysis completed to assist decision makers.

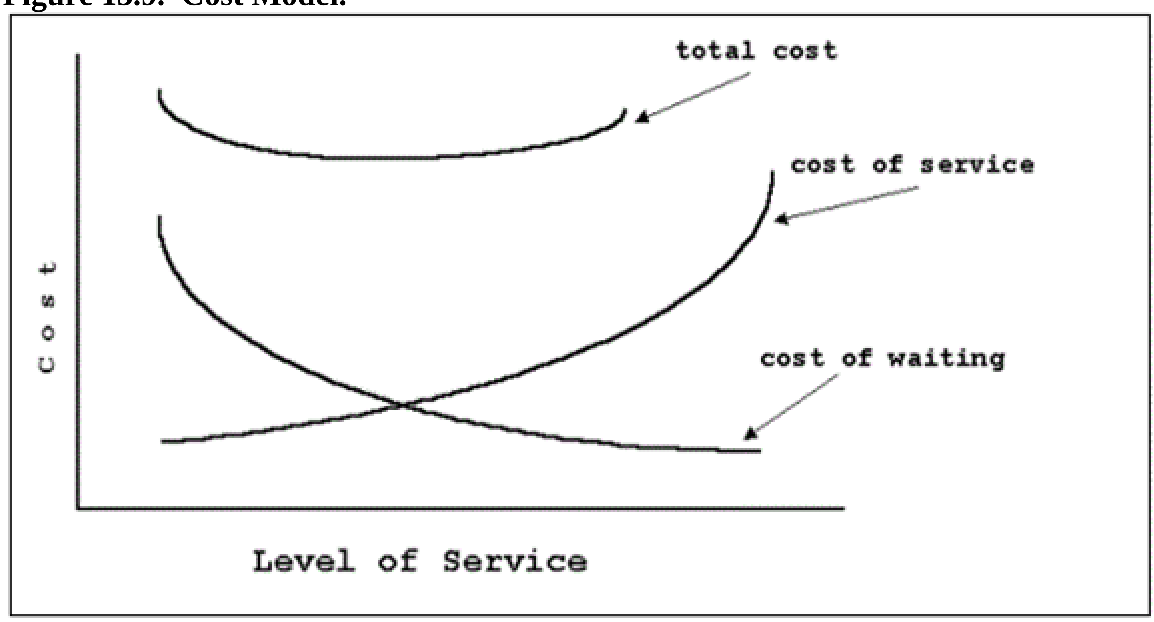
13.1.29. General Costing Considerations. Of course, making the service process more efficient or controlling customer arrival rates are practical and preferred means to reduce queue sizes and customer wait times and should always be explored.

13.1.29.1. However, when customer arrival and service rates cannot be improved further, the number of service channels can be varied to see the effect on the number of customers waiting for service and on the average waiting time. Such an alternative likely results in an increase in idle time for the servers.

13.1.29.2. However, there is also a decrease in idle time for the customers and possibly other resources waiting in line. Thus, adding more servers increases the operational costs in terms of servers, but the total system cost may be reduced when considering the reduced idle time of customers and other factors.

13.1.29.3. Thus, the total system cost can be viewed as the cost of service and the cost of waiting. Figure 13.9 depicts three curves: the total cost, the cost of service, and the cost of waiting. Figure 13.9 shows that as the level of service is increased (e.g., adding more service channels), the cost of providing the service also increases. As the level of service is increased, customers do not have to wait as long for service, and the cost of waiting decreases. Since the rate of waiting costs declines faster than the cost of service increases, the curve of the total cost starts out decreasing. This figure shows initially adding more servers cuts waiting time enough to lower the total cost. However, the total cost curve reaches its minimum and then increases since now the rate of servicing increases greater relative to the cost of waiting. Thus, at one point (the ebb of the total cost curve), additional servers become increasingly more expensive. Note: The minimum total cost does not have to occur at the intersection of waiting and service costs since other costs may be part of the total cost analysis.

Figure 13.9. Cost Model.



13.1.30. Determining System Service Costs. For our example, the cost of service is determined by totaling the incremental salary costs of additional servers. Thus, if one queuing model scenario requires an increase from one to three tool crib attendants (i.e., servers), and each attendants is paid $10.00 per hour, then this scenario's cost of service is three times or $30.00 per hour. (Note: The source for determining the various salary costs of US Air Force resources (military or civilian) and associated grades can be found in AFI 65-503, United States Air Force Cost and Planning Factors, and its associated attachments.)

13.1.31. Determining System Waiting Costs. The cost of waiting can be more difficult to compute than the system's service costs. For example, what is the cost of an aircraft waiting to be loaded during an emergency? While this type of cost may not be easily quantifiable, other costs of waiting can be quantified. The ME analyst should recognize that there are different types of costs involved in waiting.

13.1.31.1. Salary Costs of Customers Waiting. When customers are human, or involve human operators, the obvious cost of the salary paid to the person standing in line waiting for service should be considered. This person is idle, thus creating a waiting cost.

13.1.31.2. Associated Resource Costs. Other resource costs may be affected by the customer waiting to be serviced. For example, although the queuing system might have defined the system as a machine, what are the costs involved with human operators forced to be idle? If the downtime of the machine truly causes unavoidable delay, then the ME analyst would do well to capture these costs in the total analysis.

13.1.31.3. Allowance for Loss. The cost of material that goes bad while waiting for a customer to be serviced should be taken into account. For example, if a dining facility's food freezer goes down and all other freezers are at capacity, the cost of food spoiling while waiting for the freezer to be serviced and placed back on line should be considered.

13.1.31.4. Qualitative Considerations. Other system performance measures also involve a cost that may be of key concern to Air Force leadership. These intangible costs could decrease installation morale because a customer had to wait too long for service at the Manpower and Personnel Flight or gymnasium. ME analysts performing MASs would do well to quantify other key performance measures, e.g., a survey conducted to evaluate installation gymnasium customer opinion over varying waiting times to use treadmills, as part of the overall analysis.

13.1.32. Costing a Tool Crib Example. Consider a new situation of a tool crib that services mechanics by issuing parts and tools. The tool crib supervisor has received numerous complaints from mechanics about being delayed to get daily parts and tools from the single tool crib attendant currently on hand.

13.1.32.1. Step 1. Characterize the Customer Source Population and Queue Discipline. The ME analyst assigned first assesses the system. Particularly with the huge number of mechanics, and those that come back throughout the day for parts and special tools, the ME analyst assesses customer source population as infinite. Further, determination reveals the queue discipline is first come, first served.

13.1.32.2. Step 2. Determine the Goodness-of-Fit of the Customer Arrival Distribution. The ME analyst also measures the customer arrival rates counting the number of customer arrivals per 10 min. After making one hundred observations, the ME analyst groups the customer arrival data into a histogram and tests the data's distribution to see if these arrival rates follow a Poisson Distribution. The data passed the Chi Square test, and the ME analyst concludes the arrival distribution is Poisson with an average of 16.04 customer arrivals per minute. Using the mean for the grouped data, the average customer value for the arrival rate can then be used in further analysis:

= 16.04 customer arrivals per 10 min or
= 96.24 customer arrivals per hour.

13.1.33. Step 3. Determine the Shape of the Service Times Data. The ME analyst likewise performs the Chi Square test on the service times distribution to determine if these data follow an exponential distribution. Again, the data passes the test for the exponential distribution, and the ME analyst determines the average service time is .7496 min per customer. Therefore, the average service rate (recall this data are shown as the Greek letter Mu or æ) is the reciprocal of .7496 min or:

= 1/.7496 = 1.334 customers per minute
Note: It is very important to keep all times consistent in your formulas. In this example, the ME analyst decides to keep all time in hours, therefore:
μ = 80.04 customers per hour

13.1.33.1. Step 4. Determining the Correct Queuing Formula. The ME analyst is now ready to determine which queuing model to use. From the initial analysis it is determined that the system is properly defined as shown in Table 13.10 as:

Table 13.10. Defining the Tool Crib Queue System—As Is.

Customer Population:	Service Channel (Current):	Queue Discipline	Customer Arrival Rate:	Service Distribution:	Then the following Queuing System Type* is:
Infinite	Single	First Come First Served	Poisson	Exponential	1

* From Figure 13.5.

13.1.33.2. Step 5. Determining the Utilization Factor. The utilization factor (ρ) for a queuing system is defined as the mean arrival rate (λ) divided by the service capacity of the system. The service capacity of the system is the mean service rate (μ) times the number of service channels (M) in the system.

13.1.33.2.1. Hence, ρ=λ/Mμ and represents the proportion of the total service capacity needed to service the customers. For a single server queue (i.e., M=1), when, then the customers are arriving at a faster rate than can be served, and the queue builds infinitely. In such a situation, either λ, M, or μ is changed to get < 1. From our example, the utilization factor for the tool crib, when it is operated with only one tool crib attendant, is greater than one:

$$(\rho = \frac{\lambda}{\mu} = \frac{96.24}{80.04} = 1.20)$$

13.1.33.2.2. Therefore, the mechanics always have to wait, the queue continues to build throughout the duty day since one tool crib attendant is not able to wait on the customers (mechanics) fast enough.

13.1.33.3. Step 6. Re-classifying the Queuing System. The ME analyst has determined one attendant at the tool crib cannot meet the needs of the mechanics. The ME decides to explore three new scenarios by determining the effect of having two, three, or four tool crib attendants on duty. But now this future scenario, Table 13.11, changes the queuing system type to a multiple server system such that:

Table 13.11. Defining the Tool Crib Queue System—To Be—With Formulas.

Customer Population:	Service Channel (To Be):	Queue Discipline:	Customer Arrival Rate:	Service Distribution:	Then the following Queuing System Type* is:
Infinite	Multiple	First Come First Served	Poisson	Exponential	2

* From **Figure 13.44.** Thus the following computations need to be performed:

$$W_q = \frac{\frac{\rho^M}{(M!)(1-\frac{\rho}{M})} \cdot \frac{1}{(\sum_{J=0}^{M-1} \rho^J / J!) + \frac{\rho^M}{(M!)(1-\frac{\rho}{M})}}}{\mu M - \lambda}$$

$L_q = \lambda W_q$ (or use **Table 13.3**)

$$L_s = L_q + \frac{\lambda}{\mu}$$

$$W_s = W_q + \frac{1}{\mu}$$

13.1.33.4. Step 7. Computing the System's Cost of Waiting. To compute each scenario's cost of waiting in terms of customer salary, the ME team needs to consider three key values: The average number of mechanics waiting, the average amount of time each waits, and the hourly salary cost. (Note: It is assumed that the cost of time being served (service time and any material costs) under each of the scenarios remains a constant. Therefore, changes in the mechanics waiting line size and waiting time become the pertinent cost to focus upon.)

13.1.33.4.1. Determining Hourly Cost. The ME analyst decides to use the hourly cost for the median enlisted grade of the mechanics waiting in line and determines this cost to be $25 per hour.

13.1.33.4.2. Determining Queue Length (Lq). The ME analyst needs to determine the Lq and uses Figure 13.4. The utilization factor has been previously calculated " (at 1.2), next, look up the expected number of customers in line for "= 1.2 for 2, 3, and 4 servers. These values are annotated in Table 13.2.

13.1.33.4.3. Determining Time in Queue (Wq). Although knowing how many mechanics on line in the queue is important, the ME analyst also determines the average amount of time each mechanic spends in the queue. Since Lq has already been determined from Figure 13.4 and the arrival rate (λ) has already been measured, the formula is reworked in Figure 13.4 for the length of the queue as follows:

$Lq = \lambda Wq Wq = \frac{L_q}{\lambda}$

Therefore, for two servers (M=2): $W_q = \frac{.67500}{96.24} = .0070$ hours

For three servers (M=3): $W_q = \frac{.09412}{96.24} = .00097$ hours

And for four servers (M=4): $W_q = \frac{.01588}{96.24} = .00017$ hours

13.1.33.4.4. Determining the Final Cost of Waiting. To determine the final cost of waiting, the ME analyst multiplies the mechanics hourly pay cost per hour, the average time a mechanic is expected to spend waiting in the queue, and the average arrival rate of mechanics entering the queue. The cost of waiting for two servers calculates as:

$\$25 \frac{dollars}{\cancel{hour}} \times .0070 \frac{waiting\ time\ (\cancel{hours})}{\cancel{mechanic}} \times 96.24 \frac{\cancel{mechanics}}{hour} = \$16.84$ mechanic waiting time per hour

Follow the same computations for 3 and 4 multiple server lines and records these times in Table 13.12.

13.1.33.5. Step 8. Determining the Cost of Service. Determining the cost of service is somewhat simpler. For these costs, the ME analyst simply multiplies the hourly cost of each tool crib attendant times the total number of tool attendants and records these costs in Table 13.12. This method is fair as it does represent the total service cost to the system to include any idle time assuming the tool crib attendants do not perform any other activities.

13.1.33.6. Step 9. Determining the Total Cost of Service. The total cost of service for the tool crib simply becomes a matter of adding the cost of service plus the cost of waiting. The ME analyst performs this final calculation and records it in Table 13.12.

Table 13.12. Computation of Average Customer Waiting Time and Average Number of Customers in the System and In the Queue.

Average rate of arrival for each customer	**96.24 mechanics** arrive/hour		**96.24 mechanics** arrive/hour		**96.24 mechanics** arrive/hour	
Average rate of service for each attendant	**80.24 mechanics/hour**		**80.24 mechanics/hour**		**80.24 mechanics/hour**	
Average time mechanic spends waiting in system (hrs)	**.007**		**.00097**		**.00017**	
Average number of mechanics waiting in system	**.67500**		**.09412**		**.01588**	
Pay rate for the mechanics		**$25.00**		**$25.00**		**$25.00**
COST OF WAITING:	**Total hourly cost for mechanics waiting (arrival rate x pay rate x time in line)**	**$16.84**		**$2.33**		**$.41**
Pay rate for the attendants		**$10.00**		**$10.00**		**$10.00**
COST OF SERVICE:	**Total hourly cost to pay (pay rate x number of attendants)**	**$20.00**		**$30.00**		**$40.00**
TOTAL HOURLY SYSTEM COST FOR THE TOOL CRIB		**$36.84**		**$32.33**		**$41.43**

13.1.33.7. When the information in Table 13.2 is compared in terms of the cost of service versus the cost of waiting, USAF's leadership have some key information to base its final decision. In this example, the cost of three servers offers the cheapest hourly cost. Of course, other data (e.g., quantitative and qualitative) should also be considered and presented, but the queuing model information is a key element in the decision process.

13.1.34. Simulation or Queuing Analysis. Simulation and queuing analysis share much in common and collect much of the same information to complete the models. Both analysis define customer (entity in simulation), arrival rates, number of servers, and SATs and can provide information on queues (number and/or time in line, system, etc.) If a problem is relatively simple, then a queuing model should be the default solution.

13.1.34.1. Consider simulation modeling when:

13.1.34.2. Queuing disciplines are complex. For example, if certain customers have priority over other customers, simulation modeling is probably the best tool to use.

13.1.34.3. When arrival patterns and service patterns follow complex distribution (other than exponential or Poisson), or show considerable variation from cycle to cycle, then consider simulation. Note: Queuing modeling is considered deterministic that is, in using averages, the patterns always produce the same number. Although simulation models can be deterministic, the power of simulation modeling is to allow a random selection of a variable against a determined distribution allowing different results to occur at the end of any given simulation iteration.

13.1.34.4. If customers go through several phases and the routing to different phases becomes variable and complex, consider simulation modeling.

Chapter 14

SIMULATION MODELING

14.1. General Concepts.

14.1.1. Simulation modeling is an analytical tool used in the MEP to model complex processes. These models can be updated as an organization changes without the need for a complete re-study of a function's processes. This chapter is not intended to provide the methods or practices used for any particular simulation software. It is intended to provide general simulation modeling philosophy, methods, and practices to guide a ME analyst through a simulation study; whether it is for a manpower determinant, man-hour assessment, manpower assessment, or MAS.

14.1.2. A simulation model is based on a scenario which includes a description of the purpose for conducting the study, scope, objectives, and level of detail, business rules (assumptions), and resources needed to conduct the study. Simulation should not be used solely due to the availability of a software tool. The ME analyst plans and prepares for the simulation study through use of basic management principles and practices.

14.1.3. Simulation modeling software provides a way to capture the dynamic behavior of systems (group of processes). When the simulation model is run, it gathers and summarizes performance statistics and produces a realistic graphical animation of the system. A key capability is the ability to quickly conduct what-if analysis (also referred to as analysis of alternatives (AoA)) by changing parameter values within a given scenario. Simulation modeling facilitates process improvements for all manpower study types. The ME analyst should also realize no model (non-simulation or simulation) ever matches the real world absolutely perfectly. The focus should be on allowing Air Force leadership to make sound defendable decisions.

14.2. Non-simulation versus Simulation Study.

14.2.1. Simulation modeling provides many capabilities traditional management engineer techniques do not.

14.2.2. Non-simulation techniques provide results based on data at a specific moment of time, does not consider system interdependencies, nor provide an accurate impact of facility or resource constraints. Most models require extensive or complete rework to update. Typically, the resultant model output is in man-hours per month.

14.2.3. Simulation brings the data to life by imitating the actual system in compressed time, provides "what-if" capabilities, provides a visually appealing presentation of the system and associated analysis reports, and provides a durable simulation model that is easier to update than traditional manpower models. A constrained simulation model provides FTEs as its output.

14.2.4. A manpower determinant may use simulation modeling alone or in conjunction with other ME tools. An automatic application tool based on spreadsheets or simulation software is developed for future manpower determinants. Once simulation models are initially developed, the model is maintained as a function's processes are modified, removed, or added. This makes the models durable and saves time and money in future development costs.

14.2.5. MASs and Man-hour or Manpower Assessments may be used to support evaluation of a commander's problem. The visual appeal of the simulation model coupled with the ability to test potential solutions prior to implementing changes provides timely information to help make decisions.

14.2.6. The Air Staff and MAJCOMs need programming tools to allow quick evaluation of potential programming actions. There is a desire to capitalize on simulation modeling capabilities by using a combination of models to evaluate impacts at squadron, group, and/or wing-level.

14.3. Simulation Modeling.

14.3.1. Simulation modeling can be viewed in several contexts, but in the end, all simulation models are used to explore and understand something about the system being evaluated. As a minimum, the ME analyst first defines the process in terms of its inputs, outputs, activities, constraints, and resources used to deliver its outputs, and an agreed upon level of service.

14.3.2. Simulation modeling provides a way to model a dynamic system (group of homogenous processes) in compressed time, so defined interactions may be evaluated, system improvements can be identified, and a comparison of what if scenarios can be accomplished via statistical output reports. The model is developed through a simplified representation of the system that promotes understanding. A model is developed through an iterative approach. After the model is developed and simulated the ME analyst continues to revise it until an adequate level fidelity of understanding is demonstrated. Simulation allows the analyst to capture system variability, interdependencies, and constraints.

14.3.3. System variables require an understanding of how the systems elements impact each other and the performance objectives. There are three system variables: (1) decision or independent variables that impact the behavior of the system: (2) response or performance variables that measure the performance of a system in response to decision variable setting: and (3) state variables that capture the status of a system at any specific point in the simulation timeline. Define the nature or pattern of the independent variability and assess the range of impact on the system. Reduce or eliminate independent variability when possible. However, simply ignoring system variability distorts results and provides inaccurate information. Some examples include uncertainty in delivery of parts to repair a vehicle, equipment failures, personnel not available (leave, sick leave, etc.), and actual differences in the time it takes to accomplish an activity.

14.3.4. Interdependencies result when any element of the system has an impact on the behavior of other elements within the system. As the number interdependences increases, so does the complexity of the model. For example, a pharmacy technician is waiting on a patient and is unable to wait on another until the current transaction is complete. The delay in serving the next patient may set other forces in motion (i.e., backlog, or balking). Modeling a system achieves synergies not attainable if each process were to function in isolation. Ensure resources are not underutilized or there are not excessive backlogs.

14.3.5. Constraints result from limitations associated with tools, materials, work areas, personnel, other resources, and policy or guidance DoD Instructions, AFIs, common practices or business rules, or assumptions).

14.4. Typical Applications of Simulation Modeling. Based on the study's purpose most simulation models may contain several of the following applications found in Table 14.1.

Table 14.1. Typical Application of Simulation Modeling.

Application	Use
Bottleneck Analysis	A more defined form of capacity analysis which identifies system bottlenecks and how marginal changes at the bottlenecks affect the studied system's overall performance
Capability Analysis	System capability to meet specific performance requirements (e.g., throughput or waiting times)
Capacity Analysis	Maximize processing or capacity of the system. Look to identify and eliminate bottlenecks with the goal of increasing system capacity
Cycle Time Reduction	Explore ways to reduce cycle time within the system
Inventory Reduction	Evaluate ways to reduce inventory and decrease costs from storage, expiration, and destruction
Layout or Facility Analysis	The analysis of various facility layout designs and the effect on throughput
Performance Analysis	How well a system behaves under different scenarios can be accomplished by exploring various levels of service or other scenarios, e.g., peacetime versus wartime, and quantifying the resultant impact on resource utilization, throughput, or cycle-time
Productivity Improvements	Any experiment within the model to evaluate potential improvements in the system
Throughput Analysis	Evaluate the system's ability to complete actions on a given input
Visualization	Effective visualization of the system dynamics
Work Prioritization	Evaluate the impacts of work prioritization on a system

14.5. Principles of Simulation Modeling.

14.5.1. Below are principles of simulation modeling that are relevant in light of the goals of the MEP.

14.5.2. Define the Model's Purpose. By focusing on the model's purpose, the ME analyst also focuses on the relevant information needed to design the model within the study scope, the formulation of key performance measures and experiments to be simulated (e.g., manpower required at different levels of service), and ultimately the success of the study. This is arguably the primary overarching principle of simulation modeling. Simulation should be used when the process is complex, repetitive, and quantifiable.

14.5.3. Simulation Modeling is an Iterative Process. Simulation models are built in an iterative fashion progressing from simple to complex over time. Details are provided in **Chapter 14**, paragraph 14.12 (Simulation Study Process).

14.5.4. Avoid Unnecessary Detail. The key here is to capture the essence of the system rather than every possible variable. For example, there is no need to model lunch breaks unless the work center is required to be manned to service customers during that time. ME Analysts may run into situations that may seem relevant initially, which subsequent analysis does not support.

Remove the element or feature once it is determined to be unimportant to the model's purpose. A key economical consideration is to not design for peaks of 80-90% when the peaks only occur 5-10% of the time.

14.5.5. Simulation is an Evaluation Tool. The simulation model describes how a defined system behaves over time, not how it should be designed. The ME analyst should understand how the system is supposed to operate and use care in the use of input data and interpretation of output summaries, charts, and reports. The simulation model should help enable one to understand the complex dynamics of a system and is not a substitute for analysis and evaluation by the ME analyst.

14.6. Benefits of Simulation Modeling.

14.6.1. Simulation modeling provides optimized solutions through a dynamic (previous events can influence subsequent events) process analysis to describe a current or hypothetical system by emulating a system's behavior over time. Simulation uses stochastic (random) selection of activity times and other data inputs within predefined distributions to capture process interdependency and variability. Simulation modeling generates a visual presentation of work flow that greatly enhances communication of the system and impact of system variables on multiple performance measures. Simulation also provides a way to validate whether or not the best decisions are being made for a function, system, or process. This may be done by designing an improved system through experimentation with data variables to reduce waste and maximize process efficiency. Simulation modeling avoids the expense, time, and disruption that traditional trial-and-error techniques use to improve a system or process. Years or weeks of system operation can be simulated in a short period due to compressed run times. Some key benefits of simulation modeling are following:

14.6.2. "What-If" Scenarios. Allows the ME analyst to run scenarios to determine the feasibility of various concepts of operation for a given function and/or process. For example, simulation can demonstrate the impact on Centralized Classification when associated resources are converted from military to civilian. The model can show the impact on surge and steady-state manpower requirements prior to actual implementation, making simulation less disruptive than experimenting on most actual systems.

14.6.3. Capturing the Complex. Simulation lends itself to the capture of data associated with complex systems where other mathematical techniques may fall short.

14.6.4. Communicating Results. Simulation modeling is visually appealing and engages people's interest while providing results and information on multiple performance measures that are easy to understand and communicate. It takes emotion out of the decision-making process by providing objective evidence.

14.6.5. Defining Levels of Service. Experimentation with various what-if scenarios in a simulation model offers a tool to explore different levels of service and allows senior functional leadership to understand the effects of different levels of service on the mission.

14.6.6. Durable Manpower Simulation Models. Allows for the update of only the portion of the function and/or processes that have been changed, realigned, or removed.

14.6.7. Interdependencies and Variation. Accounts for interdependencies and variation that provide insight into the complex dynamics of a system that cannot be obtained using other analysis techniques.

14.6.8. Model Development. The development and design of the model provides an opportunity to evaluate the details of a system or process. Often solutions present themselves as the model is being built, which encourages thinking outside-the-box.

14.6.9. Sensitivity Analysis. Changes in one factor of the model may have unexpectedly large or small changes in other key performance measures. For example, an increasing work count may not result in a linear, or direct, need for associated resources, as there may be economies of scale.

14.7. Using Simulation Modeling.

14.7.1. Many but not all functions are candidates for simulation modeling. Do not use simulation modeling when there is a more appropriate MEP tool for the particular situation. When the work center meets the criteria below simulation modeling is appropriate.

14.7.2. Logical or Quantitative Decision. When an operational (logical or quantitative) decision is being contemplated. However, it is not very useful in solving qualitative problems such as those involving technical or sociological issues.

14.7.3. Process is Well Defined and Repetitive. When the process being analyzed is well-defined and repetitive. However, it does not mean uncertainty exclude it from the system. Probability expressions and distributions can be used to simulate random (uncertain) behavior. Use simulation only when the model can demonstrate how the process works.

14.7.4. Activities and Events are Interdependent and Variable. A combination of interdependency and variability of activities within a process may make that process a suitable candidate for simulation.

14.7.5. Simulation Costs Less than Implementation of a Decision. Simulating a proposed course of action in general costs less than an experimental (trial) implementation, in terms of both time and money. Real savings come from allowing ME analysts to make mistakes and work out design errors in the model rather than on the actual system. Additional savings may come from identifying and eliminating problems and inefficiencies in the system.

14.8. Simulation Model Types.

14.8.1. There are many characteristics to a given simulation model. Below is an overview of the types of simulation models applicable to manpower requirement models. These modeling characteristics are not mutually exclusive.

14.8.2. Static Simulation Modeling. Static simulation is not time-based and often draws random samples to generate a statistical outcome.

14.8.3. Dynamic Simulation Modeling. Dynamic simulation is based on the passage of time and the status of variables are changed and recorded as time advances. Manufacturing and service systems operating over time are well suited for this type of simulation.

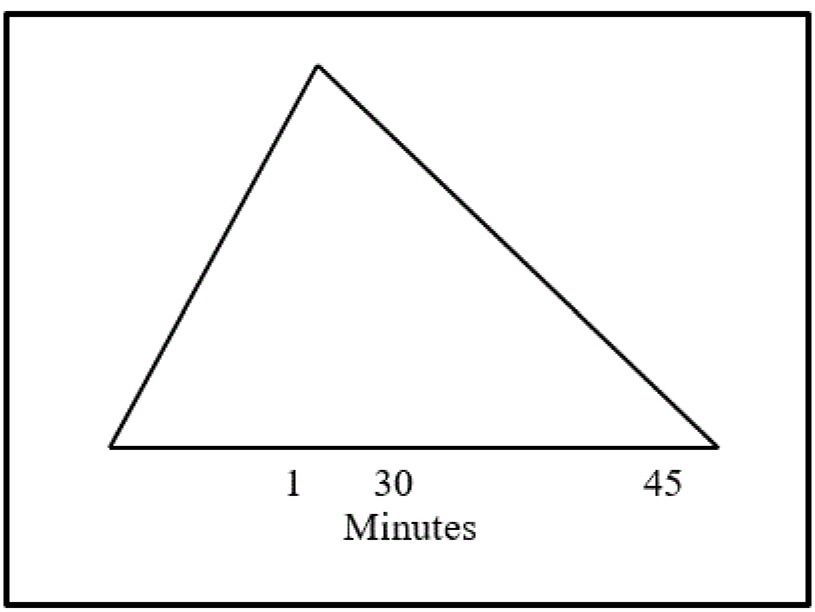
14.8.4. Monte Carlo Simulation Modeling. Monte Carlo simulations utilize probability theory by establishing distributions of key system variables sampled randomly and repeatedly to determine the expected behavior of the system of interest. These sampled distributions used in Monte Carlo simulations can be theoretical or empirical (based on data from the current or a similar system). By repeatedly re-sampling and recording these distributions, one can begin to discern expected values of these (key) system variables.

14.8.5. Discrete Event Simulation Modeling. In discrete event simulation modeling, earlier events create conditions that have an effect on later events. Thus, each event that occurs represents some kind of change to the system; e.g., the number of customers in line; the number of aircraft to be repaired; the number of primary care patients seen by the physician, etc. Although different sequences of modeled events can occur even in a discrete event simulation, the various sequences (i.e., production routings), and the probability of any given path to the next event is based upon the results of previous events as captured by the simulation ME analyst.

14.8.6. Deterministic Simulation Modeling. A deterministic simulation model is a model where key parameters are fixed amounts. For example, a per accomplishment time for the time a blood sample centrifuge may be set automatically for exactly 10 min. Another example is a mechanic who arrives to pick up tools at a tool crib every 6.5 min. Thus, a deterministic simulation model would always choose a per accomplishment time value of 10 min (blood sample centrifuge) or 6.5 min (tool crib) each and every time these activities are accomplished.

14.8.7. Stochastic or Probabilistic Simulation Modeling. A stochastic or probabilistic simulation model is a model where key parameters are allowed to vary within a set distribution. For example, the per accomplishment time to perform a 30-day inspection on an aircrew helmet might be modeled using a triangular distribution where the minimum time to complete the activity is 25 min, most often 30 min, and maximum time set at 45 min. In this situation, the simulation model randomly selects a time between 25 and 45 min, with a central tendency toward 30 min, for each time the helmet inspection is performed. A triangular distribution is graphically represented in Figure 14.1.

Figure 14.1. Example of a Triangular Distribution.



14.8.8. It should be noted a model may contain both deterministic and probabilistic elements. Further, whether a choice is made between a static constant for the value of an output (e.g. 5 min activity time) or a probabilistic distribution, (example: normally distributed mean of 5 min with a standard deviation of one minute) both represent a type of system constraint. Some level of variation is inherent in every system, so, most models should contain elements of both based on analysis of the system under study.

14.8.9. Continuous Simulation Modeling. Describes the likelihood of a value being in a given range. For example, a machine may have a cycle time of between 1.2 and 1.8 min; an infinite number of possibilities exists within this range.

14.8.10. Terminating Simulation Modeling. Terminating simulation models begin and end at set (predetermined) times.

14.8.11. Non-terminating Simulation Modeling. Non-terminating models do not have specific start and end points. Implied here is these models have to reach a set point in time where steady state is achieved and (normally) where statistics for the model begin to be collected.

14.9. How Discrete-Event Simulation Works.

14.9.1. Typically, the MEP uses discrete-event simulation modeling. The model presents a process-oriented world view to the user for defining models. Entities (item to be processed for example a RPA) begin the processing at activity A, then move to activity B, then moves in different directions (routes) based on a decision to activities C and D, and so on. These process flow definitions are translated into a sequence of events for running the simulation. There are two types of events:

14.9.2. A scheduled event is an event whose time of occurrence can be determined beforehand and can therefore be scheduled in advance.

14.9.3. A conditional event is an event triggered by a condition being met rather than by the passage of time.

14.9.4. Events, whether scheduled or conditional, trigger the execution of logic associated with that event. For example, when an entity frees a resource, the state of and statistical variables for the resource are updated, the graphical animation is updated, and the input waiting list for the resource is examined to see what activity to respond to next.

14.10. Simulation Pitfalls.

14.10.1. Simulation studies may fail due to poor planning and execution. Simulation fails to produce useful results more often because of a lack of understanding of system dynamics than a lack of knowing how to use the software. This may be caused by an unskilled analyst, unavailability of data, and or unsupportive management. It may also fail to meet decision maker needs due to unclear objectives or unmanaged expectations. Therefore, the best way to ensure success is to ensure everyone involved in the study understands the process, benefits, and limitations of simulation.

14.10.2. Documentation Requirements. Documentation of facts, assumptions, data, and analysis is important for any study. However, it becomes more critical to the success and durability of the model when using simulation. The study team provides detailed model assumptions and rationale on the assumption decisions. By documenting the assumptions, the study team facilitates functional communities, other ME analysts, and ultimately the decision maker's ability to understand the simulation model's context. Clear and concise assumptions provide credibility to the simulation model. Simulation modeling software provides the capability to capture all the study's documentation, facilitating quick and timely changes to the model for a particular function for years into the future.

14.10.3. Data Preparation and Analysis. The simulation model is only as good as the data collected and analysis conducted. Process activities are accurately and clearly defined to facilitate accurate work measurement (i.e., process activity times and/or WUCs). Critical analysis is required for process activities and work measurement data throughout the study. Ensure the data gathered is logical and supportable.

14.11. Simulation Modeling Verification and Validation.

14.11.1. Verification and validation are critical to providing decision makers a credible model on which to make timely decisions.

14.11.2. Verification. The process of determining whether the documented assumptions have been correctly translated into the simulation model, and that the model operates as intended. Through analysis, the ME analyst attempts to detect and eliminate unintended errors or bugs in the models logic, calculations, or programming. Syntax errors may be grammatical, or may be notations that prevent the model from running correctly. Semantic errors are more difficult to detect and occur when the ME analyst's meaning or intent is not clear, often resulting in logic errors causing system behavior differing from what was intended.

14.11.3. Validation. The process of determining whether a simulation model is an accurate representation of the system. Validation is an intricate part of each aspect of model development. It begins with conceptual model validation (structured walk-through of the assumptions document) with functional representatives and SMEs. Validation continues through each part of model development and concludes with a comparison of the model's outputs and those of the existing system. A valid model typically has results similar to those of the existing system. If that is not the case, changes to the model should be done one step at a time, so the analyst understands what results a particular change makes on the model. When there is no existing system to which a model may be compared, results of the model should be logical, reasonable and defendable to be considered valid.

14.12. Simulation Study Process. Each study requires a model based on the current system. When developing improvement to the system, a proposed model or scenarios is used. The analyst does not make improvements to a model until understanding of how the current system works. This does not prevent the analyst from identifying potential improvements when developing the current system. However, the analyst does not attempt to incorporate improvements into the current model, as there is no way to verify or validate the accuracy of the results.

14.12.1. Proper data collection and data analysis are critical before the simulation model is developed. Process flowcharts and data may be collected within or outside of the software tool. However, the study team uses all techniques and tools (i.e., histograms, Pareto charts, etc.) available to verify the data is logical and correct.

14.12.2. When developing improvements, consider eliminating or realigning workload, optimizing manpower resource skill mix, and changing processes or procedures to reduce backlogs and/or cycle and process times. Identify potential risks and mission impacts.

14.12.3. When conducting MASs, man-hour or manpower assessments the analyst should consider developing models or scenarios to evaluate the impact of issues on the current workforce, such as training, staffing, backlog, or projected increases to workload.

14.12.4. Document both the current and proposed simulation model results in terms of resources, cycle and process times, and backlogs. Through use of scenarios it is possible to provide leadership with sound data with which to make decisions on level-of-service issues.

14.12.5. Simulation Procedure. Provides a summary of the steps used in simulation modeling, deliverables, in relationship to AFMD study phases. There are similarities and some differences between a typical manpower determinant development efforts. However, MEP principles are applicable to both. See simulation modeling steps in Table 14.2.

Table 14.2. Simulation Modeling Study Steps.

Simulation Modeling Steps	Simulation Modeling Deliverables	Relationship to AFMD Study Phases
Step 1: Define purpose, objectives, scope, and requirements.	Memorandum of Agreement Scenario Conceptual Model Measurement Plan	Familiarization
Step 2: Collect and analyze system data.	Process Flowcharts Data Elements – Collected and Validated	SWD Development
Step 3: Build the model.	Simulation Model Run Unconstrained Model	SWD Development
Step 4: Validate the model.	Model Verification Model Validation	Analysis
Step 5: Conduct experiments.	Run Constrained Model AoA	Analysis
Step 6: Present the results.	Final Report	Reporting

14.12.6. Step 1. Define Purpose, Objectives, Scope, and Requirements. The study team clearly documents the study purpose, objectives, scope, and requirements. This should help all involved parties to understand what is included in the simulation model and what questions it does and does not answer. The study team should then follow the documented plan. This does not mean course corrections cannot be made as new information is discovered. However, course corrections should be limited to those issues impacting the study's original purpose. Changing the purpose midway can result in undesired results. Remember to document any course corrections and share with all involved. The study team's memorandum of agreement should include the purpose, objectives, scope, and requirements.

14.12.6.1. Defining the Model's Purpose. The most critical aspect of model design is to correctly define the model's purpose which should be the same as the study purpose. In defining the model's purpose, the study team should answer the following questions:

14.12.6.1.1. What questions need to be answered by the simulation model?

14.12.6.1.2. What decisions are made with the results of the simulation model?

14.12.6.1.3. Is simulation the best tool to use based on the purpose? Is there a simpler tool or approach?

14.12.6.1.4. If simulation modeling is the best tool, what are the variables of interest? How should the variables be captured or computed?

14.12.6.1.5. What is the desired statistical confidence and precision?

14.12.6.1.6. Does the model help determine minimum manpower requirements to accomplish a function's mission?

14.12.6.1.7. Does the model aide in the evaluation of potential solutions?

14.12.6.2. Defining the Study Objectives. Effective objectives should identify constraints that have high potential impact, be achievable, specific, quantifiable, and measureable. Examples of well-stated objectives:

14.12.6.2.1. Find the lowest resource cost solution to reduce customer wait time in the finance office so that no more than 10% of customers wait longer than 15 min.

14.12.6.2.2. Increase the throughput of the pharmacy by an average of 20% without additional capital expenditures.

14.12.6.2.3. Defining the Study Scope. The scope should be defined by a detailed study specification that establishes expectations and responsibilities by clarifying to all involved exactly what the simulation includes or excludes and who is responsible for gathering data. A detailed specification should be drafted to ensure the budget and schedules are realistic. It should include:

14.12.6.2.4. Model Scope. What are the model's boundaries? Does the study purpose require simulation of the function's entire system or a specific area? Do not include elements that are irrelevant to the study's purpose.

14.12.6.2.5. Level of Detail. What level of detail is required to meet the stated purpose? The level of detail is determined by the degree of accuracy required. When developing simulation models to determine manpower requirements, ensure the level of detail facilitates measurement. The appropriate level of detail dictates the required level of effort, which in turn helps maximize results.

14.12.6.2.6. Data Gathering. Data gathering is the most time-consuming and difficult task in the simulation study. Document data gathering responsibilities and establish firm timelines to receive data from study participants.

14.12.6.2.7. Experimentation. The study team should understand the current system prior to developing manpower requirements or considering improvements. Therefore, a current model is developed prior to developing improvements in a future model or models. These models facilitate verification and validation, as well as show any savings resulting from the future model. Plan the number and nature of scenarios from the beginning based on established functional business rules. A function's business rules may be operating procedures, historical practice, or policy and guidance.

14.12.6.2.8. Study Results. The decision to be made and the background (understanding of function being studied and tools being used determine results) of the decision maker are keys to determining the kind and quantity of information needed. Ensure adequate information is available and effective visualization is used to facilitate the best decision. This may be done by presenting results from two or more scenarios in a scoreboard showing comparisons of key performance measures.

14.12.6.2.9. Defining the Study Requirements. Determine resources, budget, and time requirements. Ensure resources (personnel, computers, software, and conference facilities) have been identified, along with a budget of TDY expenses. Develop a timeline based on the size and difficulty of the study. Keep in mind data gathering and analysis can take more than 50% of the study timeline, while building the model may take 10-20% of the time. Allow several weeks to conduct experiments and several days to clean up the model and develop presentation materials. The information gathered in this step frames the scenario to be modeled. The scenario provides the operational concepts, supply and/or materiel requirements, and specific policies impacting a study. Scenarios are developed by the study team and are coordinated with the functional representative. Once a coordinated scenario has been received the study team may continue study efforts. Clearly identify what is to be simulated and what is to be determined with other manpower tool or techniques. There is no need to simulate overhead, directed requirements, or direct supervision.

14.12.7. Step 2: Collect and Analyze System Data. Identify, gather, and analyze the data defining the system to be modeled. Systematically collect data needed to build the model. Data collection is much more productive when approached with the end result in mind. Keep the study purpose, objectives, scope, and scenario in mind when determining what data is required, or the study team may waste valuable time. The output of this step is the beginning development of a conceptual model and a data document on which all can agree mimic the process to be modeled. Data integrity is critical to the success of any model developed. The following steps are helpful when gathering data:

14.12.7.1. Determine Data Requirements. This step should be dictated based on the study scope and level of detail to meet the study's purpose.

14.12.7.2. Identify Data Sources. Unfortunately, all needed information is rarely readily available from a single source. Conduct research and interviews to find and determine the validity of data; using more than one source to get the best results. Persistence, careful observation, and communication skills contribute to getting data that adequately supports the simulation effort.

14.12.7.3. Collecting Data. Generally, it best to gather this information during a functional workshop with functional personnel who currently do the work being defined.

14.12.7.4. System Outputs. Begin by identifying system outputs (what the function produces); such as a completed travel voucher, an identification card, etc. Do not include any activities in the model that do not contribute to an output.

14.12.7.5. System Inputs. Determine what initiates the process to get to the output. The items processed through the system such as products, customers, and documents have unique characteristics also known as an entity.

14.12.7.6. Process Flow Chart. Develop a basic process flow of the required major activities, decisions, and routings. This is a logical sequence of activities the entity flows through and defines what is being done to the entity. The process flowchart defines processes based upon the standardized methods for accomplishing required work. The functional representative is responsible for assisting the study team in defining the most efficient and effective processes.

14.12.7.6.1. Use standard flowchart symbols, a well-organized visual presentation, and concisely worded activity titles.

14.12.7.6.2. Generalize into a few defined patterns the numerous instances of a particular process or activity.

14.12.7.6.3. Develop step-by-step activities that facilitate measurement. This may be done by expanding the number of activities in a process flowchart, drilling down into sub-models, or listing individual steps within the activity.

14.12.7.6.4. Ensure clear start and stop points are identified for measurement.

14.12.7.6.5. When a decision point is reached, determine whether it is based on a probability (percentage) or condition. A percentage estimate from the functional representative may suffice, yet a data source is always better.

14.12.7.6.6. The study team may be tempted to include potential process improvements as the flowchart is being developed. Any potential improvements need to be documented separately and worked separately from the current model. Usually, it is best to develop potential process improvements after the simulation model has been refined for two reasons: (1) the current model can be copied and modifications made only on those areas where potential improvements are identified and (2) the study team has a much better understanding of the current system, facilitating better analysis of potential improvements.

14.12.7.7. Once the study team and functional representative agree that all processes have been accurately depicted, the study team develops activity times for each activity.

14.12.7.8. Developing Activity Times. When developing activity times the ME analyst should clearly explain the times are based on one input and should include only time directly associated with the respective activity. The activity time represents the standard process activity times across the Air Force each activity.

14.12.7.9. Do not attempt to collect WUC data while facilitating activity time development. This can cause significant confusion for all involved.

14.12.7.10. Do not include system caused delay in the activity time.

14.12.7.11. Analysis of an activity helps determine the appropriate type of distribution to use when associating a time or times with an activity. Triangular distribution is the most prudent distribution to use in a workshop environment where there is a reasonable expectation of a range of time (variability) for that activity from input locations; lacking substantial supporting data. However, this does not prohibit the use of a mean value or a range (minimum and maximum values), or even a single time value when the SMEs agree and the functional representative supports it. While developing a triangular distribution is similar to optimistic-most likely-pessimistic per accomplishment times, there are subtle differences that can have major negative impacts on the resulting model. The triangular distribution is based on minimum, most often, and maximum times to accomplish the activity. Again, use care in the use of minimum or maximum times. These values should support normal minimum or maximum times, not extreme values that have a low probability of occurring.

14.12.7.12. Minimize the deviation between distribution data points through activity breakdown to determine if specific activities or sub-activities trigger more time. If so, that part of the task may need to go through a decision block so high activity times are isolated and only a small percentage of the entities flow through the higher activity time. While there is no specific rule, analysts should use care when activity times exceed 60 min and/or high WUCs drive a high number of man-hours. Generally, this may be a sign more detail is required for that portion of the model. Also, consider how often the activity occurs. A once a year occurrence may be insignificant and not impact the results. However, a high daily occurrence is significant and may have a major impact on results.

14.12.7.13. Decision blocks and routings generally do not have associated times, as the decision is predicated on the previous activity. The decision block and routing is used as a pointer for the next step based on a percentage or certain conditions. Routings may include move time when the entity is required to move from one physical location to another. Do not use activity times when using delays in the process flowchart to depict the function is waiting for some other unit or function to complete an action.

14.12.7.14. Once the study team and functional representative agree all activity times have been accurately depicted, the study team collects WUCs and resource data.

14.12.8. Collecting WUCs and Resource Data. This data may be collected in the workshop or as a follow-up action. Generally, models developed for use as manpower determinants are simulated for one year to obtain full-time equivalent manpower requirements. WUCs for each of the function's processes and resource data should include a minimum of 12 months of data, yet 24 months are preferred. Use care when making prediction when less than 12 months of data are available.

14.12.8.1. WUCs. Define the specific source, collection period, and the method for data collection. Analyze data to identify potential outliers and/or errors, and resolve any identified issues. These counts may be used as the arrival rate for an entity coming into the model or to develop an arrival rate distribution.

14.12.8.2. Resource Data. Collect both assigned and authorized manpower for input locations of the function being studied to include Air Force Specialty Code (AFSC), grade, and skill level. Simulation modeling provides a means by which to identify other resources, such as facilities, equipment, or materials that impacts entity throughput. Analyze data to identify potential errors and resolve any identified issues.

14.12.8.3. At this point there is enough data to construct a basic model. Building the model helps identify missing information and data. Furthermore, it helps define and validate system data.

14.12.9. Defining Additional Details and Refining Data Values. Remember simulation modeling is an iterative process. With purpose and scope in mind, continue to add details (i.e., system downtimes, shifts, and work priorities) to the model and refine the data.

14.12.9.1. Modeling Assumptions. Often some data is unavailable or unreliable. In those cases, document any assumptions made and provide rationale behind those assumptions.

Be sure to validate assumptions with the functional representative. Run experiments with assumptions to ensure no illogical results exist. It is very important for the study team to set aside a section of the final report dedicated to detailing the model assumptions made and reasons why. Generally, the simulation model is based on one year (52 weeks), plus an appropriate warm-up period (**Chapter 14** paragraph 14.12.30.1.). By documenting the assumptions made, the study team helps the functional community, decision makers, and other ME analysts to understand the simulation model's context.

14.12.9.2. Data Analysis. Data is analyzed and interpreted so the simulation model correctly reflects the process. Remember, the study team is working to develop simplified models of complex operations. Generalize into a few process flowcharts when there are numerous possible instances of an entity flowing through a group of activities.

14.12.9.3. Use scatter diagrams, distribution charts, or other analysis tools to evaluate the data. Discard irrelevant or insignificant data. This is appropriate for activities that occur a few times a year with low activity times. Does the activity impact the desired result? For example, does an activity with a triangular distribution, T(30, 120, 175), and an occurrence of twice per a year result in enough man-hours to significantly impact the model? In many cases it does not, and there are no specific rules to determine whether the activity should be included or not. Analysis, logic, and justification are the keys to making that decision.

14.12.9.4. Once analysis is complete it is converted to a suitable form to be used in the model. There are three options: (1) use as recorded, (2) use an empirical distribution (characterization of the data), or (3) use a theoretical distribution (best fits the data). Using theoretical distributions is the preferred method as it smooths data irregularities and includes some extreme values. Use bounded distributions to ensure the value does not become negative or go into the range beyond the maximum value. A trial-and-error process is used to determine the fit of a distribution. The process consists of three steps: (1) one or more distributions are selected as candidates for being good fits to the sample data, (2) estimates of the parameters for each distribution is calculated, and (3) goodness-of-fit tests are performed to determine how well each distribution fits the data. Fortunately, many software products offer some form of distribution fitting.

14.12.9.5. Develop forecasts for WUCs based on historical data when practical. Forecasted WUs allows for projecting future manpower requirements.

14.12.9.6. Data Documentation. When analysis is complete the study team documents the study data and assumptions using appropriate data collection tools (spreadsheets, databases, and/or diagrams). Include all items discussed within this section of the chapter. These documents may be used later to provide supporting data, compete the final report or conduct further analysis and/or studies.

14.12.9.7. Developing Process Improvements. First have a working model of the current process. Then evaluate potential improvements through an iterative approach. Use care by changing only one item at a time and documenting findings each time. Changing more than one item at a time can potentially break the model or cause faulty conclusions or assumptions.

14.12.10. Step 3: Build the Simulation Model. Simulation model design is a thorough process the study team plans for and evaluates from the beginning of the study. In order for a system to be simulated, first define it in terms of entities (inputs and outputs), locations (activities, delays, and/or decisions), resources (people, equipment, and/or facilities), and paths (where the entities or resources travel) used to deliver particular outputs. Begin with the conceptual model developed in the data-gathering effort. Remember the model is a simplified representation of reality based on the study purpose, scope, and scenario. Therefore, the ME analyst does not change the model arbitrarily; changes are systematic and documented. This may be done to translate complex operations into simplified concepts. Table 14.3 provides the structural elements of a system. The following paragraphs provide some practical techniques for minimizing structural elements while preserving the accuracy of the representation:

Table 14.3. Structural Elements of a Simulation Model.

Object	Represents	Characteristics	Collected Statistics
Entity	Inputs and Outputs	Follow one or more routing Processes performed on entity Arrive from outside system or created within Normally exits system Use entity attributes to determine routing or gather information	Cycle-time Throughput Process time (touch time or value-added time) Wait time Work-in-progress (WIP)
Location	Places in system for processing, wait, or decisions	Room, workstation, entry point, queue, or storage Buffer capacity Available times May have priorities for processing	Queue/average contents Process time Utilization Downtime Idle time
Resources	Used to process entities	Static (are stationary) examples: fax machine, computer, or facility Dynamic (move within the system) examples: people or automated equipment	Utilization Availability Response time Quantity needed
Paths or Routing	Defines course of travel for entities or resources	May be isolated (routing) between activities for entity flow May be connected (path network) to create travel ways for material handling equipment	Move time

14.12.10.1. Entities. How many of the entities need to be modeled? Do not include an entity if the model accurately captures the dynamics of the system. An example could be when several paper forms are included in a package to be processed. Aggregate entities when all entities are processed through the same activities, even when there are minor differences that can be addressed with attributes or probabilities. Otherwise, each variation becomes cumbersome without significant benefit. Customers are one example of when entities may be aggregated. At times entities may be grouped together and processed and/or moved in batches, such as a group of like parts that are loaded onto an assembly for painting. The entity is the assembly during the move, painting, and while the parts are drying. Once the entities are unloaded from the assembly, each part becomes a separate entity.

14.12.10.2. Locations. Deciding what locations to model depends on what actions are taken at the location. When there is no action it is probably not necessary to include it.

Locations should be included when the entity is undergoing an activity, waits for a condition to be met, when logic is executed, or when a decision is made.

14.12.10.3. Resources. The decision to model a resource is dependent on what impact it has on the behavior of the system. Traditionally, the MEP has only modeled the manpower resources needed to support the function's required mission. However, simulation modeling provides an opportunity to include facilities or equipment that significantly impacts the system.

14.12.10.4. Modeling Non-Manpower Resources. Assume a study on vehicle maintenance where two different bases are required to support the same number of vehicles (1,000). Yet, base A has two maintenance bays and base B has four maintenance bays. A C&R-based equation would result in the same manpower requirements. An assumption could be made that probably half of the assigned personnel at base A would be unproductive due to the facility constraints. Simulation modeling provides a methodology to determine the production capacity at each base, thereby providing a tool with which to quantify the appropriate manpower requirement and/or identify the need for two additional maintenance bays at base A (or lack of need at base B).

14.12.10.5. Maximum Availability and Utilization Rates. The following guidelines are provided for determining manpower resource maximum availability and utilization rates for simulation modeling. Keep in mind manpower resources are defined in terms of FTEs, not man-hours per month when using simulation.

14.12.10.6. Maximum Availability Rate. Use Table 14.4 below to determine availability rates for an all military, combined, or all civilian work centers. When the work center is combined use the military availability rate for all resources. Once the maximum availability rate has been computed, round the result based on normal rounding rules. The maximum availability rate is assigned to the particular resource in the model. During simulation manpower resources are not be constrained beyond the maximum availability rate.

14.12.10.7. Maximum Utilization Rate. A maximum utilization rate is defined by constraining resources in the model to a point that the model produces desired results (i.e., expected throughput, manageable backlog). Furthermore, there is not a firmly defined minimum utilization rate, as crew requirements for safety or security may dictate lower utilization rates than commonly expected.

14.12.10.8. Both maximum availability and utilization rates are a common practice in the development of Air Force Logistics Composite Model (LCOM) manpower determinants and commercial industry. The ME analyst is expected to document assumptions and rationale for both.

14.12.10.9. For simulation models that do not use the MAF, use the approved LCOM conversion factor for each operating environment (peacetime and/or wartime).

Table 14.4. Manpower Maximum Availability Rates (Note 1).

Non-available Categories	Military Or Civilian Overseas	Civilian CONUS	Military Only		
			Extended 48-Hour	Wartime Emergency	Wartime Surge
Assigned	100.0%	100.0%	100.0%	100.0%	100.0%
Non-available	10.6%	14.3%	9.7%	5.7%	9.7%
IAF	6.19%	6.19%	6.19%	6.19%	6.19%
Personnel, Fatigue, & Delay (Note 2)	6.25%	6.25%	6.25%	5.00%	4.16%
Maximum Availability Rate	76.96%	73.26%	77.86%	83.11%	79.95%

Note:
1) Non-available, IAF and the PF&D factors were derived from approved MEP guidance and **Chapter 10** of this manual.
2) Typically, this factor is used as the minimum PF&D factor to be used with simulation models. Additional PF&D factors may be used based on guidance within **Chapter 10** of this manual.

14.12.11. Skills and Grades. The level of detail for skills and grades built into the model is a matter of judgment. It is possible to either create a resource for every potential manpower resource required or a generalization for a function's mission.

14.12.11.1. Assume each activity in a function being studied can clearly identify the AFSC, skill-level, and grade required. The ME analyst can use logic (Get or Get Jointly) to use a particular resource or group of resources. The logic can also establish a priority for getting a particular resource. Use the resource with the lowest cost that can accomplish the activity first when prioritizing. The simulation results yield the number of each resource type and the utilization rate of each type.

14.12.11.2. In another scenario, assume there is more flexibility in determining the skills and grades required to accomplish the activities are more flexible. The ME analyst may use one resource for an AFSC to capture the total manpower number and then develop a percentage to be used to determine skill and grade requirement.

14.12.11.3. For either of the above situations, further analysis is then required to determine whether: (1) the minimum skill and grade necessary are being used, and (2) the utilization rate of a particular skill and grade is appropriate. Some functions require a larger number of lower grades to accomplish the direct mission and fewer higher grades to manage and supervise. Conversely, other functions require more skilled and experienced personnel. There is a balance to the analysis of skills and grades. Ultimately, the minimum level of skills and grades required to accomplish the mission should drive the specific manpower requirements.

14.12.12. Resource Travel Time. Consideration should be given to any travel time required for the given resource.

14.12.12.1. Examples for manpower resources include the time it takes to move a piece of aerospace ground equipment to a particular aircraft for support maintenance activities, or the time it takes a plumber to travel from the shop to the location where the repair is required. The time may be a function of the distance traveled.

14.12.12.2. Transport resources are used to move entities within the system. Some examples include forklifts, buses, trains, and aircraft. These resources are dynamic and are usually capable of carrying multiple entities, with multiple stops, and/or routes.

14.12.13. Consumable Resources. It may be appropriate to model consumable resources such as fuel and supplies. A variable could be used to represent fuel consumption on aircraft loading equipment that may impact the amount of equipment that may be loaded, before additional fuel is required.

14.12.14. Paths or Routing. The number of paths needed in a model depends on the sequence of activities or the location to where resources travel for process entities.

14.12.15. Operational Elements. Operational elements define the behavior of the different physical elements in the model and how each interact with one another. Operational elements are explained in the following paragraphs:

14.12.15.1. Routings. Define the sequence of flow of entities from location to location and specify the criteria for selecting from among multiple locations. Rules used to determine the next location include probabilistic, first available, random or condition. At times an entity passes through a location multiple times. An attribute may be added to the entity to keep track of the number of times to determine future routing. Sometimes a particular routing is not required as long as a set of locations are visited, such as, mail delivery and pickup. Again, an attribute can be set for each location to zero as each location is visited the value is changed to one, with subsequent routing based on the remaining locations, still set at the original value.

14.12.15.2. Entity Operations. Defines what happens in terms of the time required to complete the action, the resources used for the action and other logic that impacts the system performance of an entity when it enters a location. Entities may be consolidated by accumulating packages to fill a truck, or by grouping people together to attend a class, known as batching. Attaching entities may be attaching a wheel assembly to an F-16 or attaching a shipping label to a pallet. Entities may be divided by either cutting sheet metal into multiple pieces for use on an aircraft or a pallet being broken down into individual mobility bags.

14.12.15.3. Entity Arrivals. The arrival pattern defines the time, quantity, frequency and location of entities entering the system and is derived from WUCs for a particular process entering the system. Use only one of the input bases to build the initial model. The remaining input bases can be added to the model or modeled through a scenario after a working model has been verified and validated. Table 14.5 depicts the ways entities may arrive for processing, characteristics, and examples.

Table 14.5. Entity Arrival Patterns.

Arrival Patterns	Characteristics	Examples
Periodic	Same or similar interval Dependent on previous arrivals Varying quantities May be random variables	RPAs are received at any time during a given day. Rather than using another arrival rate, divide the years total RPAs received by the number of min in a year to get the period arrival.
Scheduled	Specific times with defined variation May use external file data Independent of previous arrivals	Patients scheduled for dental checkups Personnel arrive for weapons training
Fluctuating	Fluctuates with time Pattern may repeat each day	Personnel arriving at the dining facility Calls received in a call center Customers arrive at bank
Event Triggered	Introduced by an internal trigger	Fuel supplies drop to the re-order point level Delivery signal is received to fuel an aircraft for a mission

14.12.15.4. Movement of Entities and Resources. The decision on when and how movement of entities and resources are modeled depends on several factors. When the move time is insignificant it may be ignored or included in the activity time. However, when it is significant and routing congestion is light it should be defined as a move time. Conversely, when significant and routing congestion is high, define a path network. A path network defines many routings sharing common segments of a path.

14.12.16. Location and Resource Access. Determining when an entity can use a location or resource can be handled in three ways: priorities, preemption, and task selection rules. Entities may be assigned priorities based on type, where type 1 is assigned a priority of 0 and type 2 a priority of 1. Therefore type 2 (higher value has the greatest priority) is processed or gets the resource first, and this method does not interrupt processing or risk resources being used on another entity. When a resource or location is needed immediately it is preempted. Task selection rules determine which entity waiting for a location or resources is allowed use when the location or resource is available.

14.12.17. Location and Resource Scheduling. Scheduling may account for unavailable time such as off-shift, breaks, and preventive maintenance. Generally, when modeling a function that works a normal 5-day work week it may be more effective to model the 8 hours (0800-1600) of a day without lunch and/or without breaks (already included in non-available time and personal, fatigue, and delay). Using this method simplifies the modeling effort without compromising the results. Below are some specific scheduling issues and approaches to handling them:

14.12.17.1. There are three approaches available when a scheduled resource goes off-shift in the middle of a task: (1) do not start the task, (2) interrupt the task, or (3) complete the task. The approach to use depends on the amount of time needed to complete the task and whether the task (i.e., waiting on customers waiting for an identification card) needs to be complete before going off shift.

14.12.17.2. Determining location or resource utilization time is based on the scheduled availability of the location or resource. For example, a resource scheduled for a normal 5-day work week be available 40-hours (100%). The actual utilization rate would then be based on the percentage of actual work time to the total available time. Therefore, if the resource were used 20-hours during the week the utilization rate would be 50%. Using a location or resource schedule facilitates gathering the correct statistics. Normally location schedules are not needed unless there is a specific need for location statistics. Non-available and indirect work were not included in this example.

14.12.17.3. There are three courses of action available to handle arrivals during off-shift times: (1) allow them to arrive and wait in a queue (i.e., processing of electronic transactions), (2) schedule arrivals during shifts, or (3) create a logic test that causes the entity to exit the system when a function is closed.

14.12.18. Downtimes and Repairs for Resources and Locations. A person may be called away to handle a personal emergency or a machine may fail. In these cases distributions may be used to determine when such an event occurs and the duration of unavailability. When a machine requires preventive maintenance, the event may be triggered by total elapsed time, time in use, or the number of times used.

14.12.19. Programming Logic. Simulation software provides standard design functions to model behavior of a system. However, there are times behavioral decisions need programming logic to test probabilities, attributes, and variables.

14.12.19.1. Probabilities. Operational elements may exhibit random behavior and may be modeled using probability. For example, a decision goes to Activity A 75% of the time and Activity B 25% of the time. When used in activity operations the probability can be used along with if-then or if-then-else logic.

14.12.19.2. Attributes. Establishing attributes in a model provides additional information about a specific entity. For example, when modeling fueling of aircraft an attribute could be assigned for the aircraft type. This attribute may be used in the logic to determine the amount of fuel required for the type of aircraft and the specific mission. Used along with variables that keep track of the amount of fuel on the truck and the amount of fuel need for the aircraft's mission, attributes determine whether the fuel truck needs to return to the fuel storage area or have another fuel truck dispatched.

14.12.19.3. Global Variables. Defined by the user for user as placeholders for values that may change during the simulation. These variables may be used anywhere in the model. For example, a variable may be used to determine the amount of WIP by incrementing the variable as the entity enters the process and decrementing upon exit. Simple or time weighted statistical values of the WIP variable can be generated.

14.12.19.4. Local Variables. Declared within logic for the current object primarily as a logic loop and may be thought of as temporary attributes of the object.

14.12.20. Other Modeling Issues to Consider:

14.12.20.1. Data Element Standardization. The process of documenting, reviewing and approving unique names, definitions, characteristics and representations of data elements according to established procedures and conventions.

14.12.20.2. Modeling Extreme Values and Events. Simulation modeling normally ignores extreme values and events as the model is developed based on the normal behavior of the system. This reduces modeling time, simplifies the model, and helps maintain focus on key input variables. There are circumstances where a rare event would be modeled to determine the impact on system behavior. However, it would not be used to predict when it might happen.

14.12.20.3. Modeling Large Systems. When modeling a large and/or complex system, it may be best to build several sub-models rather than one large model. This way, each sub-model can be built and validated before merging with the large model of the entire system. Three potential approaches to integrate models are to (1) integrate all sub-models as built, (2) use only the recorded outputs from one or more of the sub-models, or (3) represent the output of one or more sub-models as statistical distributions.

14.12.20.4. Modeling Costs. Generally, dollar costs would not be included in a manpower determinant development effort. However, using resource, supply, and equipment costs may prove valuable when conducting a MAS. The simulation model's ultimate purpose is to serve as a guide as to whether costs should be included.

14.12.20.5. Roll-up Activities. When activities are not independently variable, it is preferable to roll up the activity and maintain the task level details in the notes.

14.12.21. Run Unconstrained Model. Once the current model has all required elements completed the ME analyst runs unconstrained resources (manpower and facilities) to ensure throughput of entities. This is done by making a large number of each resource available to the activities using the maximum availability rates established in Table 13.4. This ensures the model runs at the fastest speed possible in a manner unimpeded by resource constraints. After the model runs, statistics are collected to see if output data and model performance match expectations.

14.12.22. Run Constrained Model. Once the unconstrained model is determined to be working correctly, the model is then constrained (optimized) to determine the manpower requirements based on established performance standards. System optimization searches for the best combination of decision variable values that either minimize or maximize some objective function (manpower, costs, etc.). Limits or constraints to values that the independent variable takes may cause optimization problems.

14.12.22.1. At times there are conflicts between study objectives. An example could be the goal of minimizing service cost for the pharmacy and minimizing wait cost for the military member. Some may view the military member's wait time as no cost, however, the time away from the duty station impacts the work center's ability to meet mission requirements. Therefore the ME analyst needs to use care in setting up the simulation model so it optimizes the results based on both criteria. There is a point at which the cost of adding another resource can no longer be justified by the diminishing incremental savings in waiting costs that are realized. Determine the right trade-off or balance between the number of resources and the waiting times so total cost is minimized.

14.12.22.2. During the constraining process, changes need to be accomplished systematically, one at a time. When evaluating the results of a simulation the ME analyst needs to analyze factors such as backlog, bottlenecks, WIP, cycle times, process time, throughput (capacity), move time, and resource utilization. The end result of optimization is a solution that gets close enough to required purpose and objectives within the time constraints for making a required decision.

14.12.22.3. Build Model. The current model is fully verified and validated before proceeding to build the future-state model. Then the current model can be copied and modified as needed to capture the potential process improvements in the future-state model.

14.12.23. Step 4: Simulation Model Verification and Validation. Do not neglect verification and validation. It is an ongoing activity that is accomplished throughout the study. A ME analyst may facilitate verification and validation by: (1) validating the study purpose, scope and scenario are consistent with the simulation model, (2) reducing the amount of complexity in the model, (3) using logic (coding) so it is readable and understandable, (4) using object-oriented techniques to organize the model data and (5) thoroughly documenting model data and logic. Common techniques used for verification and validation are provided in the following paragraphs:

14.12.24. Model Verification. The ME analyst carefully and systematically reviews the model to detect errors in data and logic. There are two types of bugs: syntax errors and semantic errors. Models with syntax errors either do not run or run incorrectly. These errors are caused by unintentional notations that are added, omitted or misplaced. Most simulation model software has some level of error detection, yet the ME analyst is responsible for eliminating these errors. Once errors are removed the model is debugged. Semantic errors associated with the ME analysts meaning or intent are more difficult to detect. These errors affect the behavior of the model and are most often associated with logic statement or numeric values being entered incorrectly. Focusing on the task at hand, eliminating distractions, and re-checking data entered into the model helps to reduce the number of semantic errors. Also, common sense and simplified mathematics helps with verification, along with the following:

14.12.24.1. Model Logic Code Review. The simulation model can be run using test data in either a bottom-up or top-down approach to check for errors or inconsistencies.

14.12.24.2. Reasonable Outputs. Check for reasonable outputs by replacing random times with constant times. This allows for precise prediction of results that can be compared to the simulation results.

14.12.24.3. Review Animation (when available). Used to verify whether the simulation operates the way the ME analyst intended. This technique is more useful in demonstrating that a problem exists as opposed to showing the details of the underlying problem. Some common symptoms include: (1) simulation running for several hours and then freezing, (2) work waiting when resources are available, and (3) the entity never flowing through a conditional routing, etc.

14.12.24.4. Trace and Debugging. Most simulation software provides feedback through trace and debugging functions. Trace messages describe chronologically what happens during the simulation, from one event to another. Debugging displays and steps the ME analyst through the logic used in the model.

14.12.24.5. Model Validation. The ME analyst needs stakeholder involvement to determine whether the model is a meaningful and accurate representation of the real system. This does not mean agreeing with the manpower results, it means agreeing with assumptions, process flowchart (including activities, decisions, etc.), model inputs, and model outputs.

14.12.24.5.1. The behavior of the simulation should correspond to the actual process being modeled. While there is no single test or checklist of tests to assure validation of the model, the ME analyst should challenge every input and question every output for logic and reasonableness. Some techniques are statistically oriented, while others are subjective. Many of the techniques used for verification should be used with the stakeholder's involvement. The ME analyst makes conclusions on the accuracy of the model through use of available evidence and a combination of techniques. Some techniques that may be used are:

14.12.24.5.2. Compare the results of the simulation model with the actual system, other models, or modeling techniques, for example Queuing. Good operator timing is also a useful technique in model validation.

14.12.24.5.3. Conduct extreme condition tests by increasing or decreasing key input data.

14.12.24.5.4. Use knowledgeable stakeholders to determine whether the system behavior seems reasonable.

14.12.24.6. Compare with historical performance data.

14.12.24.7. Perform sensitivity analysis to determine the effect changes to the input values have on the model's behavior and outputs. What is the effect on the model when variables deviate from expected values and contribute the most to variability in the model outputs?

14.12.24.8. Show stakeholders the animated model with dynamic counters and output statistics to determine validity of the model behavior.

14.12.24.9. Validation is accomplished to mitigate risks associated with making decisions based on the model. As with any type of modeling effort, there is a point of diminishing returns resulting from continued validation.

14.12.24.10. The model should be maintained to reflect the current system and requires continued validation. A method to maintain model validation is to deny model users (manpower and functional personnel) access to the data model. However, users may be provided a custom interface that allows them to enter limited data sets (i.e. WUCs and/or base names), run the model, and receive an output report that provides FTEs required.

14.12.25. Step 5: Conduct Experiments. Run the simulation for each of the scenarios to be evaluated and analyze the results. Analysis involves both judgmental and statistical procedures. The degree used depends on the problem to be resolved, the impact of resulting decisions, and the validity of the data. When developing experiments, keep in mind the purpose and scenario to avoid wasting valuable time. Before running the simulation model there are decisions to make concerning the modeling parameters to facilitate output analysis.

14.12.26. Replications. The use of distributions and variability in the model results in different output results for each replication. Each replication uses an initial seed value to generate the random numbers used in logic, activity times, and resource availability.

14.12.26.1. A replication is one independent run of the simulation experiment or one sample. By running multiple independent replications of the experiment the ME analyst is able to use the output responses to estimate expected or mean values. A good indicator of what can be expected to happen for subsequent replications is determined through a representative sample size.

14.12.26.2. When a representative sample has been observed, statistical methods may be used to estimate the expected or mean value of the model's output response. Two methods are used to determine the estimates: (1) point estimates (mean, standard deviation, queue time, or WIP) and (2) interval estimates (confidence intervals).

14.12.26.3. Use the sample size from paragraph 9.1.6 to determine the number of input locations for a manpower determinant study. Manpower assessments and MASs may require computation of the sample size, use spreadsheet data analysis tools or other statistical sources to compute the sample size.

14.12.27. Terminating and Non-terminating Simulation. Determining experiment procedures is dependent on whether the simulation is for a terminating or non-terminating system.

14.12.27.1. Terminating Simulation. Terminating simulation begins with a defined time or state and ends with another defined time or state. A designated point in time begins and ends a simulation run. For example, the time military personnel flight customer service section opens (0730) and closes (1630). Prior to opening, no customers are in the queue (starts empty). The doors are locked at 1615 terminating additional arrivals; remaining customers are served and exit the system (queue empty). Another example would be at the end of a defined production period (weekly, monthly, or yearly). A state may be the number of parts in the system at the start of the workday or once the state value equals 200; the required number of components complete production. At the end of each cycle the system is emptied, statistics captured, and the next cycle begins.

14.12.27.2. Non-terminating or Steady-State Simulation. Non-terminating does not necessarily mean the system never ends, only that it could theoretically continue indefinitely with no statistical change in behavior. For example, travel vouchers being processed are reviewed and approved on a continuing basis throughout the year. The work center processes these actions on one Monday through Friday shift (0730-1630). At the beginning of the next day work continues where it ended the previous work day. The queue of travel vouchers to be processed increases or decreases each day based on the distribution of arrivals and the capacity of the resources. The steady-state period has approximately the same distribution of observation values.

14.12.28. Method for Experimenting with Terminating Simulations. This method focuses on production counts and changes in behavior over time. For example, what number of pharmacy technicians is needed throughout a day to minimize customer wait times? The peak customer queues may require four technicians, yet off-peak queues may only require two technicians. It typically would not be prudent to determine two technicians could keep up with the demand. That is, unless two technicians could wait on customers during off-peak hours while the other two do other required productive work, such as reordering pharmaceutical supplies. During peak hours all four can wait on customers. Statistics need to be gathered on performance measures of successive intervals during the period. Three issues should be addressed for terminating simulations:

14.12.29. Initial Model State. The initial state is how the system looks at the beginning of the simulation. Referring to the example of the customer service section in **Chapter 14** paragraph 14.12.27.1., the initial state is no customers (entities) are in the customer service section (system) and the Personnel technicians (resources) are idle. This is the state until customers begin to arrive and resources are called for in the system logic. Some terminating simulations may begin with entities and resources being used. For example, to measure the time for everyone to exit an air show on base the initial state of the model would reflect a large number of entities (air show enthusiasts) in the system.

14.12.29.1. Terminating Event. An event that occurs and causes the simulation to end. This may be a certain time of day or when a condition is met. For the Customer Service section this is when the simulation clock is equal to or greater than 1615 and all customers have exited the system. Warm-up periods are not used with terminating simulations.

14.12.29.2. Number of Replications. Generally, begin with 10 replications and add replications until the desired confidence interval is met.

14.12.30. Method for Experimenting with Non-terminating Simulations. Generating meaningful outputs for non-terminating simulations are somewhat different from terminating simulations. Three issues need to be addressed for non-terminating simulations.

14.12.30.1. Warm-Up Period. Systems typically do not start empty. Therefore, a warm-up period is inserted before statistics are captured; otherwise bias may be captured in the results. Below are some methods that may be used to estimate the warm-up period.

14.12.30.1.1. Run a preliminary simulation of the system with 10 replications, average the output values at specific simulation times across each replication, and observe what time the system reaches statistical stability (flattened or repeated pattern emerges). Plotting the data points helps with identifying where warm-up ends and statistics may be gathered for a steady state.

14.12.30.1.2. When the data points are erratic, record the model's output response for a queue's average content during a defined time period and average the output values from each time period across the number of replications. Another approach is to use a moving average.

14.12.30.2. Sample Observations. One method that may be used after determining warm-up and run length is to run each replication of the model independently to determine sample observations. Another method is to use statistics from separate periods within long simulation runs.

14.12.30.3. Simulation Run Length. Determining the simulation run length is quite simple for a terminating simulation because a natural event or time point defines it. However, for a non-terminating simulation this determination is more difficult, as the system could run indefinitely. Determining the run length depends on the interval between the least frequently occurring events, assuming multiple replications are used.

14.12.31. Comparing Systems. Simulation does not solve a problem, but it merely provides a means to evaluate proposed solutions. Simulation facilitates the comparison of two or more alternate designs to a system to identify the best one based on performance measures. Careful analysis is required to ensure differences in observations are based on actual differences in performance, not statistical variations. Alternate configurations or operating policies may be evaluated by performing multiple replications and comparing the results. Hypothesis testing can be used to make these comparisons. In frequency probability, these decisions are almost always made using null-hypothesis tests. One use of hypothesis testing is as a tool to help decide whether experimental results contain enough information to cast doubt on conventional wisdom. Another use is as a tool to analyze the result of all outcomes (experiments) to determine if that is causing the null hypothesis to be rejected in favor of the alternate hypothesis. The null hypothesis typically proposes a general or default position. The following steps are used in hypothesis testing: (1) formulate a hypothesis about what design or operating policies work best, (2) set-up an experiment in the simulation model, (3) test the hypothesis through multiple replications of the simulation and (4) draw conclusions about the validity of the hypothesis.

14.12.32. Simulation Optimization. Optimization uses different combinations of values for the variables to provide the optimal output. For example, how many traffic lanes and entry controllers are needed to maximize traffic throughput at the main gate on weekdays from 0630-0830.

14.12.32.1. Some simulation software requires the ME analyst to manually build and evaluate each experiment, while other software automates the running of experiments after the ME analyst has identified decision variables (parameters). Parameters are those values that can be adjusted by management (number of maintenance bays, number of front-end loaders, or number of pharmacy technicians). The following steps help guide optimization efforts:

14.12.32.1.1. Decision Variables. Identify all decision variables associated with system outputs, then define the numeric value (real or integer) and its lower and upper bounds. Include only those decision variables known to significantly impact the outputs and limit the range of lower and upper bounds.

14.12.32.1.2. Objective Function. From the main gate example above, the objective function measures the entity's (vehicles) throughput, enabling the maximum number of vehicles to enter the base while minimizing wait time, traffic lane congestion, and the number of entry controllers. The objective function measures are based on statistics collected on the experiment, along with reported data for the entity, resources, and variables. Objective functions should be very specific and use the minimum number of statistical data elements required to determine the optimal solution. Since an objective function is a random variable, initial experiments are conducted to determine the standard deviation (variability). A number of replications of the model are run to minimize variability until the estimate reaches a desired level of precision.

14.12.32.1.3. Evaluate Solutions. As a general rule, simulation modeling algorithms find better solutions with larger population sizes, however, larger populations increase the time needed to determine the optimal solution. Avoid bias by evaluating each potential solution to determine whether it supports the study's purpose and objectives.

14.12.32.1.4. Choose Solution. While a best solution may seem obvious, the ME analyst needs to evaluate all potential solutions, based on each one's utility as measured by the objective function. Select the highest rated potential solutions and run additional experiments and/or replications as needed. Sort and graph results to assist in interpreting the data and to better understand how the system behaves. Determine the optimal solution by analyzing the potential solutions meeting the study purpose and objectives and select the best one.

14.12.32.2. Ultimately, the ME analyst evaluates the potential solutions and identifies the optimal one based on the model's purpose and objectives.

14.12.33. Step 6: Present the Results. Present the findings based upon standard reporting procedures for a manpower determinant, manpower assessment, or MAS and make the appropriate recommendations. Simulation models provide various output reports, charts, and graphics that are statistically-based and may be used to support study assumptions and recommendations. In addition to the traditional components of a final report for manpower determinants, a simulation model requires three additional components: a change sheet and an automated application tool.

14.12.33.1. The scenario developed in step one of the simulation study that was coordinated with the functional community prior to model development.

14.12.33.2. The change sheet documents all changes impacting the coordinated scenario.

14.12.33.3. The automated application tool may be a spreadsheet, a protected simulation model, or a combination of the two allowing the base or MAJCOM manpower function to input WUC data and other data elements as required, run the model, and receive an output report showing manpower requirements by skill and grade. The application tool should also include any non-simulated requirements.

14.12.33.4. Updating Simulation Models. A significant reason for using simulation modeling is the ability to update a model without a complete rework of a study. The strategic vision is to update simulation models on a regular basis as a function changes. Manpower Requirement Squadrons are responsible for maintenance, request for AoA, and/or updates to models.

Chapter 15

LOGISTICS COMPOSITE MODEL

15.1. Tool Description.

15.1.1. The LCOM tool is a computer simulation and modeling tool primarily used to determine and validate a weapon system's logistics footprint (manpower, parts, support equipment, etc.). The detailed nature of LCOM and its sensitivity to input data changes makes it a critical tool essential for weapon system acquisition (F-22, CV-22, or joint strike fighter), and in validating proposals affecting reliability and maintainability improvements or modifications.

15.1.2. LCOM has the ability to quickly evaluate various "What if" scenarios regarding primary aerospace vehicle inventory (PAI) mixes, sortie rates, operational scenarios, maintenance support levels, maintenance policies, etc., and any potential impact on sortie generating capabilities and/or support postures.

15.1.3. LCOM studies can identify peacetime and wartime manpower requirements and are able to provide a more defensible budget position and allow for effective use of available resources.

15.2. Air Force LCOM Program Management Office (PMO) Responsibilities:

15.2.1. Develop, field, and maintain the software, tools, policy, and guidance required to quickly and accurately quantify minimum and essential direct manpower requirements for those functions being modeled and simulated using the LCOM software, integrating Air Force MEP policy and principles to the maximum extent possible.

15.2.2. Develop and implement LCOM Program policy, guidance, and standard processes for utilizing LCOM software and tools for manpower determination studies. Serve as primary point of contact for all matters concerning Air Force LCOM policy and processes. Identify and coordinate LCOM specific training requirements.

15.2.3. Develop program performance metrics to provide basis for process, software, and tool improvement and informed program decisions.

15.2.4. Ensures LCOM software and tools are maintained and documented in accordance with accepted software development guidelines.

15.2.5. Chairs the LCOM Requirements Board.

15.2.5.1. Ensures effective change and configuration management (version control) of LCOM simulation software and tools.

15.2.5.2. Creates a forum for direct, involved program management.

15.2.5.3. Provides an information forum to optimize LCOM analytical capabilities and training opportunities.

15.2.5.4. Provides a forum for defining and prioritizing future LCOM software and tool requirements and modifications.

15.2.6. Reviews, evaluates and approves all LCOM software and tool modification requests to evaluate benefit of change(s) and potential impact on determining and/or validating manpower requirements.

15.2.7. Directs implementation of LCOM PMO-approved software and tool modification requests and informs requestor(s) and user(s) of planned action.

15.2.8. Performs software functional testing on all software and tool modifications/updates prior to authorizing release.

15.2.9. Maintains and monitors a schedule of LCOM software and tool development activities.

15.3. LCOM Study Products.

15.3.1. LCOM Scenario Description. The LCOM study Scenario states study objectives as well as setting the ground rules of the study. The scenario also states whether historical maintenance data or predicted reliability and/or maintainability data can be used in the model. The LCOM scenarios are developed by the LCOM study team in collaboration with functional authorities and coordinated with the appropriate logistics, operations, and plans staff functional representatives to assure operational and maintenance concepts are accurately outlined in the scenario.

15.3.2. Scenario Requirements. Each LCOM study addresses all of the applicable operational environments, (i.e., peacetime, wartime, etc.) in the study and contain as a minimum the following information:

15.3.2.1. Define purpose and scope of study.

15.3.2.2. Identify locations to be used for failure data collections, field measurements, and data validation if required and the associated time periods.

15.3.2.3. Identify the environment being modeled, PAI, which work centers manpower requirements are being simulated.

15.3.2.3.1. Unless specifically waivered by AF/A1M, simultaneous models are built for the peacetime, split operations/Air Expeditionary Force (AEF), and sustained wartime environment for each mission design series (MDS) based on current deployment force presentation practices.

15.3.2.3.2. Distinct modeling may be required to replicate the way the annual flying program is actually executed (to include attrition overhead requirements, TDYs, maintenance recovery teams, OREs, flying hour restrictions, surges and other variables that drive deviations from the standard scheduled flying hours schedule) and are determined on an as-needed basis.

15.3.2.3.3. The finalized AFMD requirement is based on the most demanding scenario by work center; therefore, the final application may be comprised of more than one scenario within a specified location.

15.3.2.4. Identify the functional structure appropriate to the unit(s) under study to include the functional title and description.

15.3.2.5. Identify the manpower shift profiles for the environment under study, i.e., three 8-hour shift? Two 12-hour shifts? Monday or Friday coverage? Weekend coverage?

15.3.2.6. OJT Factor.

15.3.2.6.1. In an effort to standardize LCOM accounting for 3-level impacts to the simulated manpower requirement, a single OJT/upgrade training accounting process is used to derive the simulated manpower requirement for all active component maintenance. This method was originally approved by the Total Force Indicator Round Table to derive a more accurate training, peacetime, and/or AEF home station maintenance model. This method applies to all AFSCs equally in the model. It adds a probability that OJT is performed on a task, increases the time by a percentage and increases crew size if the crew size is one. The OJT task pool includes all work except high repetition general tasks (i.e. tows, engine runs, wash, jacking, Joint Oil Analysis Program, launch, recovery, refuel, defuel, loading).

15.3.2.6.2. The probability of occurrence is determined by using AFSCs under study to comprise the 3 skill level percentage determined from the most accurate data source.

15.3.2.6.3. The task time percentage increase uses the Total Force Indicator Round Table approved determinant of 40% until otherwise rescinded. Task crew sizes less than two have a trainer position added for training to occur or if the normal crew size would not be sufficient to properly train.

15.3.2.7. Maintenance policies and concepts that are to be modeled: 2-level maintenance? Limited back shop support? Cannibalization?

15.3.2.7.1. Crediting cannibalization (CANN) workload. AFI 21-101, Aircraft and Equipment Maintenance Management reads: "CANN actions may be necessary when a condition prevents the accomplishment of a mission and the required assets are not immediately available from supply. Prior to performing a CANN action, verify the required component cannot be sourced from LRS, tail number bin, or back shop. When authorizing a CANN, the expenditure of man-hours and potential damage to equipment need to be weighed against the expected benefit. High risk CANNs should not be performed unless priority aircraft are involved or lack of ready equipment impedes mission accomplishment." CANN is a documented and accepted practice; it is integrated into the models based on valid historical CANNed parts data.

15.3.2.8. Specify and describe en-route maintenance or maintenance repair teams if to be considered in the study.

15.3.2.9. End Of Runway (EOR). Workload associated with EOR activities are included in the simulation model and are based on specified airframe requirements. Methodology for simulation is further developed and evaluated to include: provide minimum manpower per shift for EOR operations; add simulated requirement to minimum requirement; apply conversion factor to determine total requirement. Total impact should be identifiable to ascertain the effectiveness of modeling the workload and its impact.

15.3.2.10. Programmed Flying-Hour Program

15.3.2.11. Description of mission or sortie to include (some used in peacetime studies only):

15.3.2.11.1. Aircraft type.

15.3.2.11.2. Mission name.

15.3.2.11.3. Percent of total sorties, by mission type.

15.3.2.11.4. Mean sortie length.

15.3.2.11.5. Ratio of day to night missions if applicable.

15.3.2.11.6. Flight size (maximum and minimum).

15.3.2.11.7. Multi Leg Mission information (if applicable)

Note: All references to the WMP-5 Average Sortie Duration and Sortie Rate should specify where they are derived from in the WMP-5, specifically Appendix K.

15.3.2.12. Probability and quantity of weapon expenditure, if applicable.

15.3.2.13. Any additional data considered to be pertinent to the study.

15.3.2.14. Supply Data (if applicable). Provide not-mission-capable supply rates if to be considered and a constraining factor in the study.

15.3.2.15. Support Equipment and Facilities (if applicable). Identify special equipment available at home or at deployed location if to be considered a constraining factor in the study.

15.4. Time Compliance Technical Order (TCTO) Workload. Due to the uneven nature of TCTO issuance and in conjunction with functional community perspective, workload associated with TCTOs currently is not included in the model. However, it is requested that the TCTO data be collected and document in a "historical capacity" to determine the impact this type of maintenance plays in day-to-day functioning to be revalidated for inclusion in future studies.

15.5. Data Base Development.

15.5.1. Preliminary Maintenance Data Analysis. Before starting work measurement activities for a LCOM study:

15.5.1.1. Acquire at least 12 months of historical maintenance data along with the corresponding operation data (fly-hours, missions, sorties) for the location(s), unit(s) or MDS(s) under study.

15.5.1.2. Process the collected data to produce the preliminary LCOM database. Review data to determine level of detail required for OA.

15.5.1.3. The use of automated data from the functionally mandated maintenance data source is vital to LCOM and should be used "as is" to the fullest extent possible. Adjustments are only made when errors are validated/documented using current ME techniques and SME input.

15.6. Simulation. The LCOM Analyst runs multiple simulations within multiple environments to determine the optimal manpower requirement.

15.7. LCOM AFMD development report and AFMD. AFMD development report and AFMDs are prepared and formatted IAW the approved template. The LCOM AFMD development report and AFMD is submitted for coordination and/or review to the appropriate logistics, operations, and plans staffs involved in the original LCOM Scenario review process.

15.8. LCOM AFMD Implementation. Upon implementation of all LCOM derived AFMDs, MAJCOMs must use the MSI "L" for simulated requirements only. (**T-2**).

15.9. LCOM Study Products. At the conclusion of the LCOM study, all LCOM study-related files and documents are provided to AFMAA for archival purposed and audit trails. These products include but are not limited to: original historical maintenance and operational data, initial dataset, Maintenance data, LCOM data files used to produce the model and the final copies of the approved scenario and final report.

Chapter 16

STAFFING PATTERN

16.1. General Concepts. Certain work centers do not require work measurement to develop all or part of a determinant. In these work centers, the objective of determining the manpower requirement can be met at less cost with acceptable validity by using functional models (**Chapter 18**), minimum manpower situation (**Chapter 17**), staffing pattern (including directed organizational positions), and IAF. Use these methods in combination with measured data.

16.2. Staffing Pattern. A staffing pattern recognizes long-standing use of manpower and standard operating procedures in a work center responsible for subordinate organizational elements. A directed organization position (for example, a commander) and the associated direct support position (for example, vice commander and secretary) are examples of a staffing pattern. The study team decides if a WLF is relevant when using a staffing pattern. The size of the organization, in terms of manpower requirements or the number of subordinate elements, may drive the size of the work center. Explain pattern variations between locations in terms of workload or conditional factors. A staffing pattern, used as the basis for a determinant, may result in a quantitative expression that is variable in terms of workload or may result in a constant manpower requirement for all applicable locations. The staffing pattern is normally used in work centers that command or manage two or more subordinate elements. Use the staffing pattern when these apply.

16.2.1. The work center is a specified element of a formal organizational structure approved by HQ USAF/A1M.

16.2.1.1. The work center is reasonably stable as shown by consistent use of manpower in terms of the number, AFSCs, and grades of personnel over at least a 2-year period.

16.2.2. Directed organization position specifies a fixed manpower requirement to fill a particular named assignment (that is, wing commander, installation commander, etc.). This requirement is essential to the existence of a work center and does not change regardless of increases or decreases in workload or changes in the MAF. The directed organization position is usually the result of a staffing pattern or OA study. The directed organization position requirement is dictated by the need for one to be on duty in a given office of responsibility even though the individual may not be continuously productive. The man-hours an office is manned are required man-hours. If a policy calls for several assistant personnel in a given office at a particular time, measure the assistants to validate the need. Do not conduct a measurement in the case of a stated two-man policy that is driven by security or safety reasons.

Chapter 17

MINIMUM MANPOWER, STANDBY DETERMINATION, AND MAN-HOUR SHIFT PROFILE ANALYSIS

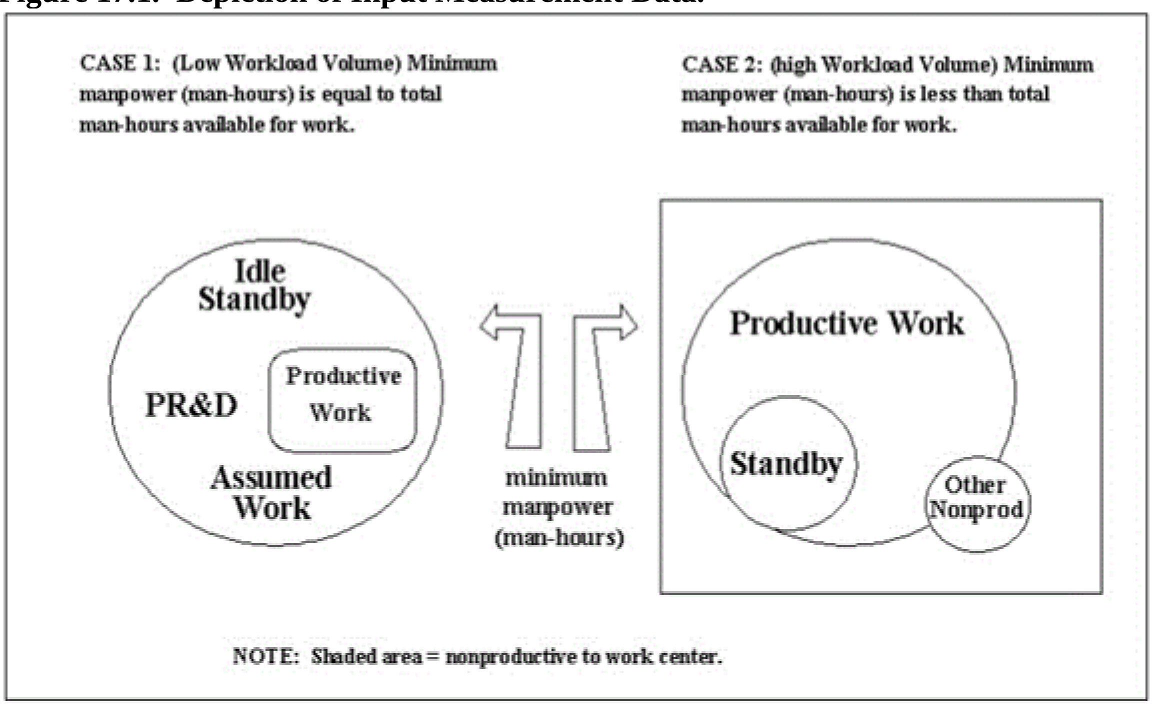
17.1. Minimum Manpower.

17.1.1. General Concepts. Importance of Minimum Manpower and Standby. Management decisions often produce minimum manpower levels that drive standby time. Since all standby time included in a manpower determinant is nonproductive and costly, it needs to be justified. Mission-essential standby time is allowed in manpower studies; however, to merely show the computations used to derive standby time is not enough. Validate management decisions leading to minimum manpower requirements and associated standby time.

17.1.1.1. Standby Levels. Standby, delay, and on-call time are defined in Attachment 1, Terms. Standby time can occur at any workload volume, and minimum manpower requirements may change from location to location.

17.1.1.1.1. Figure 17.1. Depiction of Input Measurement Data is a Venn Diagram depicting minimum manpower requirements at low (case 1) and high (case 2) workload volumes. In both cases, the minimum manpower requirements are considered constant and are represented by circles of the same size. In case 1, the minimum manpower requirement is equal to the total man-hours available to do work, that is, the universe is equal to man-hours required by minimum manpower requirements. Standby is the difference between man-hours required by minimum manpower and man-hours required by productive work.

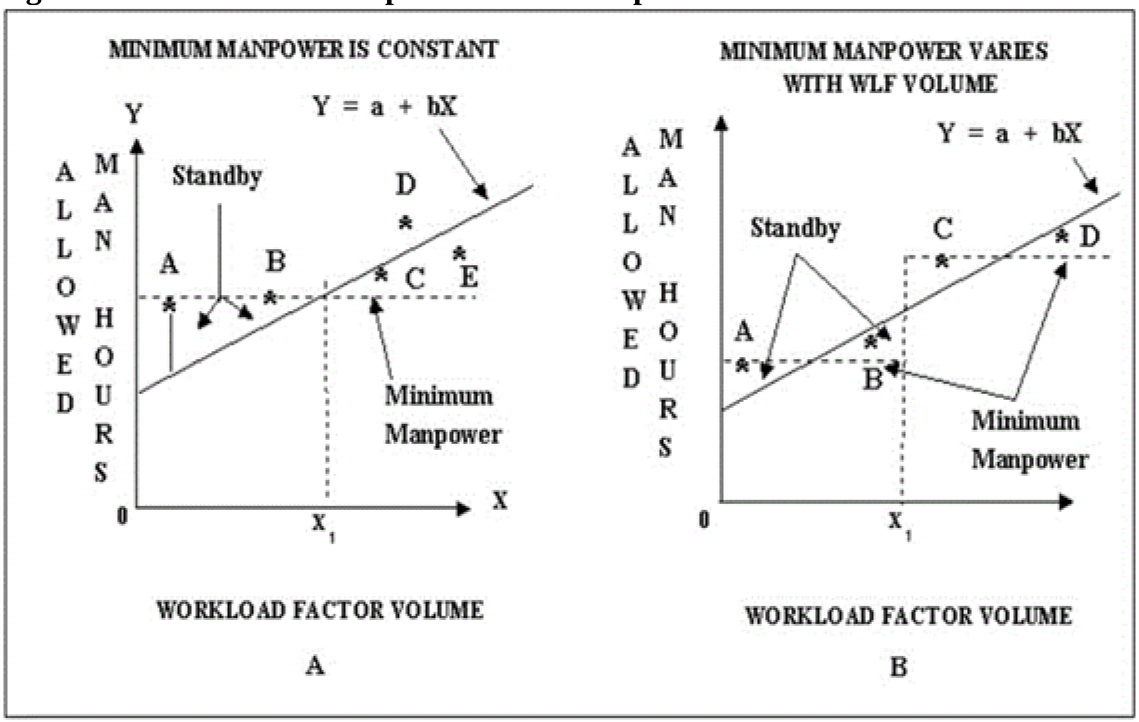
Figure 17.1. Depiction of Input Measurement Data.



17.1.1.1.2. In case 2, Figure 17.1, the minimum manpower requirement is less than total man-hours available for productive work. That is, the universe is equal to total hours available to do productive work. Derivation of standby in this case is more difficult.

17.1.1.1.3. In situation I, bases A and B whose workload volume is less than Xi, represent a case 1 situation. Bases C, D, and E whose workload volume is greater than Xi, represent case 2. For case 1 (bases A and B), derive standby time as shown in the previous paragraph. At bases C, D, and E, however, this procedure cannot be applied. In situation II, bases A and C represent a case 1 situation.

Figure 17.2. Minimum Manpower Relationships.



17.1.1.2. Minimum manpower requirements may be constant for each shift (Figure 17.1 and Figure 17.2, A, show this condition), or may vary with workload volume. Figure 17.2, B, shows minimum manpower at two levels: one for workload volumes less than Xi, and one for workload volumes greater than Xi. This situation is possible, for example, in an aircraft loading operation where a second load crew is needed to meet specified turnaround or ground time. Note in Table 17.2 bases A and C on the chart show varying amounts of standby time. The standby time is derived and computed as part of the allowed man-hours. It is not dependent on the regression line.

17.1.1.3. When the regression equation excludes standby time, a particular location may not have enough man-hours to cover the directed standby requirement. This location would receive credit for either the computed man-hours or measured man-hours (work center man-hours plus standby), whichever is greater. This standby time is referred to as derived standby. Document the minimum manpower condition in the application instructions in the manpower determinant.

17.1.2. Observations Regarding Standby Time.

17.1.2.1. Minimum manpower requirements may be the same at all locations or may change with workload volume.

17.1.2.2. Identify minimum manpower requirements by MEP work measurement methods if levels of service are properly defined before measurement.

17.1.2.3. Allow only standby necessary for mission accomplishment.

17.1.2.4. Reduce standby time by transferring productive work to replace measured standby man-hours.

17.1.2.5. Classify standby work inherent in one's assigned duty (for example, a craftsman continuously observing instruments) as productive work.

17.1.3. Rationale for Minimum Manpower. Contributing Factors. Numerous factors contribute to establishing minimum manpower requirements. Some of these factors, often a result of management decisions, are:

17.1.3.1. Mission needs

17.1.3.2. Performance standards

17.1.3.3. Machine design

17.1.3.4. Facility limitations

17.1.3.5. Hours of operation

17.1.3.6. Shift size and necessity

17.1.3.7. Crew size

17.1.3.8. Post-manpower requirements

17.1.3.9. Safety

17.1.3.10. Security

17.1.4. Evaluating Minimum Manpower Requirements. Carefully check the need for minimum manpower. Question the basic need. Offer alternatives and clearly define the cost of such service. Study documentation contains rationale to justify minimum manpower requirements. After the functional OPR confirms minimum manpower requirements, quantifying standby time is generally straightforward. Reduce or minimize standby time through improved shift scheduling, reorganization, planning, and workload control techniques. MEP personnel should be ready to show the manager how to meet the needed performance standards with minimum standby time. When standby time is minimized, the total manpower requirement is also minimized.

17.1.5. Minimum Manpower Computations.

17.1.5.1. In those situations that meet the criteria, you can use the minimum manpower factor (MMF) method to develop a determinant. This method uses predetermined manpower factors to compute manpower requirements for an OPR-approved position. Compute the factor by dividing the man-hours for position coverage by the pertinent MAF times the overload factor (for military). Adjust the MAF to allow for additional man-hours associated with position coverage. These additional man-hours fall into two categories.

17.1.5.1.1. The first category consists of man-hours needed for processes that are done either before or after the position coverage starts. In the case of security police guard posts, for example, the security police officer gets a weapon and ammunition from the armory and attend guard mount before assuming the post. Likewise, at the end of the shift, the officer turns in the weapon and ammunition to the armory. The time associated with this work is in addition to the time needed for post duty and should be measured as such.

17.1.5.1.2. The second category of additional man-hours consists of recurring training time needed to keep an individual qualified to fill the position. This is training that cannot be received while the individual is actually on position duty. An example of this type of training is proficiency or refresher training needed by all security police officers such as weapons training. Before developing a special allowance, make sure such training has not already been credited in the MAF.

17.1.5.1.3. When additional allowances are given for these two types of position-related man-hours, derive the man-hours used in computing the allowances from work measurement. To compute required manpower, divide the position coverage in man-hours by the MAF times the overload factor. For example, a position requiring coverage 7 days a week (including holidays), 24 hours a day, by one individual generates a requirement for 730.464 monthly man-hours. If the work force is military, on a 40-hour workweek, the manpower requirement is 4.476 (730.464/(151.5 x 1.077)). However, if the work force is military on a 6-day, 60-hour workweek, the manpower factor is 2.971 (730.464/(245.9 x 1.012)). These numbers, 4.476 and 2.971, are MMFs. Standby time is normally an inherent part of positions based on MMF application, such as security police assigned to a base access gate and firefighters.

17.1.5.2. Use this equation to compute MMFs. Use continuous calculations, i.e., don't round until all calculations are done.

$$MMF = \frac{(Days/Wk)(Hrs/Day)(4.348\ Wks/Mo)(PQT)\ (Crew\ Size)}{\text{Man} - \text{hour Available Factor x Overload Factor}}$$

17.1.5.3. In certain situations, additional time is added to the MMFs, PQT and post related time (PRT). PQT is a constant man-hour requirement directed by higher HQ policy in addition to duties for a minimum manpower situation. The PQT is equal to 1.000 unless the work is not part of the duties for a minimum manpower situation. For example, if each person receives 2.50 hours per month of proficiency or refresher training, and training cannot be received while the person is on the job. PRT is constant man-hours required to be performed before and after the shift hours. PRT is used for Security Forces to arm and have guard mount before and after the shift begins. Compute the PQT and PRT using the following equation:

PQT/PRT = 1 + [T/((MAF-T))] **WHERE T = REQUIRED TRAINING HOURS**

17.1.5.4. If T = 2.5 and MAF = 150.7, then

$$PQT = 1 + \left[\frac{2.5}{(150.7 - 2.5)}\right] \xrightarrow{yields} 1.017$$

17.1.5.5. Furnish the MMF computations per paragraph 17.1.5.2 as backup.

17.1.5.6. Calculate the PQT for training.

$$PQT = 1 + \left[\frac{T}{(MAF - T)}\right] \xrightarrow{yields} 1 + \left[\frac{5.4}{(150.7 - 5.4)}\right] \xrightarrow{yields} 1.037$$

17.1.5.7. Since the MAF for a military 40-hour workweek is 150.7,

PQT = 1 + [5.40/ (150.7 - 5.40)] = 1.037

17.1.5.8. Apply this factor to the total man-hours required to fill the post, that is, to both the basic position coverage and the position-coverage associated work.

$$MMF = \frac{(Days/Wk)(Hrs/Day)(4.348\ Wks/Mo)(PQT)\ (Crew\ Size)}{\text{Man} - \text{hour Available Factor x Overload Factor}}$$

$$MMF = \frac{(7)(24)(4.348)(1.037)\ (2)}{(150.7) * 1.077} \xrightarrow{yields} 9.334$$

17.1.5.9. When determining MMFs for multiple posts of the same make-up in hours of operation, crew size, PQT, etc., compute the minimum manpower equation for a single post and multiply the result by the number of posts authorized for the function under study.

17.1.5.10. Document minimum manpower as follows:

17.1.5.10.1. When the minimum manpower computation is not the sole measurement method for the work center, compute the man-hours by multiplying the rounded minimum manpower requirement by the pertinent MAF multiplied by the overload factor.

17.1.5.10.2. When the minimum manpower computation is the sole measurement method for the work center, furnish only the MMF computation. There is no need to convert the rounded minimum manpower into man-hours.

17.2. Study Design.

17.2.1. A well-designed study accurately shows minimum manpower requirements and true standby time. The measurement plan tells how to measure minimum manpower requirements and how to identify standby time. Necessary standby man-hours cannot be identified during determinants development, when it is grouped in with other nonproductive categories of time and when the minimum manpower requirements have not been accurately documented.

17.2.2. Clearly define the method for measuring standby when the possibility of standby time exists. Use MEP standard data collection and work measurement procedures to identify standby; however, some innovation is needed with these methods. Do not simply state the queuing or shift profile analysis is used to quantify standby time; tell how inputs use these techniques. Standby time is discussed in conjunction with various data collection and analysis procedures in the paragraphs that follow.

17.2.3. Include standby time computed according to procedures of this section as input to regression analysis when developing the determinant man-hour equation. Build a variance for applicable locations if standby time does not exist at all locations.

17.3. Data Collection and Analysis Procedures.

17.3.1. Use a man-hour shift profile chart to aid in analyzing standby time when WS or queuing is used and standby time exists.

17.3.2. Queuing Analysis. Queuing data does not directly identify allowed standby time. The percentage of server time in productive direct work may be determined with the queuing utilization factor after an acceptable level of service has been determined (for example, the number of taxi drivers needed to give a 4 minute response time). Queuing also shows when servers are not busy, including standby time. Design the study to collect queuing data on standby time if queuing is used. Details describing queuing techniques are in **Chapter 13.**

17.3.3. WS.

17.3.3.1. Identify standby time during WS observation rounds when minimum manpower requirements are previously defined. For example, suppose a finance office requires customers with pay inquiries be waited on within 30 min of customer arrival. It has been predetermined two finance clerks are necessary to give this level of service at the finance counter between 0900 and 1500.

17.3.3.2. Make provisions to isolate and identify the required standby time when the work sampler knows this information before the study begins. On each observation round, the work sampler records each worker in the respective process. The observer may enter a maximum of two standby tallies during each observation round but this would occur only if both service clerks were awaiting customers.

17.3.3.3. Use standby time derived in this manner to show management the manpower cost of providing this level of service. Analysis of WS observation sheets and waiting time data (for example, the time finance customers actually wait for service) may reveal the specified level of service has been exceeded or a second server is needed only during peak periods, such as pay days.

17.3.3.4. Standby time collected in this manner represents adjusted or derived standby time required to support a predetermined level of service. Record it on an Input Data Computation, per Table 17.1. However, if the level of service is not clearly defined, it is impossible to identify whether the worker should be sampled as idle or standby. Build a man-hour shift profile chart to find required standby when this is the case.

Table 17.1. How to Prepare an Input Data Computation.

BOX	Enter
1	Appropriate title.
2	MAJCOM and the measurement location.
3	Date the form is prepared.
4A	Productive processes in the order listed in SWD, TOTAL DIRECT, TOTAL INDIRECT, and PRODUCTIVE TOTAL headings are also entered (See note 1).
4B	Process adjusted man-hours and the total from the WS Record.
4C	Monthly allowed man-hours, by process, from the Time Study Record.
4D	Monthly allowed man-hours, by process, from the 1040, OA Data Worksheet, for activities that were measured by OA techniques.
4E	Monthly allowed man-hours, by process, from either 1040 or other supporting man-hour documentation for activities that were measured (determined) by minimum manpower, queuing, position manpower, or other specialized methods. Identify the types of measurements conducted in REMARKS (See note 2).
4F	Sum of entries in boxes 4B, 4C, 4D, and 4E by process to establish monthly allowed man-hours for the work center.
5	Total man-hours in boxes 4B, 4C, 4D, 4E, and 4F.
6	MAF. Use the military MAF times the overload factor for mixed work centers.
7	Results of box 5F divided by box 6.
8	Explanation of the method used in box 4E or any other pertinent data. Attach supporting documents and rationale as necessary.
Notes: 1) If standby time was sampled, enter "Standby Time" below the PRODUCTIVE TOTAL heading and explain in REMARKS, Block 8. Enter measured man-hours under the appropriate measurement method (Block 4B, 4C, or 4D) that was used to determine the time. If it was derived through other measurement methods, then enter time under "Other", Block 4E. 2) Reference specialized man-hour computations in REMARKS, Block 8, and attach supporting data.	

17.3.3.5. Show the standby time derived through this procedure on the WS Record. Do not level or apply allowances to this time. Use standby time to reduce personal and rest allowances for other productive process man-hours.

17.3.4. OA.

17.3.4.1. Include enough rationale in the final report to support the minimum manpower requirement when using OA as the primary work measurement method. It is not necessary to measure standby time if the minimum manpower requirement represents the total man-hour universe as in case 1, Figure 17.1.

17.3.4.2. Minimize and fully explain all standby allowed in the study when the total man-hour universe is greater than the minimum manpower requirement (case 2, Figure 17.1). Developing a man-hour shift profile chart from OA measurement may be difficult because process times are not associated with each hour of the duty day. Therefore, consider using short-cycle WS to collect man-hours for a man-hour shift profile chart. Use the WS as back-up for the OA man-hours.

17.4. Man-Hour Shift Profile Analysis.

17.4.1. Introduction to the Man-Hour Shift Profile Chart. Man-hour shift profile charts are an effective way to identify and minimize standby time. The charts aide the analyst in defining the minimum essential manpower levels by:

17.4.1.1. Leveling workloads to economize on nonproductive standby periods.

17.4.1.2. Identifying minimum standby time based on the accepted level of service.

17.4.2. Use of the Man-Hour Shift Profile Chart.

17.4.2.1. The man-hour shift profile chart helps functional managers realize economies of operation and helps MEP personnel build accurate manpower determinants. Use this process as a data analysis technique during management consultant studies or with other data collection methods during a manpower determinants study.

17.4.2.2. The man-hour shift profile is used by manpower management personnel to justify standby requirements. ME analysts use the chart to find the proper amounts of standby time to include in measurement reports when:

17.4.2.2.1. Queuing analysis is the primary determinant development technique, or

17.4.2.2.2. WS is the primary work measurement method and standby time cannot be distinguished from other nonproductive categories during the sampling period.

17.4.3. How to Develop the Present Man-Hour Shift Profile Chart.

17.4.3.1. Only construct the profile chart from data obtained during work measurement if certain provisions are taken during data collection. That is, collect data so it can be summarized by process on a stratified time basis (normally, hour-by-hour).

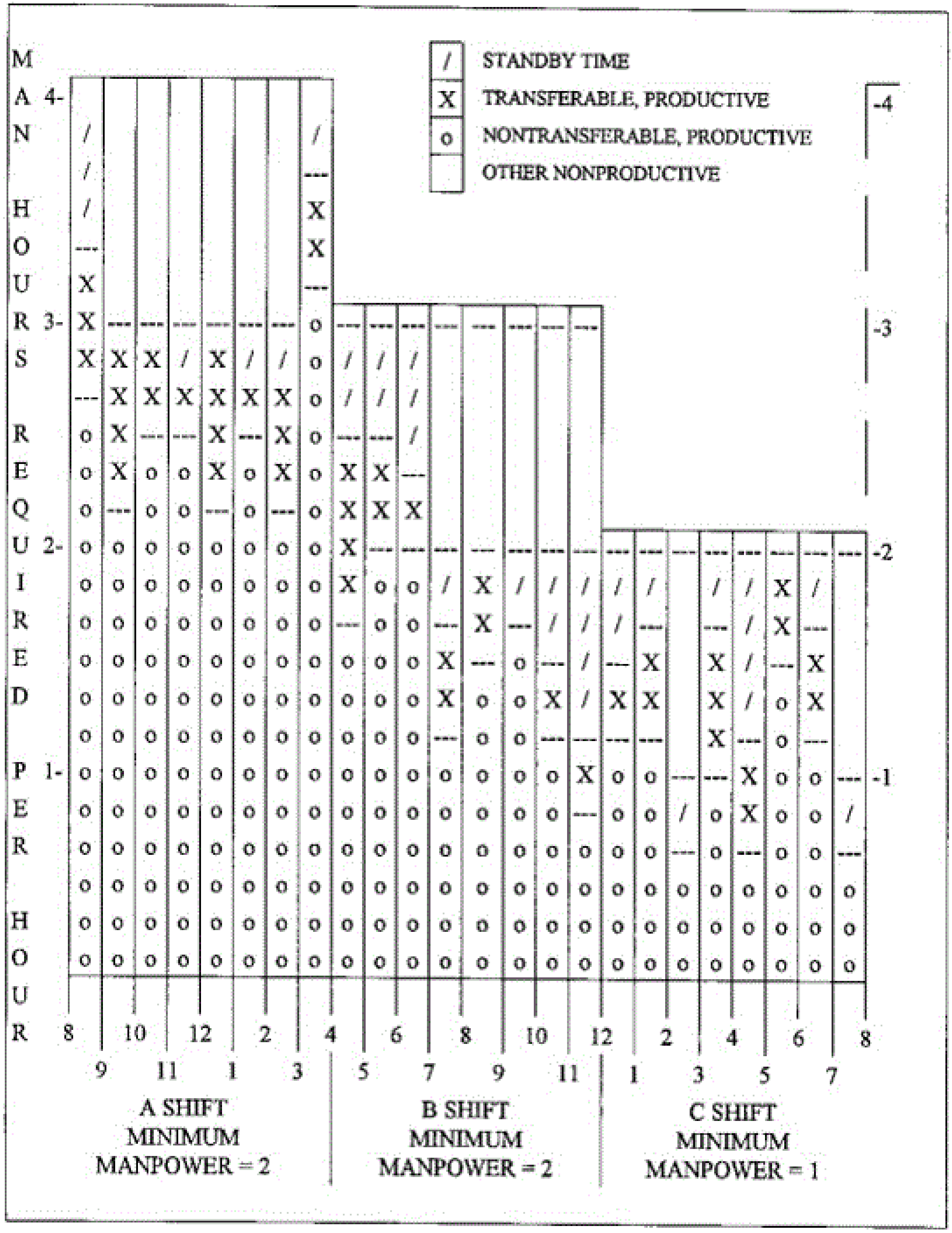
17.4.3.2. Identify work in the SWD as transferable and nontransferable when a man-hour shift profile chart is needed. This helps in making the shift profile chart show productive work for the stratified time increments.

17.4.3.3. The basic steps in developing man-hour shift profile charts are collecting necessary data, doing end-of-study computations, and constructing the chart. Derive the average man-hours for each hour of the day that are used in the profile chart from queuing analysis or from WS data. When using the shift profile chart to minimize standby time, make sure the sample size is large enough to support recommendations based on the profile chart. The procedures for developing a shift profile chart using WS data follow:

17.4.3.3.1. Accumulate the transferable and nontransferable time on a daily basis for each hour or half-hour of each shift. Average this time for the study period. Extract this time from the WS Recapitulation. On some occasions, a separate WS study may be needed to develop the profile chart. When this is so, take enough samples to reach desired accuracy and collect only the productive time. Classify the productive work into transferable or nontransferable work. Consult work center personnel to make this classification if the SWD has not been marked.

17.4.3.3.2. Construct the present man-hour shift profile chart on graph paper (See Figure 17.3) as follows:

Figure 17.3. Man-Hour Shift Profile, Present.



17.4.3.3.3.1. Identify average man-hours per hour on the vertical axis.

17.4.3.3.3.2. Identify each stratified period for each shift (hour or half hour) on the horizontal axis.

17.4.3.3.3.3. Extend a vertical line downward from the duty hour corresponding to each shift change, and state the minimum manpower requirement for that shift.

17.4.3.3.3.4. Plot, from bottom to top, the average nontransferable and transferable man-hours computed for each stratified period.

17.4.3.3.3.5. Identify the nontransferable and transferable time within each stratified period. Colored pencils are helpful in this identification when the charts do not have to be reproduced.

17.4.3.3.3.6. Group the various periods that make up each existing shift. Find the largest requirement within each shift and extend a dark horizontal line over the entire shift.

17.4.3.3.3.7. Extend vertical lines from each stratified period up to the next whole hour above the plots for transferable time. When there is only nontransferable time within the strata, extend the vertical line from that plot to the next whole hour. The extended portion of the column is potential standby time. In most cases, the total man-hours per shift period include both potential standby time and other nonproductive time.

17.4.3.3.3.8. Prepare a legend for the chart identifying nontransferable, transferable, standby time, and other nonproductive time.

17.4.3.4. How to Analyze the Man-Hour Shift Profile Chart. Shift profile analysis can point out deficiencies in scheduling practices, or it can point out excessive minimum manpower levels. Further study of the actual shift profile chart may lead to additional benefits such as more efficient choices for shift hours.

17.4.3.4.1. ME analysts analyze the actual shift profile chart to find the proper adjustments to make to standby time before constructing the proposed shift profile chart. An analysis of the chart may show the need for overlapping or split shifts. Although split shifts are sometimes necessary, split shifts should be kept to a minimum. During analysis, remember:

17.4.3.4.1.1. An evenly spread workload often reduces manpower needs.

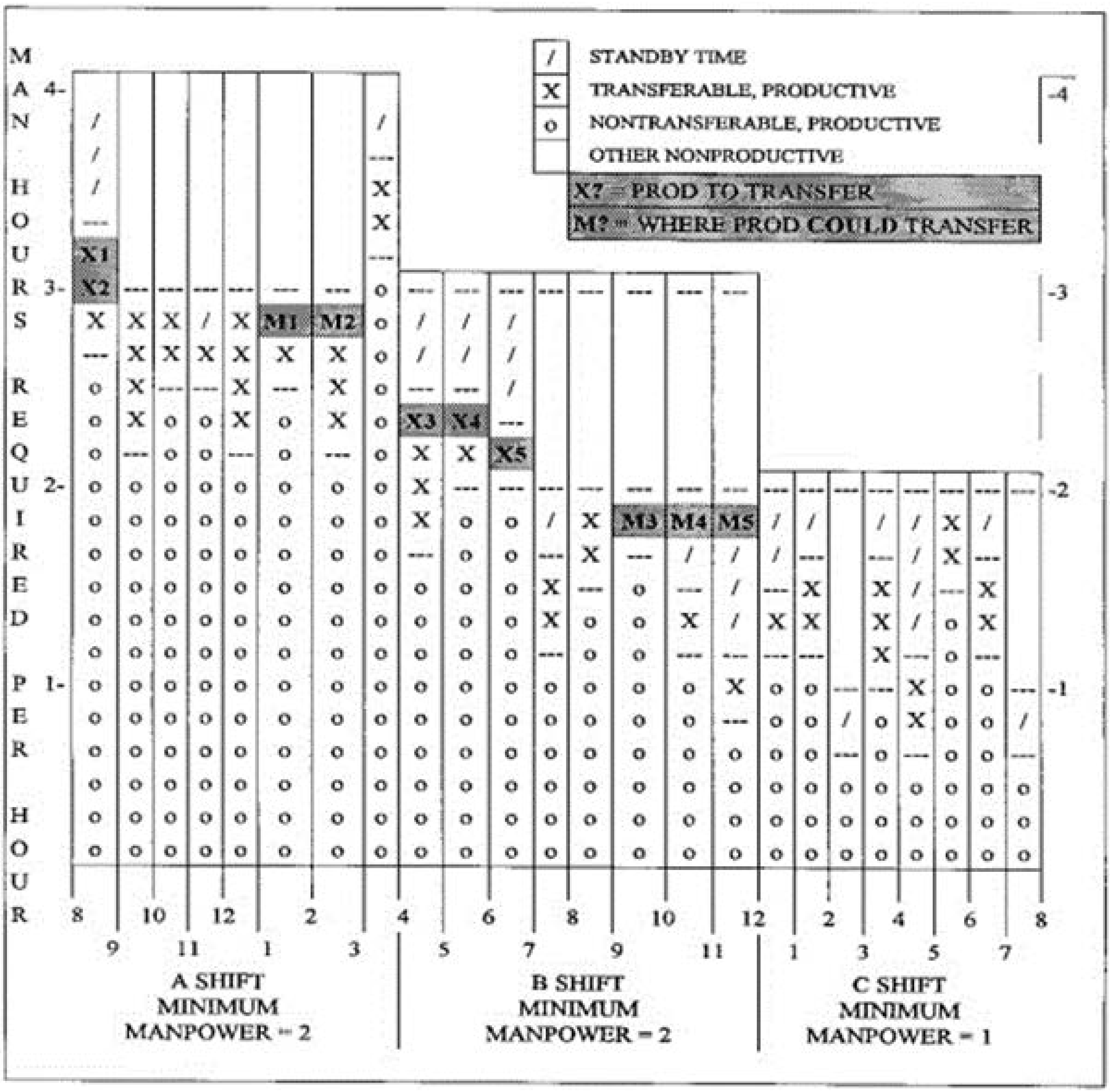
17.4.3.4.1.2. A related work center with standby man-hours may be able to accept some transferable work. This can take place only if the work can be done by the individuals receiving the work.

17.4.3.4.1.3. Adjustments to existing standby time should be coordinated with local OPRs. Adjustments are not to add man-hours that exceed the stated level of service.

17.4.4. Study teams analyze the charts sent by measurement teams. A large amount of standby time at one location may mean a variance is needed for that location. On the other hand, it may mean the ME analyst did not properly adjust the standby time. The study team does not adjust standby time without coordinating with the measurement team. This prevents dual adjustments of the same time. The study team does not average or prorate standby time during data analysis.

17.4.5. Figure 17.4 shows a properly constructed man-hour shift profile chart that identifies recommended time movements.

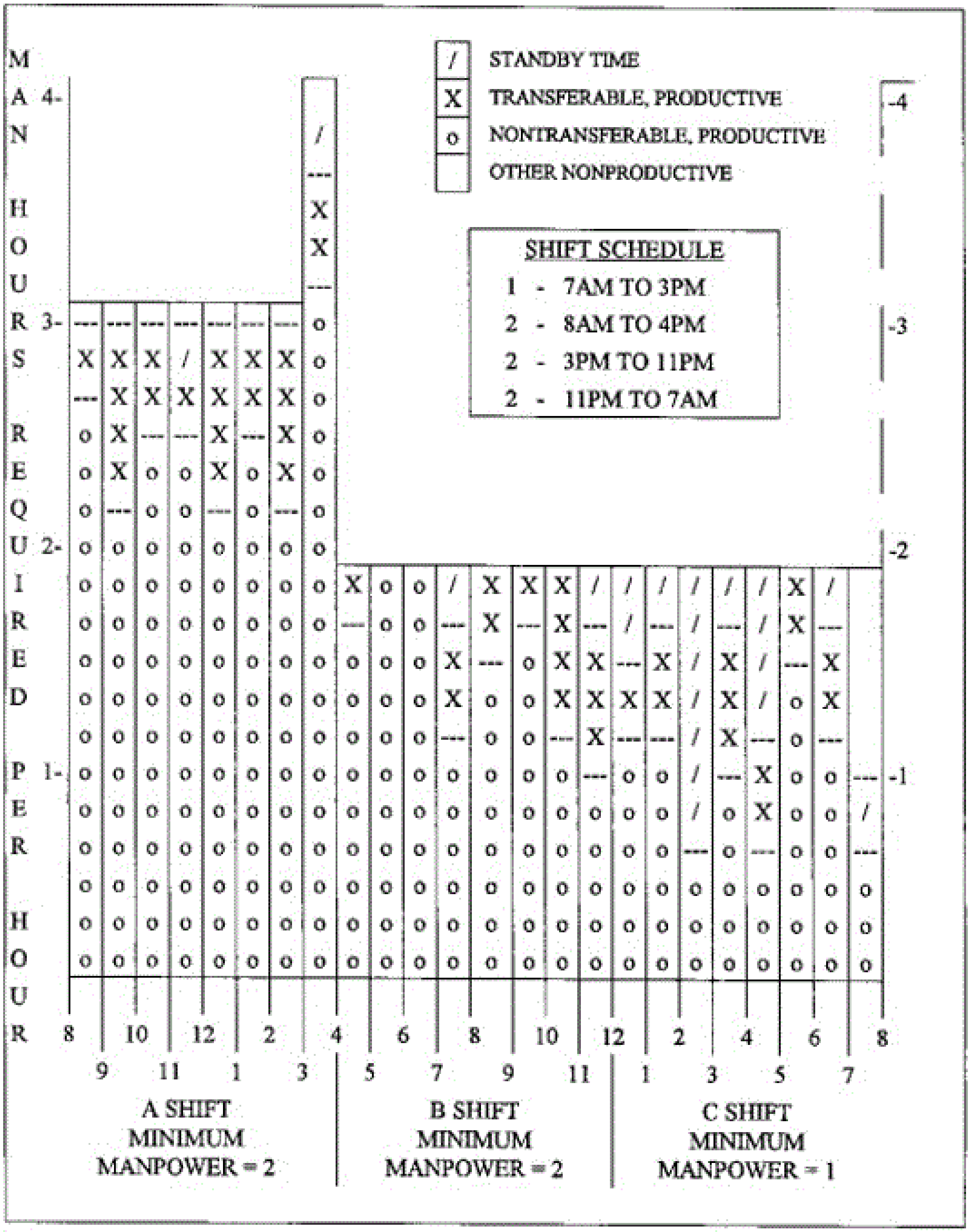
Figure 17.4. Man-Hour Shift Profile, Time Movements.



17.4.6. How to Develop the Proposed Man-Hour Shift Profile Chart. Construct a proposed shift profile chart when an improvement can be made to the actual shift profile. Construct this chart the same way as the present profile chart, but do it in conjunction with the analysis step. The proposed chart often uncovers faults with analysis of the present profile chart.

17.4.7. These steps tell how to develop a proposed profile chart (See Figure 17.5).

Figure 17.5. Man-Hour Shift Profile, Proposed.



17.4.8. Step 1. For purposes of this example, assume the prestated minimum manpower required for the A and B shift is two and the minimum manpower required for the C shift is one. The proposed chart accommodates this minimum manpower requirement.

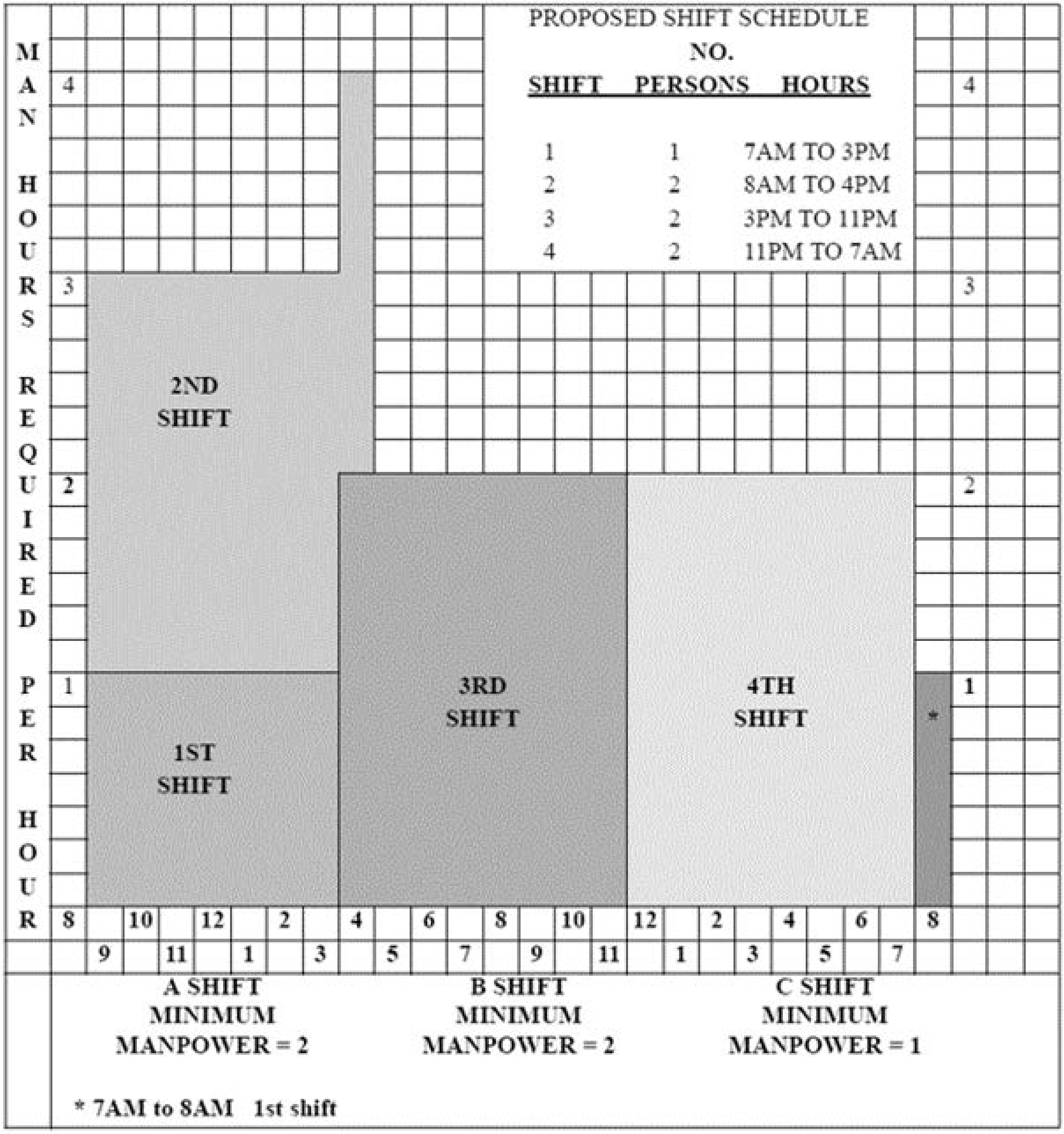
17.4.9. Step 2. Examine the present man-hour shift profile. In Figure 17.3, examination shows large standby and nonproductive time within shifts A and B. This is a logical place to look for improvements.

17.4.10. Step 3. Experiment with different arrangements by moving transferable man-hours into periods with large amounts of standby. Move the transferable time to nearby hours within the same shift if possible. The objective is to reduce the nonproductive time that results when each column on the chart is extended up to the total man-hours required per shift line.

17.4.11. Step 4. Experiment with different shift hours or with overlapping shifts to reduce nonproductive time. Consider this possibility when a large man-hour required per shift column exists near a proposed shift change period. Figure 17.6. Man-Hour Shift Profile, Proposed, shows where transferable man-hours were moved within the same shift. Figure 17.6, Proposed Shift Schedule, shows how overlapping shifts were used to reduce man-hours required per shift.

17.4.12. Step 5. Compute the derived standby time from the proposed chart.

Figure 17.6. Proposed Shift Schedule.



17.4.13. Comparison of the Present and Proposed Charts.

17.4.14. Compare the proposed chart with the present chart to determine:

17.4.14.1. If the proposed chart fully accounts for all transferable and nontransferable time.

17.4.14.2. If minimum manpower requirements have been satisfied for all shifts.

17.4.14.3. The extent of shift man-hour savings on the proposed chart.

17.4.14.4. A comparison of man-hour savings for the present and proposed charts (Figure 17.3 and Figure 17.5) is summarized in Table 17.2. This comparison shows a man-hour savings of 16 hours per day or 487.04 man-hours per month (16 x 30.44 = 487.04).

Table 17.2. Shift Comparison.

	PRESENT		PROPOSED		SHIFT
SHIFT	ACTUAL PERSONNEL	SHIFT HOURS	PROPOSED PERSONNEL	SHIFT HOURS	HOUR DIFFERENCE
A	4	32	2	16	- 16
B	3	24	2	16	- 8
C	2	16	2	16	0
D	-	-	1	8	+ 8
TOTALS	9	72	7	56	- 16

17.4.15. ME analysts use the proposed man-hour shift profile chart to:

17.4.15.1. Support the standby time included in the measurement input.

17.4.15.2. Justify the derived (reduced) standby time to the local OPR.

17.4.16. Wartime Operation Measurement. Functions having definite wartime capability requirements supported by Air Force policy are prime candidates for MMF manning. Examples of these functions include aircraft security, perimeter defense, and tactical air control system operations. Fully explain the use and justification of MMF manning. Quantify standby man-hours and use them to accomplish associated work of another work center or processes of work driven by other than MMF manning requirements. Consider using standby time between work centers when MMF manning is used.

17.5. Deriving Standby Using Minimum Manpower and Measured Man-Hours General Concepts.

17.5.1. Use an Input Data Computation Worksheet to account for man-hour data obtained from WS, OA, time study, and other specialized measurement methods. Use the form to add sampled standby time with measured data.

17.5.2. Follow the full instructions in Table 17.1 when completing the Input Data Computation Worksheet. The derivation of standby is shown in Table 17.3. In this figure, the difference between the total allowed time and the minimum man-hour requirement is standby time. Derive standby time for WS studies with the man-hour shift profile chart.

Table 17.3. Deriving Standby Using Minimum Manpower and Measured Man-Hours.

The following minimum manpower computation (based on the MMF equation) supports the derived standby time:

Shift A 0800-1600 5 days/week

$$\left[\left(5\frac{days}{wk}\right)\left(8\frac{hrs}{day}\right)\left(.4.348\frac{wks}{mo}\right)(1.00\,PQT\,*)\right]4\,(persons\ rqd) = 669.12$$

Shift B 0800-1600 7 days/week including holidays

$$\left[\left(7\frac{days}{wk}\right)\left(8\frac{hrs}{day}\right)\left(4.348\frac{wks}{mo}\right)(1.00\,PQT)\right]\ 2\,(persons\ rqd) = 486.98$$

Shift C 1600-2400 7 days/week including holidays

$$\left[\left(7\frac{days}{wk}\right)\left(8\frac{hrs}{day}\right)\left(4.348\frac{wks}{mo}\right)(1.00\,PQT)\right]\ 2\,(persons\ rqd) = 486.98$$

Shift D 2400-0800 7 days/week including holidays

$$\left[\left(7\frac{days}{wk}\right)\left(8\frac{hrs}{day}\right)\left(4.348\frac{wks}{mo}\right)(1.00\,PQT)\right]\ 2\,(persons\ rqd) = 486.98$$

Total Minimum Man-hours Per Month = 2130.06

Total Allowed Man-hours = 2032.73

Minimum Man-hours/Month =2130.06

Less Total Allowed Man-hours = <u>2032.73</u>

Derived Standby Time = 97.33

*Directed requirement factor (PQT) is a constant man-hour requirement directed by higher HQ policy in addition to duties for a minimum manpower situation. (The PQT is equal to 1.00 unless otherwise required)

Chapter 18

MANPOWER MODEL DEVELOPMENT AND SELECTION USING CORRELATION AND REGRESSION ANALYSIS

18.1. General Concepts.

18.1.1. General Uses and Principles of C&R. There are many uses for C&R analysis in the Air Force MEP including:

18.1.2. Development of a manpower determinant's man-hour equations using work measurement data.

18.1.3. Determination of FEEs and functional models using non- measurement data.

18.1.4. Evaluation of multiple potential WLFs.

18.1.5. Evaluation of differing levels of service (i.e., performance metrics) for varying levels of manpower.

18.1.6. A good manpower forecasting model developed using C&R provides a mathematical equation that provides an acceptably accurate prediction about the relationship between varying levels of workload and required man-hours for the function.

18.1.7. Although C&R may create the aforementioned manpower forecasting models, C&R statistics never prove a cause and effect relationship between the potential WLF and the function's required manpower. Rather, it is logic or science that ultimately proves a true cause (e.g., the function's WLF(s)) and the effect (e.g., the function's required manpower) relationship.

18.1.7.1. When using C&R analysis to develop a statistical manpower model, potential WLFs are identified and collected.

18.1.7.2. When C&R is not utilized (e.g., ratio unit times approach), WUs are identified and collected for use in developing the manpower determinant equation. If it is later determined during analysis that C&R is a better approach, a WU may become a viable WLF.

18.1.7.3. Although valid WUs and WLFs share many required attributes (as discussed below), the terms are not interchangeable.

18.1.7.4. A key distinguishing difference between the two terms is a WU is a direct product of an individual process, while a WLF represents a broader driver and/or indicator of workload (i.e., relates to more than just one process, if not all processes). Their correct use is dependent on how the manpower model is developed:

18.1.7.5. When using ratio unit times to develop the man-hour equation WUs are determined during the process flowcharting of the SWD.

18.1.7.6. When using C&R analysis, WLFs are identified and analyzed for potential use in the final man-hour equation.

18.1.7.7. Advantages and Disadvantages. The ME analyst weighs several factors when determining which man-hour equation development technique to use. Such factors include the future determinant's ease of application, cost associated with data collection, and the maintainability in future years.

18.1.7.8. WUs and Ratio Unit Times Techniques.

18.1.7.9. The advantages of using WUs and ratio unit times techniques to create man-hour equations are:

18.1.7.10. WUs are readily identifiable when the SWD is constructed properly.

18.1.7.11. Functional communities easily relate to WUs because WUs are something produced routinely.

18.1.7.12. Work centers often have systems in place to assist with data collection efforts.

18.1.7.13. These techniques can be used with any size population.

18.1.7.14. The disadvantages of using WUs and ratio unit times techniques to create man-hour equations are:

18.1.7.15. Work centers may often have many WU counts, making it difficult to apply the determinant.

18.1.7.16. There may be an increased number of computations due to a greater number of WU counts.

18.1.7.17. It is likely that the lack of predictability and programmability of these WUs does not assist in quantifying required manpower in the future. Management information systems or practices may not currently be in place to accurately capture WUs.

18.1.7.18. Advantages and Disadvantages of WLFs.

18.1.7.19. The advantages of using work load factors and C&R techniques to create man-hour equations are:

18.1.7.20. WLFs can greatly reduce the amount of data that is collected to apply the manpower determinant.

18.1.7.21. Programmable WLFs are easier to predict future required manpower.

18.1.7.22. The disadvantages of using WLFs and C&R techniques to create man- hour equations are:

18.1.7.23. ME analyst may not find a suitable WLF meeting minimum statistical test requirements.

18.1.7.24. Functional personnel may complain about the final man-hour equation not representing the function's workload or is not sensitive enough to mission changes to be a practical manpower determinant.

18.1.7.25. Cannot be used with less than 7 data points.

18.1.8. Identifying WUs. As such, WUs then are the quantifiable, direct outputs of work processes. Using process flowcharting and analysis, a SAT is determined for a specific WU by mathematically summing all the intermediate activity SATs within the process. See **Chapter 20** on Ratio Unit Times.

18.1.8.1. Key WU Attributes. Identify WUs for each defined work activity or process. To be of maximum utility, WUs should be:

18.1.8.1.1. Directly related to the time and effort spent on the associated process.

18.1.8.1.2. Economical and convenient to report and use.

18.1.8.1.3. Mutually exclusive, so no item is counted under more than one WU.

18.1.8.1.4. Open to audit, so the accuracy of a work count is readily verified by setting up a work count system or through existing internal work measurement programs or management information systems.

18.1.8.1.5. Readily understood by those who plan, schedule, and control the work and readily identifiable when seen produced.

18.1.8.1.6. Individually standardized in terms of the procedures needed for production.

18.1.8.1.7. WU Uses. Depending on the established or intended use of the WU, each of the above attributes assumes a varying degree of importance. The most important characteristic of a WU is it defines a specific amount of work; thus avoid vague WU titles, definitions, methods of counts, and defined sources of count.

18.1.9. Identifying WLFs. WLFs normally drive and can be logically related to major man-hour expenditures in a function. The ME analyst's ultimate objective is to select a potential WLF that is logical, collectable, relatable, programmable, and not within the control of the function.

18.1.9.1. Key WLF Attributes. The goal of C&R analysis is to identify the factor (or combination of factors) that when regressed with measured man-hours results in a statistically derived and statistically acceptable relationship (i.e., man-hour equation) accurately predicts required man-hours across a continuum of workload volumes. However, the process of C&R does not prove a cause and effect relationship rather, it is the ME analyst, using logic and science that determine the potential WLFs relatability (i.e., cause and effect) and predictability. WLFs drive the majority of the work center's man-hours.

18.1.9.2. Relatability. The potential WLF logically and statistically relates to manpower requirements to the extent any change in the value of the WLF produces a corresponding change in the man-hours needed to do the work, i.e., as the volume of work increases, so do required man-hours.

18.1.9.2.1. Relatability presents a difficult problem because accurate data for correlation analysis is rarely available early in the effort. Identification of potential WLFs should begin during Familiarization.

18.1.9.2.2. The selection problem is compounded by the relationship that often exists between accuracy and programmability. With a highly finite, precisely defined WU, there is a high probability of correlation, but the chance of predicting the future workload volume is usually small. As the definition of the WU is broadened into a WLF, the chance of accurately predicting the future volume increases, but the likelihood of getting an acceptable degree of correlation goes down.

18.1.10. Predictability. To make the determinant useful as a forecasting tool, the quantification of the WLF value should be programmable, i.e., is programmed in the USAF budget, or can reasonably be predicted for future time periods. Identify the predictability of a factor by examining available functional information.

18.1.11. Procedures for Defining Potential WLFs. WLFs should be both accurate and programmable. Factors which are also used for programming are preferred over those which are not. However, do not sacrifice accuracy for programmability in developing the determinant. When needed, a separate equation can be developed for programming manpower requirements. Identify potential WLFs using the following procedures:

18.1.11.1. First, identify external or work generator-type factors. Typical examples are: number of aircraft assigned; average monthly flying hours flown; or military population served; all of these examples also have the advantage of being programmable.

18.1.11.2. Second, refer to WUs identified during analysis of outputs of the work center (i.e., those associated with processes with the greater man-hour requirement). These are the internal or production-type WUs such as a jet engine overhauled, an airframe repaired, an item issued, or a form processed.

18.1.11.3. The ME analyst should then prepare a list of the potential WLFs identified from the above procedures, listed in the order of development (i.e., the external or work generator-type, first). Leave out any potential WLFs that are not readily identified or easily counted, and any internal ones that are relatively insignificant. To obtain valid counts for all the potential WLFs during measurement, the ME analyst should define the potential WLF:

18.1.11.3.1. Title. Briefly identify what is to be counted. Use singular noun form, verb past tense, should read a Vehicle Repaired not Vehicles repaired.

18.1.11.3.2. Definition. Define, in precise terms, the WLF. Vague definitions are not acceptable. From the title example above, what types of vehicles are to be counted? For another example, if population served is the potential WLF, clearly state whether the count includes tenants, on-base population, off-base population, transients, Reserve, National Guard, and/or Individual Mobilization Augmentees.

18.1.11.3.3. Source of Count. Specifically identify the source from which the count is to be obtained. This could include the report number, report title, and possibly column number or title. Include the date or edition of the report because the format of the source might change. It is critical all individuals collecting workload data use the same exact source. Input locations should contact the study team for guidance should any questions or problems arise.

18.1.11.3.4. Method of Count. Once the source of count has been found, how is the potential WLF counted? Is the WLF count a monthly average over the past 6 to 12 months? Is it a current account of PAI supported? Are there specific counts excluded? Bottom line: ensure the ME analyst can adequately count and report the correct WLF count.

18.1.11.3.5. Rationale. Include the reasons for selecting WUs or WLFs. Describe how and why the selected WUs or WLFs are expected to relate to the measured man-hours.

18.1.11.3.6. Once a WLF is selected for use in the manpower determinant, the preceding WLF Title, Definition, Source of Count, and Method of Count are revised as needed to ensure accuracy and placed in the manpower determinant.

18.1.12. Workload Data Collection and Analysis. When possible, work count procedures should call for a minimum of 6 months historical data, while 12 months of data are preferred.

18.1.12.1. Review and Analysis. The ME analyst reviews and analyzes the data for trends and/or peaks and valleys in volume, and validates as representative before used in further analysis.

18.1.12.1.1. Establishing a Work Count System. Ideally, there is an existing resource management systems, output measurement programs, or management information systems from which the data can be obtained. However, even existing reporting systems should be validated to ensure accurate workload information. When acceptable workload counts are not readily available, the ME analyst works with the functional manager or representative to establish a work count system.

18.1.12.1.2. The collection system should be established as early as possible in the development, and only address workload data essential to determinants development (and, possibly for future determinants application).

18.1.12.1.3. Establish safeguards (e.g., a random external audit of the workload reports) to minimize the possibility of a duplicated or missed count, or a non-representative count.

18.1.12.1.4. Potential Equivalent WLFs. To increase overall standard accuracy and ease of manpower determinant application, consider the use of equivalent WLFs. An equivalent WLF is used to get a count for similar work that has different workload content (i.e., SATs).

18.1.12.2. Consider the WLF "a vehicle maintained for a vehicle maintenance unit." To produce a more accurate accounting of the WLF the ME analyst may consider using equivalents to accurately portray the workload associated with the preventative maintenance on a sedan versus a truck.

18.1.12.2.1. Suppose, during work measurement, it was determined it takes 120 man-hours to service a truck compared to 100 man-hours to service a sedan. Since the vehicle mix may vary considerably from location to location, the use of vehicle equivalencies may be the correct way to calculate the accurate manpower for total vehicles maintained for any given installation.

18.1.12.2.2. The ME analyst can use the SAT relationship to establish a mathematical equivalency between truck and sedans, the following equality can be established.

$$\frac{120 man\ hours}{truck} = \frac{100 man\ hours}{sedan}$$

18.1.12.3. Cross multiply to get

*120man hours*sedan=100man hours*truck*

18.1.12.3.1. Dividing both sides by man-hours, to get 1.2 sedans = 1 truck

18.1.12.3.2. When this type of WLF is used, a baseline output is valued at one, (in this case the sedan is given a 1.0) and the other outputs are valued in relation to this baseline (for example, the truck could be given a 1.2).

18.1.12.3.3. The total WLF count is obtained by adding all equivalents (e.g., (10 sedans X 1.0) + (5 trucks X 1.2) = 16.0 total equivalents).

18.1.12.3.4. Identify potential equivalent WLFs early. Data collection should be designed to allow creation of equivalent values. Remember, the time value of the measurement should be the same for all vehicles used in the equivalent, and it should be equal to the baseline output (in this case the sedan). This is necessary because the WLF value is being adjusted to compensate for the differences in time needed to service the sedan and the truck.

18.1.13. The end result of C&R is only as good as the logic and data the analysis is based upon. The ME analyst's dedication to the fidelity of the input data is requisite for a good result.

18.1.14. The basic steps for developing regression equations are similar regardless of the final manpower model selected. However, C&R calculations can become more complex depending on equation form, and the number of potential WLFs regressed in the case of multivariate regression.

18.1.15. Although C&R analysis is truly two separate processes, these calculations are usually both performed to provide a more complete picture. (Note: Although the Air Force MEP has traditionally used the acronym C&R, in actuality, regression analysis is performed first with correlation analysis evaluating the resulting regression line's goodness of fit.)

18.1.15.1. Regression analysis involves the pairing of a dependent variable with an independent variable(s) to define a mathematical relationship (i.e., regression fits a line to the data that may be described mathematically, with an equation).

18.1.15.2. For example, this process involves pairing the measured and/or calculated man-hours (Ym) required on the vertical (or Y-axis) with the data of an independent variable on the horizontal (or X-) axis. (Note: In reality for multivariate regression, as more independent variables are added, multiple axes are paired with the Y-axis.)

18.1.15.3. The regression analysis ultimately yields a man-hour equation (Yc), in a linear or curvilinear form (See **Chapter 17** paragraph 17.1.18. for man-hour equation forms), that can then be used for the prediction of manpower requirements under varying workload within specified extrapolation limits. (See Section 17.3. on determining a manpower equation's extrapolation limits.) For example, a regression analysis might yield a man-hour equation:

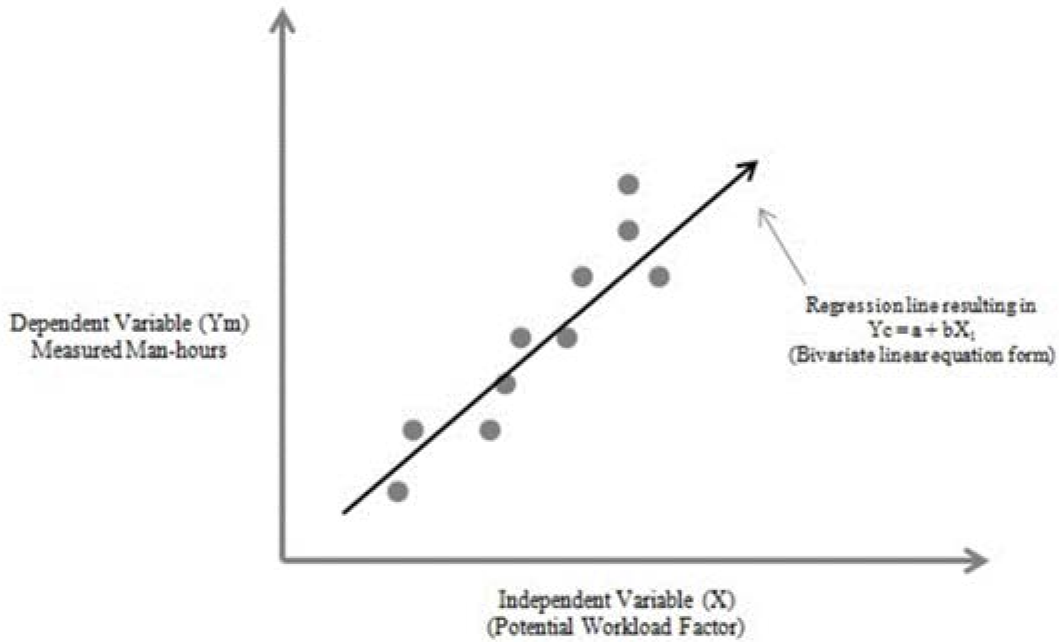
Yc = 28.6 + 104.6X1 where:
Yc = the regression equation's calculated required man-hours.
X1 = a WLF, such as PAI, supported by a work center.

18.1.15.4. For instance, in the case of a work center servicing 18 aircraft (PAI), this example man-hour equation would yield:

Yc = 28.6 + 104.6(18)
= 28.6 + 1882.8
= 1911.4 required direct man-hours for this work center scenario.

18.1.15.5. Figure 18.1 shows a scatter diagram with a regression line drawn to fit the paired data (X, Ym). **Note:** Although full time equivalents instead of man-hours can be used in the development of an equation, this approach is generally not recommended due to updates in MAFs that change the hours required to earn full time equivalents.

Figure 18.1. Scatter Diagram Pairing a Single Independent and Dependent Variable with Regression Line Shown.



18.1.15.6. Correlation analysis, on the other hand, is the process of calculating key statistics about the regression equation. These key correlation statistics and tests give the ME analyst an indication of just how good the regression equation predicts manpower requirements. Minimum correlation statistical requirements are discussed in **Chapter 18** paragraph 18.1.21.

18.1.16. Manpower Models Derived via Regression Analysis used in the Air Force MEP. Acceptable models resulting from a C&R analysis can be classified as one of the following:

18.1.16.1. Bivariate model (using a single WLF).

18.1.16.2. Multivariate model (using multiple WLFs).

18.1.16.3. Manpower models derived via regression analysis can be generally characterized as:

18.1.16.4. Linear model (an equation resulting in a straight line).

18.1.16.5. Curvilinear model (an equation whose function does not resulting in a straight line, i.e., the equation's line curves).

18.1.17. Finally, manpower models derived via regression analysis can be classified by the equation forms as:

18.1.17.1. Linear bivariate model (a general linear form).

18.1.17.2. Linear multivariate model (a general linear form).

18.1.17.3. Parabolic model (a general bivariate, curvilinear form).

18.1.17.4. Power model (a special bivariate form).

18.1.17.5. Ratio model (a special bivariate form).

18.1.17.6. Figure 18.2 thru Figure 18.5 show graphical views of the linear and curvilinear forms of a linear bivariate, parabola, ratio, power equation models (all using the same data).

Figure 18.2. Linear Bivariate Model Example.

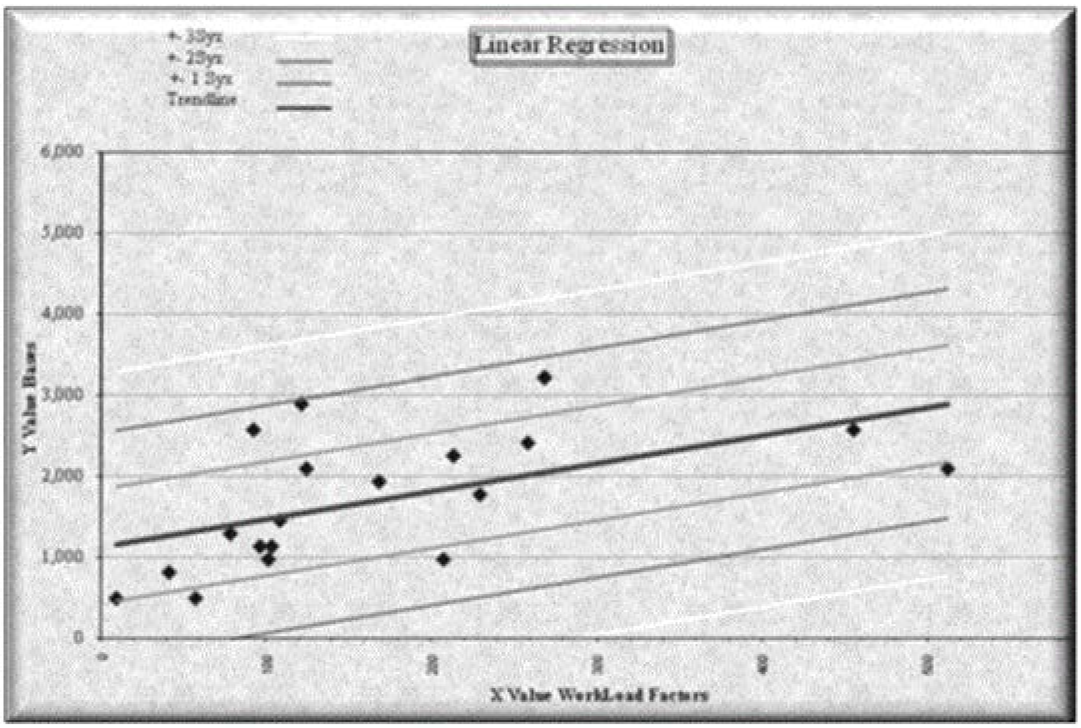


Figure 18.3. Parabola Model Example.

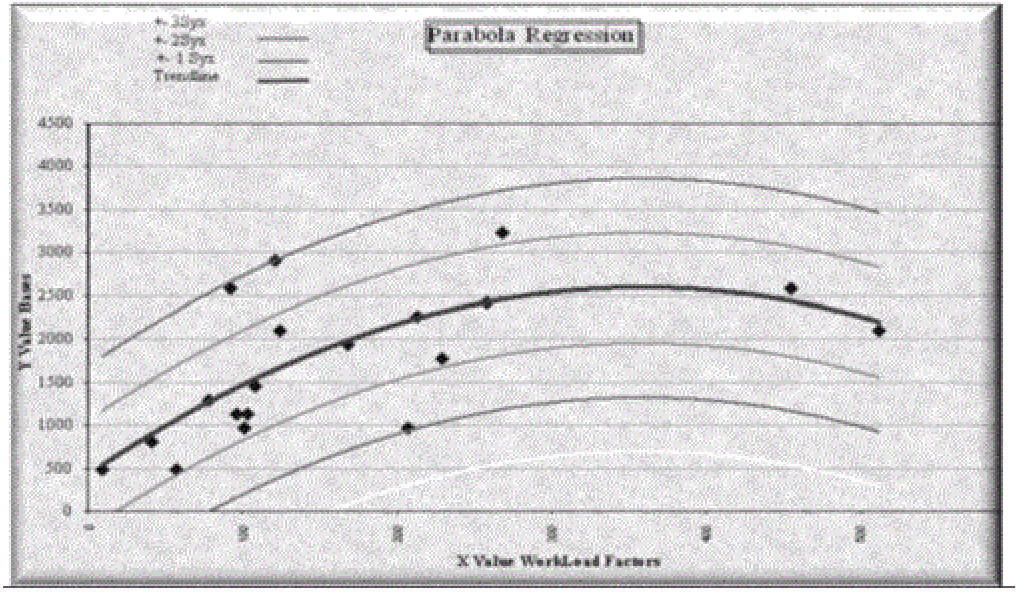


Figure 18.4. Ratio Model Example.

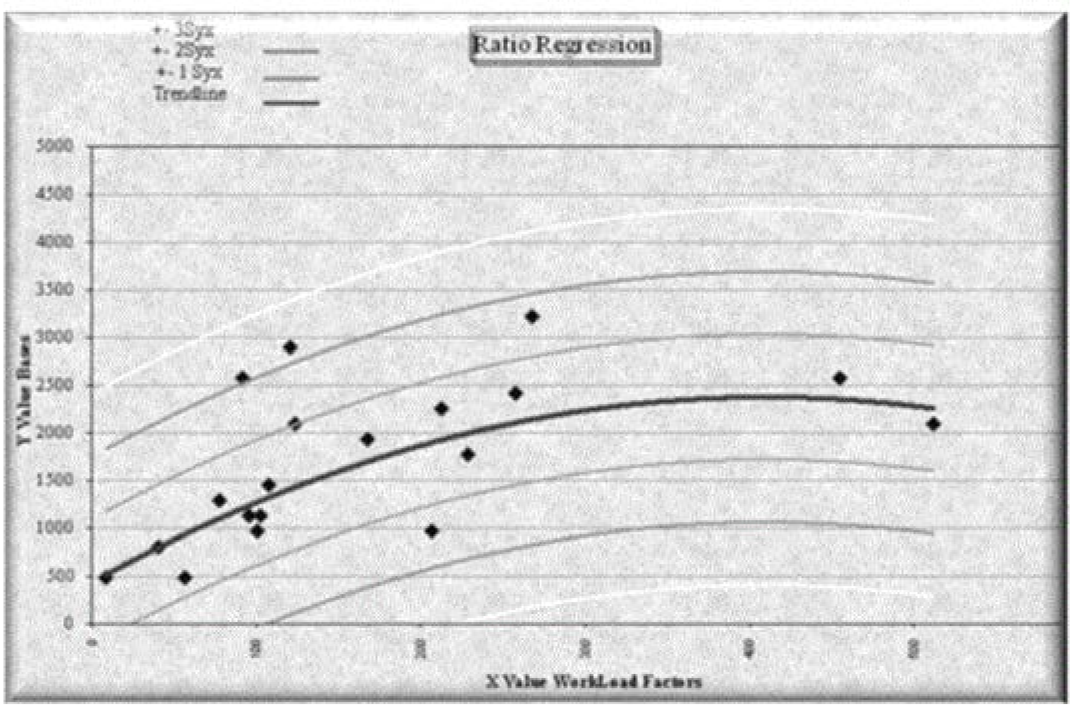
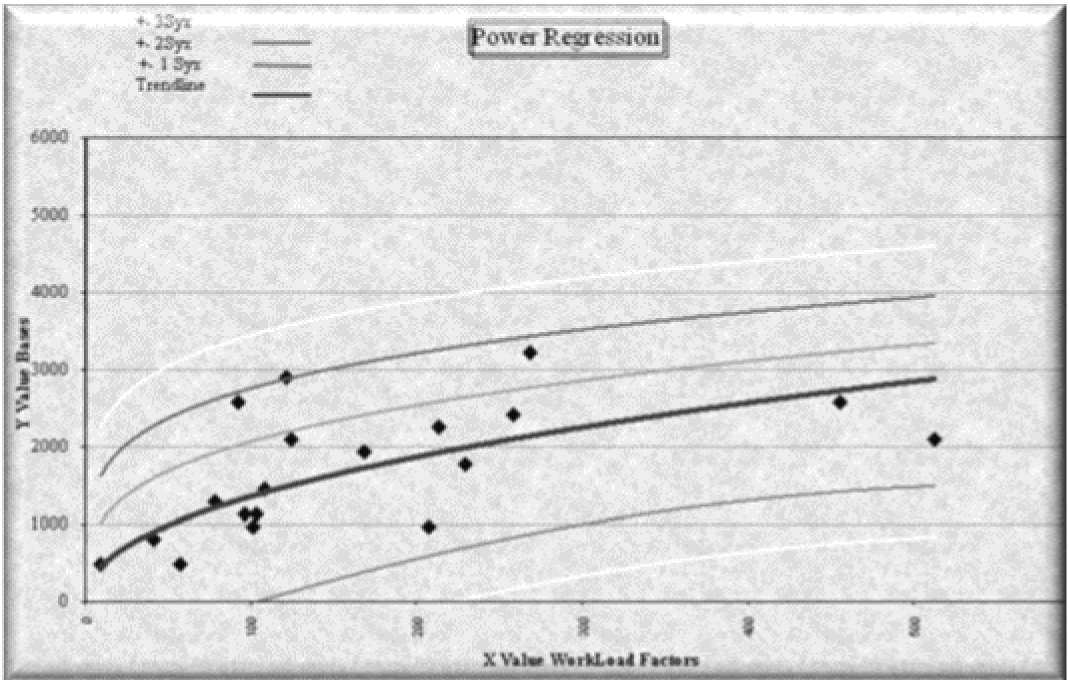


Figure 18.5. Power Model Example.



18.1.17.7. The general and special mathematical equation forms of the most common manpower models created by regression analysis are provided in Table 18.1. In each equation, the dependent variable (Yc) represents man-hours and the independent variables (X), or multiple XS (in the case of multivariate regression) represent WLF(s) volumes.

Table 18.1. General and Special Equation Forms.

General Equation Forms	
DESCRIPTION	EQUATION FORM
Bivariate Linear Model • Has two coefficients, "a" and "b" • Simplest and most direct relationship between the dependent and independent variable • Shows a constant slope (b) in a line	$Y_c = a + bX$
Multivariate Linear Model • Used when more than one independent variable is appropriate to create a useful manpower model	$Y_c = a + b_1X_1 + b_2X_2 + \ldots b_nX_n$
Special Equation Forms	EQUATION FORM
Parabolic Model • A relationship between two variables that allows for a change in the way X is influencing Y • Allows the line to curve up if the value of c is positive, or down if the value of c is negative • Has three coefficients; "a", "b", and "c"	$Y_c = a + bX + cX^2$
Power Model • An exponential curve that requires both the dependent and independent variables to be transformed • To make linear, transform the equation by taking the log of each side. The resulting equation becomes log Y = log a + b(log X).	$Y_c = aX^b$

18.1.17.8. Further Discussion of the Use of Special Equation Forms. The power curve, ratio curve, and parabola provides for manpower model to show a general deceleration in the rate (i.e., slope) at which manpower is increased for increased workload. In effect, acceptable curvilinear regression models show a certain economy of scale in a work center's required manpower as the WLF volume increases. While the ratio and power curves are legitimate mathematical forms, each cannot be directly compared statistically to the linear and parabolic forms because of the data transformations involved. These data transformations change the distributional properties upon which the statistical tests are based. Therefore, use the power and ratio models with caution and use when:

18.1.17.9. A parabola model form fits the data better than a linear equation, and the resulting parabola's apex is within the data's extrapolation range. In this case, since the parabolic model's apex occurs prior to the upper extrapolation limit (See Figure 18.6.), the equation's slope becomes negative; and thus required manpower illogically decreases as workload increases. In this case, one of the special equation forms may still represent the curvilinear nature of data in the same manner as the parabola but without the issue of the parabola model's apex.

18.1.17.10. A parabola fits the data better than a linear equation, and the apex is just outside the data range. Although the parabola does not now yield any illogical results one of the special curve forms may yet fit the data better, i.e., the special equation form's manpower requirement result makes more logical sense than the parabolic model's result.

Figure 18.6. Parabolic Equation with Apex within Extrapolation Limits.

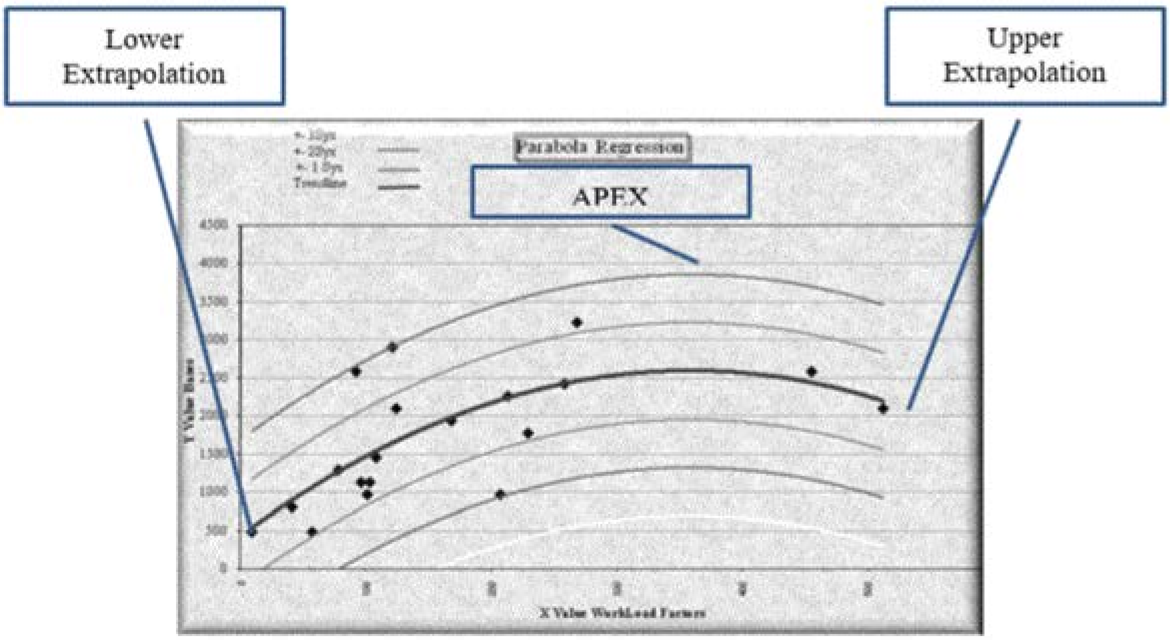
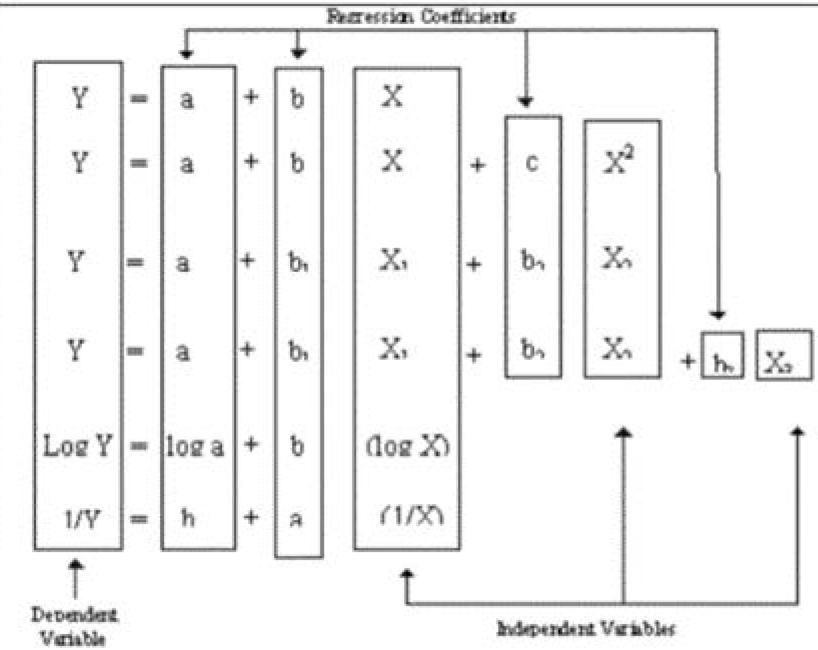


Table 18.2. Relationships Between Equation Forms and the Regression Analysis Terms.

MODEL FORM	TERMS USED IN REGRESSION ANALYSIS	VALUE OF m (Number of Regression Coefficients)
Linear		$m = 2$ (a, b)
Parabolic		$m = 3$ (a, b, c)
Multivariate - Example for 2 independent variables		$m = 3$ (a, b_1, b_2)
- Example for 3 independent variables		$m = 4$ (a, b_1, b_2, b_3)
Power (after transformation)		$m = 2$ (log a, b)
Ratio (after transformation)		$m = 2$ (b, a)

18.1.18. Understanding the Regression Coefficients. The regression coefficients, as shown in Table 18.1 for the different regression model forms, are the values resulting from regression analysis computations to form the regression equation. Table 18.2 shows a synopsis of the various equation forms discussed to this point, with the last column showing the total number of coefficients realized for the bivariate linear, parabolic, ratio, and power curve as well as two examples of a multivariate linear form. (Note: Any given multivariate form could have more than three X variables if the ME analyst decides to explore more than three potential WLFs.)

Understanding the number of coefficients (“m”, as shown in the last column) in a given regression model form becomes important later in this chapter when C&R calculations are discussed.

18.1.19. The “a” value represents the point where the regression line crosses the y-axis. As such, the “a” should never be referred to as the going-in cost or fixed man-hours. Rather, the “a” value is simply the y-intercept determined through regression computations and helps account for some of the unexplained variation within the equation.

18.1.20. Each coefficient (b-value) of the individual independent variable(s) represents an amount of influence from its corresponding X-variable given that all of the other independent variables (Xs) are held at a constant value. For example, the coefficient value b1 for X1 in the bivariate equation Yc = a + b1Xl would not have the same coefficient estimated for the same X1 in the multivariate equation Yc = a + b1X1 + b2X2, since the additional WLF (X2) now comes into consideration.

18.1.21. Minimal Statistical Criteria to Meet for Manpower Model Developed Using C&R. Manpower determinant equations developed by the ME analyst in the Air Force MEP using regression analysis must meet certain minimum correlation statistical requirements. (**T-2**) Discussion of these test statistics and the calculations are discussed later in this chapter. These minimal requirements are shown in Table 18.3. Additionally, the ME analyst must ensure each manpower equation meets the Realistic and Economic Test criteria as shown in Table 18.4 (**T-2**)

Table 18.3. Minimal Statistical Criteria for Equations Developed Using C&R.

Statistical Criteria	Minimum Value to Meet
Coefficient of determination (R^2) (Used for Bivariate Equations-All Forms)	$R^2 \geq .70$
Coefficient of Determination (Multivariate Equations—Adjusted r-squared (R^2)	$R^2 \geq .70$
Coefficient of Variation (V)	$V \leq .25$

Table 18.4. Realistic and Economic Criteria.

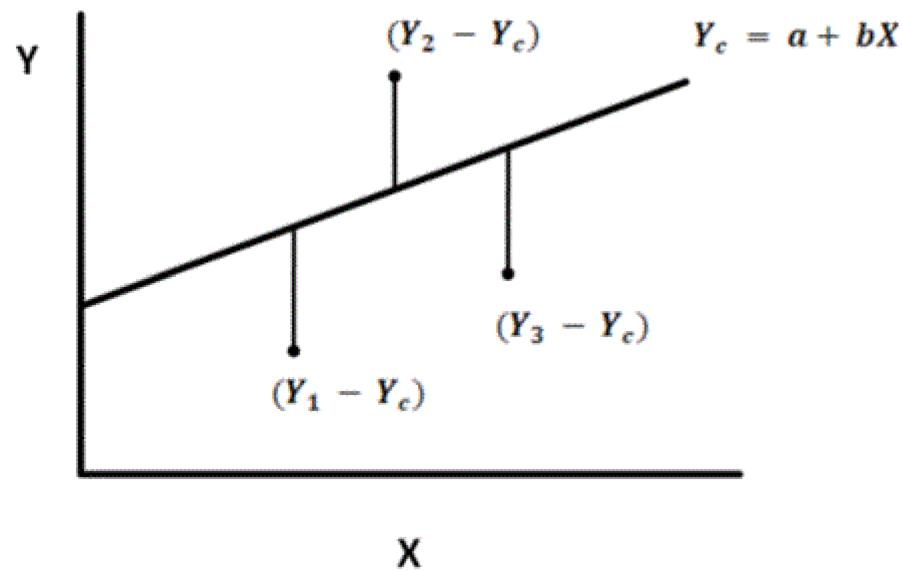
If the manpower model	Then the model meets Realistic test criteria when:	And the model meets Economic test criteria when:
Linear: $Y = a + bX$	$b > 0$	Realistic criteria is met
Parabola: $Y = a + bX + cX^2$	$b > 0 \; and \; X_u \leq \frac{-b}{2c}$ Where X_u = the WLF at the	$c < 0$
Special Equation Forms:		
Power: $Y = aX^b$	$a > 0 \; and, 0 < b < 1$	Realistic criteria is met
Ratio: $Y = \frac{x}{a + bX}$	$a > 0$	

18.1.22. Basic Assumptions for Least Squares Regression Analysis. Least Squares Regression is the regression technique used in the Air Force MEP. This technique yields an equation (Yc) that best fits the observed data (Ym) by minimizing the total variation (i.e., the residuals) for the observed data above and below the regression line.

18.1.23. The residuals are defined as the difference between the observed and calculated man-hours (Ym-Yc). Assumptions regarding residuals follow:

18.1.23.1. Residuals are independent of each other. Residuals are normally distributed with zero mean and constant variation, i.e., which is saying that the data points are normally distributed around the regression line and as the X values increase or decrease, the amount of dispersion stays constant and does not correspondingly go up or down. Figure 18.7 provides a graphical depiction of the residual differences between the regression line and specific data points.

Figure 18.7. Residuals—the Difference Between Measured Data (Ym) and the Regression Equation (Yc).



18.1.23.2. In order for an equation to qualify for linear regression analysis, it should be of the form Yc = a + b1X1 + b2X2 +…+ bn Xn, or be of a form that can be reduced to an equation of this type; that is, linear with respect to the regression coefficients (b). This qualification still allows for the transformation of the independent (i.e., WLF) variables (X) into a power (X^2), reciprocal (1/X), or log X as needed for an equation form. See 0to discuss the transformation of data for power and ratio equations.

18.1.23.3. The values of the independent variable(s) (i.e., the WLF(s)) can be measured with little or no variability.

18.1.24. Before Performing Least Squares Regression Computations.

18.1.24.1. Before starting C&R, always verify the accuracy of the input data and purge it of any data collection errors. Tools such as control charts and scatter diagrams assist in determining if data are reasonable and logical.

18.1.24.2. Ensure to obtain the minimum number of data points when performing C&R. The number of input points in regression analysis becomes important in testing the significance of the regression line.

18.1.24.3. Generally, the more input points that are used to determine the regression line, the more information that can be gained about the nature of the work center under investigation. To have a meaningful test, there should be enough data inputs to allow a good estimation of the variability within the data after the coefficients are estimated.

18.1.24.4. Never perform regression analysis on less than seven data points. In regression analysis, statistical tests are based on (n-1) and (n-m) called degrees of freedom. The total number of observations or data points is n, and m is the total number of coefficients. Therefore, the more points in the sample, the more information there is to add validity to the statistical test. The inputs should adequately portray the behavior of the data at various levels of workload. Understanding the nature of the data cannot be done with just a few data points.

18.1.24.5. Determining the Regression Coefficients Bivariate Example. Initially, after work measurement and data collection have been completed, the ME analyst pairs each input location's Y-value with the corresponding potential WLF count(s).

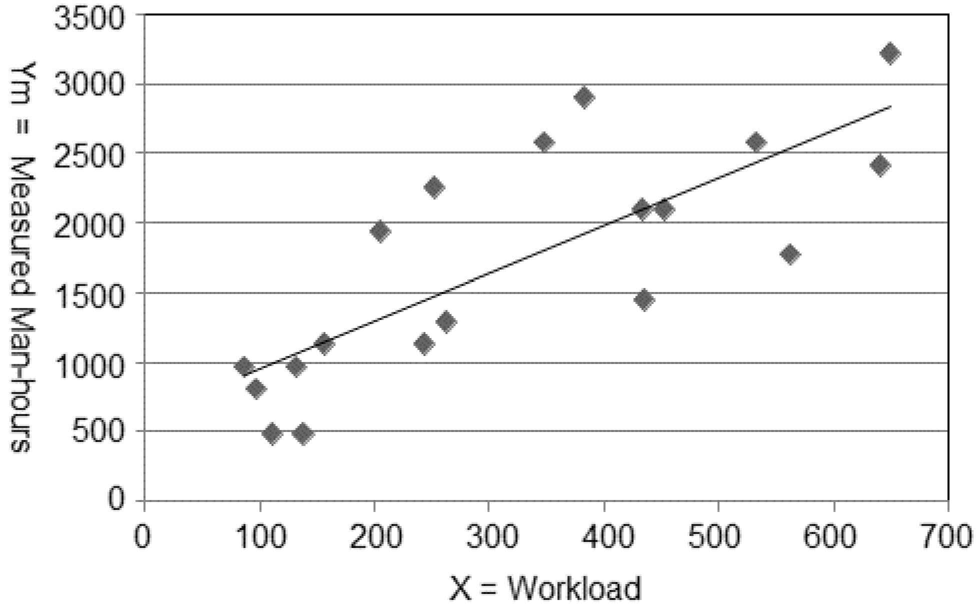
18.1.24.6. Table 18.5 shows each input location (first column) and the pairing of work measurement data (Ym, in the second column) with the potential WLF count (shown in third column).

Table 18.5. Example Input Data Showing Determined Man Hours and Potential WLF Data.

Location	Baseline Man-hours Measured (Y_m)	Potential WLF #1: ACP
89 OSS, Andrews AFB, MD	2900.16	383
437 OSS, Joint Base (JB) Charleston AFB, SC	2416.8	641
436 OSS, Dover AFB, DE	2577.92	348
317 OSS, Dyess AFB, TX	1450.08	435
92 OSS, F.E. Warren AFB, WY	1933.44	205
319 OSS, Grand Forks AFB, ND	1127.84	243
463 OSS, Little Rock AFB, AR	2094.56	452
6 OSS, Malmstrom AFB, MT	1127.84	156
62 OSS, JB Lewis-McChord AFB, WA	1772.32	563
22 OSS, McConnell AFB, KS	2255.68	252
305 OSS, JB McGuire-Dix AFB, NJ	2577.92	533
43 OSS, Luke AFB, AZ	2094.56	433
19 OSS, Robins AFB, GA	805.6	97
375 OSS, Scott AFB, IL	966.72	132
60 OSS, Travis AFB, CA	3222.4	650
15 OSS, JB Pearl Harbor-Hickam AB, HI	483.36	111
374 OSS, Yokota AB, Japan	483.36	138
100 OSS, RAF Mildenhall, United Kingdom	966.72	87
86 OSS, Ramstein AB, Germany	1288.96	263

18.1.24.7. Once the data are paired, the ME analyst should plot the individual X,Y data pairs as a scatter diagram to appreciate an initial visual assessment of the data to see if a positive correlation exists. Figure 18.8 shows the graphing of the data in Table 18.3 as an initial scatter diagram, with the resultant regression line and R2 value depicted on the graph. See Table 18.3 on minimal statistical criteria using C&R.

Figure 18.8. Graphing Table 18.5's Paired X and Y Values as a Scatter Diagram.



18.1.24.8. In order to figure the values for "a" and "b" in this bivariate equation example, the ME analyst minimizes the basic function, $\Sigma(Y\text{-}Y_c)^2$, to satisfy the least squares approach criterion. Note 1: The following approach takes the reader through a series of basic calculations to determine the regression coefficients. Although many of these calculations can be completed quickly and easily in many commercially available statistical software packages (and the approach outlined here does use some basic Microsoft Excel functions), the idea is to give the ME analyst the basics and appreciation for the calculations required.

18.1.24.9. Begin by arranging the input data. The next step that the ME analyst should accomplish is to arrange the data in tabular form to ease computations. Starting with a bivariate example (as this is the simplest to calculate), Table 18.5 is now modified slightly as Table 18.6. The ME analyst should now also determine these summary statistics:

18.1.24.9.1. The sum of Ym values (Ym). The sum of the X1 values (X1).

18.1.24.9.2. The sum of the square of X1 values (X12).

18.1.24.9.3. The sum of the product of X1Ym (X1Ym).

18.1.24.9.4. The total number of input data points (n).

Table 18.6. Arranging Initial Data for Bivariate Equation With Summary Statistics.

n	Unit		Measured Man-hours (Y_m)		X_1: ACP		X_1Y_m		X^{2}_{1}
1	89OSS		2900.16		383		1110761.28		146689
2	437OSS		2416.8		641		1549168.8		410881
3	436OSS		2577.92		348		897116.16		121104
4	317OSS		1450.08		435		630784.8		189225
5	92OSS		1933.44		205		396355.2		42025
6	319OSS		1127.84		243		274065.12		59049
7	463OSS		2094.56		452		946741.12		204304
8	6 OSS		1127.84		156		175943.04		24336
9	62OSS		1772.32		563		997816.16		316969
10	22OSS		2255.68		252		568431.36		63504
11	305OSS		2577.92		533		1374031.36		284089
12	43OSS		2094.56		433		906944.48		187489
13	19OSS		805.6		97		78143.2		9409
14	375OSS		966.72		132		127607.04		17424
15	60OSS		3222.4		650		2094560		422500
16	15OSS		483.36		111		53652.96		12321
17	374OSS		483.36		138		66703.68		19044
18	100OSS		966.72		87		84104.64		7569
19	86OSS		1288.96		263		338996.48		69169
n=	19	$\sum Y_m=$	32,546.24	$\sum X_1 =$	6,122	X_1Y_m	12,671,926.88	$\sum X^{2}_{1} =$	2607100

18.1.24.10. The ME analyst begins by determining the normal equations. This mathematical procedure in least squares regression involves differential calculus and always results in a set of linear equations referred to as the normal equations. These normal equations are solved simultaneously in order to find the values of the regression coefficients.

18.1.24.10.1. During regression analysis, there are as many normal equations as there are coefficients in the model. See the last column of Table 18.2 for the example of the number of coefficients in different equation forms. For example, a bivariate linear = + 1X1 requires two normal equations corresponding to the two regression coefficients "a" and "b". Thus, the bivariate normal equations would read:

$$\sum Y = na + b1\sum X1.$$

$$\sum X1Y = a\sum X1 + b1\sum X1^2$$

18.1.24.10.2. By way of another equation, the multivariate linear form of $Y_c = a + b_1X_1 + b_2X_2$ requires three normal equations because there are three regression coefficients; that is, a, b1, and b2. The normal equations for this equation would be solved simultaneously in order to find the values of the coefficients.

$$\sum Y = na + b1\sum X1 + b2\sum X2.$$

$$\sum X1Y = a\sum X1 + b1\sum X1^2 + b2\sum X1X2.$$

$$\sum X2Y = a\sum X2 + b1\sum X1X2 + b2\sum X2^2$$

18.1.24.11. And so forth for as many constants such that the final normal equation form number of coefficients would be: ∑XmY = axm + b1∑X1Xm + b2∑XmX2 +...bm∑X2.

18.1.24.11.1. Determining the Normal Equations-Bivariate Example. For the equation $Y_c = a + bX$ the normal equations for this example using the summary statistics in Table 18.6 yield:

∑Y = na + b1∑X1, which in this case would be: 32,546.24 = 19a + 6,122b1.

The other normal equation in this bivariate example: $\sum X1Y = a\sum X1 + b1 \sum X1^2$
The ME analyst would get: 12,671,926.88 = 6,122a + 2,607,100 b1.

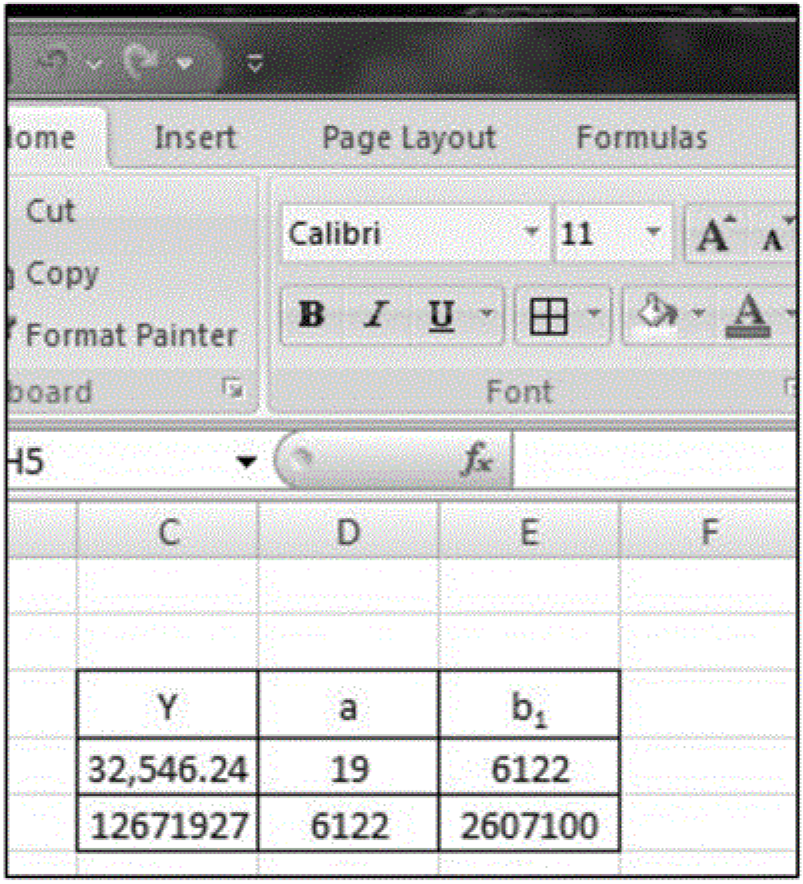
18.1.24.11.2. Solving the Normal Equations—Bivariate Example. Now the ME analyst needs to solve the normal equations simultaneously. To do this, the ME analyst needs to follow some matrix algebra techniques. This next step involves creating an original master matrix as shown in Table 18.7 from the normal equation's coefficients such that:

Table 18.7. Master Matrix.

Y	a	b1
32,546.24	19	6,122
12,671,926.88	6,122	2,607,100

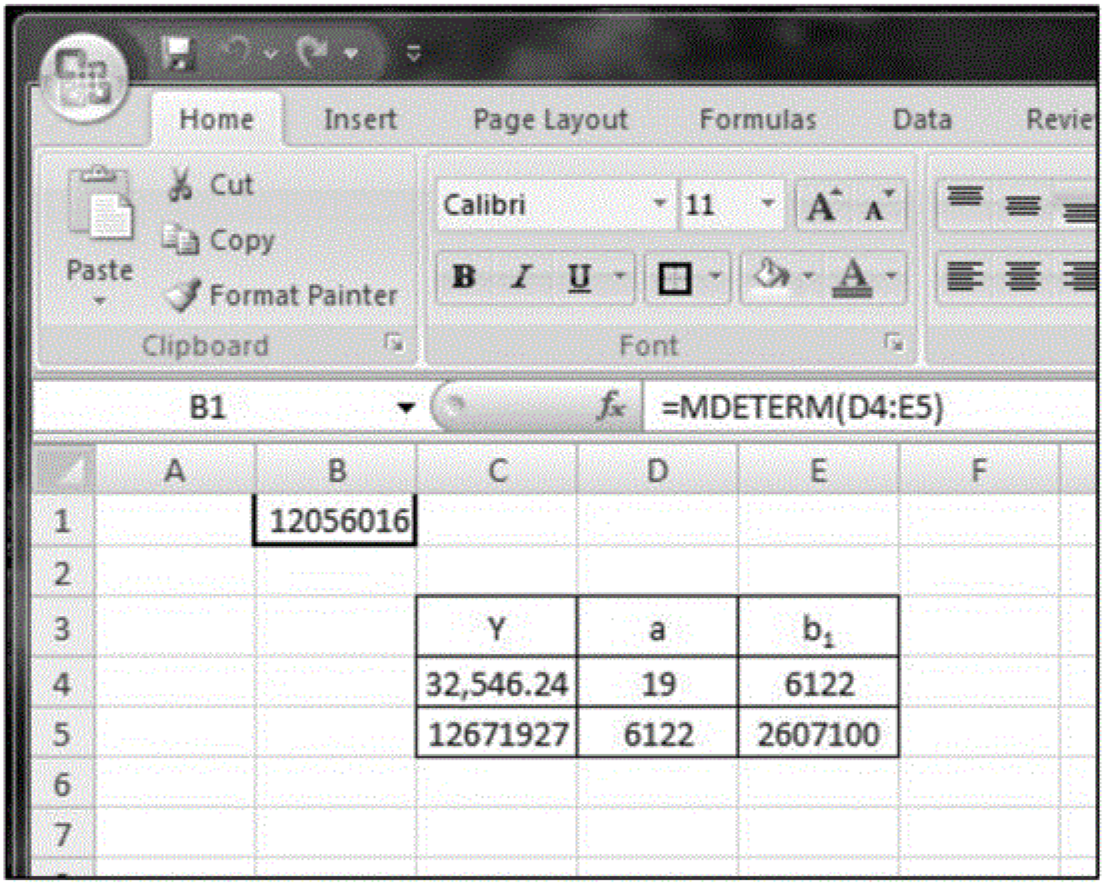
18.1.24.11.3. ME analyst determines the master matrix's determinant. Although the example here could be solved using Cramer's Rule, in preparation for determining the equations in a multivariate analysis, Microsoft Excel functions and use is highlighted here in this bivariate example. Placing the master matrix into Microsoft Excel®, the ME analyst gets the following as shown in Figure 18.9.

Figure 18.9. Master Matrix Shown in Microsoft Excel®.



18.1.24.11.4. In cell B1 as shown in Figure 18.10, the ME analyst enters the Microsoft Excel's matrix determinant function (MDETERM), highlighting the matrix's "a" and "b1" coefficient cells (shown as the [2X2] array D4:E5) as shown in Figure 18.10 which yields the matrix's determinant result of 12,056,016. This results in subsequent calculations to determine the "a" and "b1" value.

Figure 18.10. Using Microsoft Excel® to Solve the Master Matrix Determinant.



18.1.24.12. The ME analyst needs to create two additional matrixes, substituting the Ym column for the regression coefficient the analyst wish to solve, then determining the matrix determinant for that new matrix, and finally dividing each of these results by the master matrix's determinant to yield the final regression coefficients.

18.1.24.13. Therefore, to solve for "a" coefficient, substitute the Ym values, yielding the matrix: Solving for the "a" coefficient, to get the following matrix:

a	b1
32,546.24	6122
12,671,926.88	2,607,100

18.1.24.14. The matrix determinant for the "a" coefficient = 7,273,765,944.64.

18.1.24.15. To determine the value for the "a" coefficient, the ME analyst divides the "a" coefficient matrix determinant by master matrix's determinant.

18.1.24.15.1. "a" coefficient = MDETERM a

$$\frac{\text{Coefficient Matrix Determinant}}{\text{Master Matrix's Determinant}} \xrightarrow{\text{yields}} \frac{7273765944.64}{12056016} = 603.3$$

18.1.24.15.2. Solving for “b1” coefficient, the ME analyst substitutes the Ym values for the former b1 values and get the following matrix: Thus, the matrix determinant for the b1 values = 41,518,529.44.

a	b1
19	32,546.24
6,122	12,671,926.88

18.1.24.15.3. Like before, divide the matrix determinant for b1 by the master matrix’s determinant:

$$\text{b1 coefficient} = \frac{\text{Coefficient Matrix Determinant}}{\text{Master Matrix's Determinant}} \xrightarrow{\text{yields}} \frac{41{,}518{,}529.44}{12056016} = 3.443$$

18.1.24.16. Thus, the ME analyst’s new man-hour equation determined through bivariate regression would be:

$Y_c = 603.33 + 3.443X_1$

18.1.24.17. Determining the Regression Coefficients—Multivariate Regression. ME analysts should always plan to collect more than one potential WLF to explore in man-hour equation development. The same basic approach shown in determining the regression coefficients in bivariate analysis applies to multivariate regression analysis. For each potential WLF the ME analyst adds to its analysis, there is also another normal equation that is solved simultaneously.

18.1.24.18. Expanding on the data set explored for the bivariate analysis conducted in paragraph 18.1.24.5, suppose the ME analyst collected the following data as shown in Table 18.8.

Table 18.8. Expanded Potential WLF Analysis.

Ym	X1	X2	X3	X4	X5	X6	X7
Baseline Man- hours	HSD	ACP	PAI	MDS	FH	SORT	MWS
2900.16	121	383	52	9	2015.7	990	2
2416.8	258	641	48	1	4192	1416	1
2577.92	92	348	13	2	1105.7	238	1
1450.08	108	435	28	1	1665	913	1
1933.44	168	205	30	1	2021.5	380	1
1127.84	96	243	44	2	2502.8	457	1
2094.56	512	452	28	2	1085.8	672	1
1127.84	103	156	15	2	1119.9	248	2
1772.32	229	563	48	1	5170.1	1620	1
2255.68	213	252	30	2	2364.1	464	1
2577.92	455	533	42	2	3901.7	886	2
2094.56	124	433	28	1	1584.9	926	1
805.6	41	97	12	1	831.6	152	1
966.72	207	132	14	1	1374.1	440	1
3222.4	268	650	36	3	3912.4	746	2
483.36	9	111	2	2	181.8	41	2
483.36	57	138	18	4	836	391	3
966.72	101	87	15	1	586.6	145	1
1288.96	78	263	27	5	1349.1	721	2

18.1.25. Now with seven potential WLFs, plus the "a" value, the ME analyst solves for eight simultaneous equations. Those simultaneous equations to be solved would follow the same pattern as discussed in paragraphs 18.1.24.10 thru 18.1.24.11 and would result in these normal equations:

Solving for all of the coefficient pairs above would yield the following master matrix as shown in Table 18.9.

$$\sum y = na + b1\sum X1 + b2\sum X2 + b3\sum X3 + b4\sum X4 + b5\sum X5 + b6\sum X6 + b7\sum X7 \sum X1Y = a\sum X1$$
$$+ b1\sum X1^2 + b2\sum X1X2 + b3\sum X1X3 + b4\sum X1X4 + b5\sum X1X5 + b6\sum X1X6 + b7\sum X1X7 \sum X2Y$$
$$= a\sum X2 + b1\sum X1X2 + b2\sum X2^2 + b3\sum X2X3 + b4\sum X2X4 + b5\sum X2X5 + b6\sum X2X6 +$$
$$b7\sum X2X7 \sum X3Y = a\sum X3 + b1\sum X1X3 + b2\sum X3X2 + b3\sum X^2 + b4\sum X3X4 + b5\sum X3X5 +$$
$$b6\sum X3X6 + b7\sum X3X7 \sum X4Y = a\sum X4 + b1\sum X1X4 + b2\sum X4X2 + b3\sum X4X3 + b4\sum X4^2 +$$
$$b5\sum X4X5 + b6\sum X4X6 + b7\sum X4X7 \sum X5Y = a\sum X5 + b1\sum X1X5 + b2\sum X5X2 + b3\sum X5X3 +$$
$$b4\sum X5X4 + b5\sum X^2 + b6\sum X5X6 + b7\sum X5X7 \sum X6Y = a\sum X6 + b1\sum X1X6 + b2\sum X6X2$$
$$+ b3\sum X6X3 + b4\sum X6X4 + b5\sum X6X5 + b6\sum X6^2 + b7\sum X6X7 \sum X7Y = a\sum X7 + b1\sum X1X7 +$$
$$b2\sum X7X2 + b3\sum X7X3 + b4\sum X7X4 + b5\sum X7X5 + b6\sum X7X6 + b7\sum X^2$$

Table 18.9. Master matrix for Multivariate Example.

Y	A	b1	b2	b3	b4	b5	b6	b7
32546.24	19	3240	6122	530	43	37800.8	11846	27
6635727.2	3240	867706	1318454	105708	6707	8098269.6	2461483	4388
12671926.9	6122	1318454	2607100	205844	14047	15875106.6	5018843	8494
1041963.04	530	105708	205844	18476	1354	1343031.3	420572	740
81043.36	43	6707	14047	1354	167	81917.4	28321	74
76787681.3	37800.8	8098269.6	15875106.6	1343031.3	81917.4	109251090.2	32072833	51953.4
23539632	11846	2461483	5018843	420572	28321	32072832.5	10692522	16260
45113.6	27	4388	8494	740	74	51953.4	16260	45

18.1.25.1. Steps for Reviewing Workload in Multivariate Regression Analysis with a C&R analysis tool. (**Note:** The discussion of the correlation statistics and these calculations are discussed in paragraphs following. The steps for completing the multivariate regression analysis to yield a useful manpower equation are carried on here.)

18.1.25.2. Assume a new data set with the first C&R run with five potential WLFs yields the statistics and detail shown in Table 18.10. The objective of initial multivariate regression analysis is to find an acceptable equation using minimum variables (i.e., WLFs). Does an acceptable equation exist with one or a combination of the five independent variables as shown in Table 18.10? The answer at this point would be "probably yes", but until the numbers are run that answer is not certain.

Table 18.10. Initial Multivariate C&R Analysis.

		TABLE OF R VALUES BETWEEN VARIABLES— PAIRWISE ANALYSIS				
(R) OF	TO Y	TO X1	TO X2	TO X3	TO X4	TO X5
X1	0.2863	1.0000				
X2	0.3011	0.6059	1.0000			
X3	0.6059	-0.0924	0.0777	1.0000		
X4	0.4804	0.2618	0.3586	0.1399	1.0000	
X5	0.7135	0.4233	0.6524	0.1228	0.5423	1.0000
	X ORDER OF ENTRY			INTER-MEDIATE R VALUES	R^2 VALUES	
	X5			0.7135	0.5090	
	X3			0.8842	0.7818	
	X2			0.9037	0.8166	
	X1			0.9218	0.8497	
	X4			0.9239	0.8535	
a-value	R	R^2	ADJUSTED R^2	SY	V	F
-96.55	0.9239	0.8535	0.3682	29.9684	0.267	9.3249
	X (I)	B (I)	T (I)	SIG LEV		
	1	8.975406	1.320	0.223432		
	2	-18.21396	-1.861	0.099765		
	3	21.40704	3.980	0.004059		
	4	1.488722	0.461	0.6572927		
	5	19.35436	3.824	0.005060		
n	LINE	ACTUAL YM	PREDICTED YC	DEVIATION	OUTSIDE+/- 1.00SYX	
1	101	160.000	146.498	-13.502	0.000	
2	102	173.000	161.004	-11.996	0.000	
3	103	130.000	113.199	-16.801	0.000	
4	104	56.000	104.944	48.944	18.975	
5	105	82.000	39.139	-42.861	-12.893	
6	106	142.800	126.898	-15.902	0.000	
7	107	76.000	77.658	1.658	0.000	
8	108	39.000	53.378	14.378	0.000	
9	109	28.000	27.126	-0.874	0.000	
10	110	35.000	61.117	26.117	0.000	
11	111	223.500	201.14	-22.36	0.000	
12	112	146.000	159.011	13.011	0.000	
13	113	177.700	200.522	22.852	0.000	
14	114	97.500	94.837	-2.663	0.000	

18.1.25.3. C&R application tool automatically performs a stepwise regression to order the significance of the various WLFs being tested. This potential WLF ranking is determined by which WLF produces the best regression equation fit (i.e., highest R value) in combination with each ranking of the next subsequent work load factors adding the next greatest amount significance in explaining the total variation. Note: A high degree of multicollinearity (See paragraph 18.2.10.20.) can confuse the order of significance as such, there is no substitute for the ME analyst to perform a thorough review of various combinations of WLFs particularly when multicollinearity exists.

18.1.25.4. Inspection of the table of R-values in Table 18.10 shows no single WLF (X) passes the criteria for a bivariate relationship with relation to Y (the column titled "TO Y”). The ME analyst should normally run a bivariate C&R analysis using the WLF that had the highest-value greater than .7750. If no R-values are higher than .7750 (the case here in Table 18.10), do not waste time running bivariate analysis but begin by running the next highest R-value WLF pairs to see the resulting correlation statistics, equations, and impact. In Table 18.11 the WLF pair of X5 and X3 against Y has a coefficient of determination (R2) value of .7818 with an adjusted R2 of only .5405. This pair also does not yield a desired coefficient of variation (V) value (i.e., V<.25). Pay particular attention to the order of entry (See Table 18.10). The next run to try would be multivariate with Y versus X5, X3 and X2 (See Table 18.12).

Table 18.11. Second Multivariate C&R Analysis.

X ORDER OF ENTRY	INTER- MEDIATE R VALUES	R^2 VALUES
X5	0.7135	0.5090
X3	0.8842	0.7818

a	R	R^2	ADJUSTED R^2	SY	V	F
-131.99	0.8842	0.7818	0.5405	31.1972	0.2788	19.7031
	X (I)	B (I)	T (I)	SIG LEV		
	5	16.98708	4.572	0.000801		
	3	20.31130	3.708	0.003454		

n	LINE	ACTUAL YM	PREDICTED YC	DEVIATION	OUTSIDE ±1.00 SYX
1	101	160.000	176.625	116.625	0.000
2	102	173.000	140.064	-32.936	-1.738
3	103	130.000	106.206	-23.794	0.000
4	104	56.000	106.206	50.206	19.008
5	105	82.000	48.449	-33.551	-2.353
6	106	142.800	140.064	-2.736	0.000
7	107	76.000	82.308	6.308	0.000
8	108	39.000	82.308	43.308	12.111
9	109	28.000	21.115	-6.845	0.000
10	110	35.000	48.449	13.449	0.000
11	111	223.500	176.625	-46.875	-15.678
12	112	146.000	147.186	1.186	0.000
13	113	177.700	203.700	26.000	0.000
14	114	97.580	87.154	-10.346	0.000

18.1.25.5. Looking at the third C&R APPLICATION TOOL run in Table 18.12, compare the incremental improvement in coefficient of determination (R2), adjusted R2, and coefficient of variation (V). Note the fourth data point shown in the lower part of the table is the furthest out as in earlier cases; this anomaly is justification for the ME analyst to explore why this data point continues to read high with each run of the data.

Table 18.12. Third Multivariate C&R Analysis.

TABLE OF R VALUES BETWEEN VARIABLES				
(R) OF	TO Y	TO X5	TO X3	TO X2
X5	0.7135	1.0000		
X3	0.6059	0.1228	1.0000	
X2	0.3011	0.6254	0.0777	1.0000

X ORDER OF ENTRY	INTER- MEDIATE R VALUES	R^2 VALUES
X5	0.7135	0.5090
X3	0.8842	0.7818
X2	0.9037	0.8166

a- value	R	R^2	ADJUSTED R^2	SY	V	F
-78.50	0.9037	0.8166	0.5669	29.9964	0.2681	14.8408
	X (I)	B (I)	T (I)	SIG LEV		
	5	20.90170	4.579	0.001012		
	3	20.32020	3.858	0.003170		
	2	-11.77228	-1.378	0.198318		

n	LINE	ACTUAL Ym	PREDICTED YC	`DEVIATION	OUTSIDE+/- 1.00 SYX
1	101	160.000	159.464	-0.536	0.000
2	102	173.000	142.512	-30.488	-0.491
3	103	130.000	108.639	-21.361	0.000
4	104	56.000	108.639	52.639	22.642
5	105	82.000	37.573	-44.427	-14.431
6	106	142.800	142.512	-0.288	0.000
7	107	76.000	87.139	11.139	0.000
8	108	39.000	71.447	32.447	2.450
9	109	28.000	11.893	-16.107	0.000
10	110	35.000	53.265	18.625	0.000
11	111	223.500	194.781	-28.719	0.000
12	112	146.000	158.558	12.558	0.000
13	113	177.700	186.551	8.851	0.000
14	114	97.500	103.527	6.027	0.000

18.1.25.6. Continue running multivariate C&R until an acceptable equation is reached or there are no more potential workload combinations remaining to be explored. As a result of the multivariate regression analysis thus far, the ME analyst knows the most suspect point for questioning of input data is base number 4 that consistently falls outside one standard error of the estimate. The ME analyst can continue to review the input data, consider separating direct and indirect workload to regress direct workload and assist further analysis of potential outliers, and/or consider other potential WLFs.

18.1.26. Parabolic Regression Equation's C Coefficient. Recall the equation form for the parabolic equation:

Y=a + bX + cX2

18.1.26.1. To determine the regression coefficients of the parabola equation form, follow the steps below:

18.1.26.2. Power and Ratio Data Transformation. As noted earlier in paragraph 17.1.9, Power and Ratio equations undergo a data transformation. Although statistical software programs perform this transformation for the ME analyst, Table 18.13 depicts the transformation of the data originally shown in Table 18.3 to give the ME analysts an understanding of what the software is actually computing.

Table 18.13. Example Showing Data Transformation Required for Power and Ratio Equations.

n	Unit	Measured Man-hours (Ym)	X1: ACP	Log Ym	Log X1	Ym Transformation (X1/Ym)
1	89 OSS	2900.16	383	3.46	2.58	0.13
2	437 OSS	2416.8	641	3.38	2.81	0.27
3	436 OSS	2577.92	348	3.41	2.54	0.13
4	317 OSS	1450.08	435	3.16	2.64	0.30
5	92 OSS	1933.44	205	3.29	2.31	0.11
6	319 OSS	1127.84	243	3.05	2.39	0.22
7	463 OSS	2094.56	452	3.32	2.66	0.22
8	6 OSS	1127.84	156	3.05	2.19	0.14
9	62 OSS	1772.32	563	3.25	2.75	0.32
10	22 OSS	2255.68	252	3.35	2.40	0.11
11	305 OSS	2577.92	533	3.41	2.73	0.21
12	43 OSS	2094.56	433	3.32	2.64	0.21
13	19 OSS	805.6	97	2.91	1.99	0.12
14	375 OSS	966.72	132	2.99	2.12	0.14
15	60 OSS	3222.4	650	3.51	2.81	0.20
16	15 OSS	483.36	111	2.68	2.05	0.23
17	374 OSS	483.36	138	2.68	2.14	0.29
18	100 OSS	966.72	87	2.99	1.94	0.09
19	86 OSS	1288.96	263	3.11	2.42	0.20

18.1.26.2.1. Power Curve Regression Coefficients. When the general equation Y = aXb is transformed using logarithms, it becomes log Y = log a + b(log X).

18.1.26.2.2. Once the data values (i.e., Ym, and X) have been transformed values, each can then be used in the general formulas for bivariate linear regression to find a and b as discussed in paragraph 17.1.32.

18.1.26.2.3. Another means to determine the Power curve regression coefficient is to use the following equations:

$$b = \frac{n\Sigma \log X \log Y - (\Sigma \log X)(\Sigma \log Y)}{n\,\Sigma(\log X)^2 - (\Sigma \log X)^2} \qquad a = \frac{\Sigma \log Y - b\,\Sigma \log X}{ni}$$

18.1.27. The values found for these coefficients are used in the equation for all subsequent analysis. Note: This approach only gives an approximation of the true a and b values. A better estimate of these coefficients (a and b) is obtained by computing these coefficients through an iterative process using Taylor's series approximations. Once these new coefficients have been found, each can be used in the general formula for R^2. This procedure gives an unbiased estimate of a and b and reduces the occurrence of negative R^2 values.

18.1.27.1. Ratio Curve Regression Coefficients. When the general ratio equation Yc =X/(a+bX) is transformed, it becomes

$$= \frac{X}{Y}\, \mathrm{a} + \mathrm{bX}$$

18.1.27.2. The transformed values (X/Y ratios) can now be used in lieu of Ym-values in the general approach, as shown in paragraph 17.1.32., to determine linear regression coefficients (as discussed in paragraph 17.1.34.2.1. with the Power equation).

18.1.27.3. Another means to determine the "a" and "b" coefficients for the Ratio curve are to apply the following equations where:

$$b = \frac{n\Sigma\frac{X^2}{Y} - (\Sigma X)\Sigma\frac{X}{Y}}{n\,\Sigma X^2 - (\Sigma X)^2}\,;\; a = \frac{\Sigma\frac{X}{Y} - b\Sigma X}{n}$$

18.1.28. Use of a 0 Y-Intercept Equation. In situations where the Y-intercept of an equation is near zero (positive or negative) for bivariate and multivariate linear equations, the use of a no-intercept model (Y = b1X) can be supported statistically.

18.1.29. This option does not mean the original equation's a value is simply set to 0. Rather, this procedure involves a new set of calculations as the new equation's slope value (b1) now changes. Microsoft Excel® allows an option for a bivariate equation's Y-intercept to be set to zero and recalculated providing a new b1 coefficient and an estimated coefficient of determination (R2) value.

18.1.30. The no-intercept equation and its resulting new r2 or R2 and coefficient of variation (V) must still meet the minimum criteria (R2 > .70, V<.25). Ultimately, the ME analyst must ensure the 0-intercept equation's impact is logical and has at least the same, if not better, than the original equation's impact. **(T-2)**

18.2. Correlation Statistics.

18.2.1. The correlation statistics are needed to evaluate how well an equation (Yc) represents the measured data (Ym). These measures are essentially derived from the measures of the measured man-hour data's central tendency, the variation within the measured man-hours, and the regression equation itself.

18.2.2. Exploring a Linear Bivariate Equation. Table 18.14 shows the paired X,Y data (Ym data here shown in full time manpower equivalents (FTEs)) and the resulting regression equation—Yc = 1.375 + .5333X. Table 18.14 further shows the calculated value (placing each X value into the equation to determine Yc). (Note: This example is shown in FTEs for simplicity's sake, normally, all equations developed should remain in man-hours to accommodate the potential use of different MAFs during manpower determinants application.)

Table 18.14. Basic Relationship for Overall Statistics.

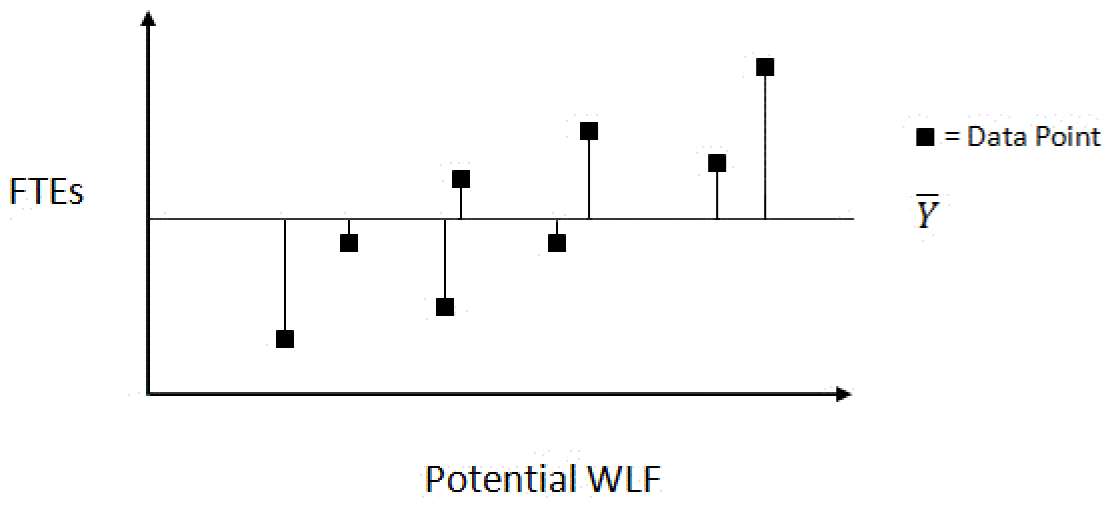
Potential WLF	FTE	$Y_c = 1.375 + 0.5333X$						
X	Y_m	Y_c	$(Y_m - \bar{Y})$	$(Y_m - \bar{Y})^2$	$(Y_c - \bar{Y})$	$(Y_c - \bar{Y})^2$	$(Y_m - Y_c)$	$(Y_m - \overline{Y_c})^2$
3	2	2.975	-5.375	28.890	-4.400	19.361	-0.975	0.950
8	4	5.641	-3.375	11.391	-1.734	3.005	-1.641	2.694
5	6	4.042	-1.375	1.891	-3.334	11.112	1.959	3.836
9	8	6.175	0.625	0.391	-1.200	1.441	1.825	3.332
13	6	8.308	-1.375	1.891	0.933	.870	-2.308	5.326
14	10	8.841	2.625	6.891	1.466	2.150	1.159	1.343
18	9	10.974	1.625	2.641	3.599	12.956	-1.974	3.898
20	14	12.041	6.625	43.891	4.666	21.772	1.959	3.838
$\bar{Y} = 7.375$								
$TSS = \sum(Y_m - \bar{Y})^2 = 97.875$ $SSR = \sum(Y_c - \bar{Y})^2 = 72.666$ $SSE = \sum(Y_m - Y_c)^2 = 25.217$								
*Some differences in summations due to rounding.								

18.2.3. Total Sum of Squares (TSS). When the data contained in the X-values are not used for prediction purposes (i.e., just the Ym-values are used), the best prediction of a new Y-value is simply the measure of central tendency or *Y*. Hence, the total variation within the system is associated with the TSS deviations of the Y-values about its own mean (*Y*). TSS computations for the data in Table 18.14 = 97.875. Figure 18.11 depicts the computations graphically.

Thus

$$TSS = \Sigma(Ym - \bar{Y})^2$$

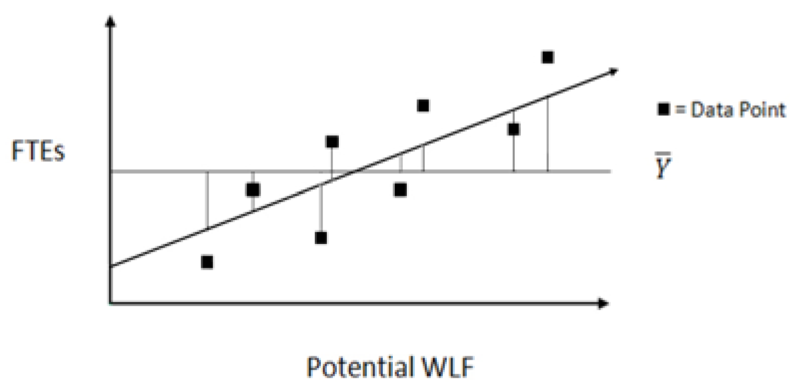
Figure 18.11. Graphically Depicting the TSS Delta Between the Mean () and Each Measured Ym Value.



18.2.4. Sum of Squares Explained by Regression (SSR). When the data contained in the X-values is used to form a prediction equation (such as, Yc = a + bX), the best estimate of a new Y-value is Yc instead of **Y**. Since Yc was created to improve the prediction of new values, the variation in the system is reduced by using Yc as a predictor instead of **Y**. The amount of reduction is defined as the SSR. The degrees of freedom for SSR are (m-1). SSR computations for the data in Table 18.12 = 72.666.

Thus
$SSR = \Sigma(Y_c - \overline{Y})^2$

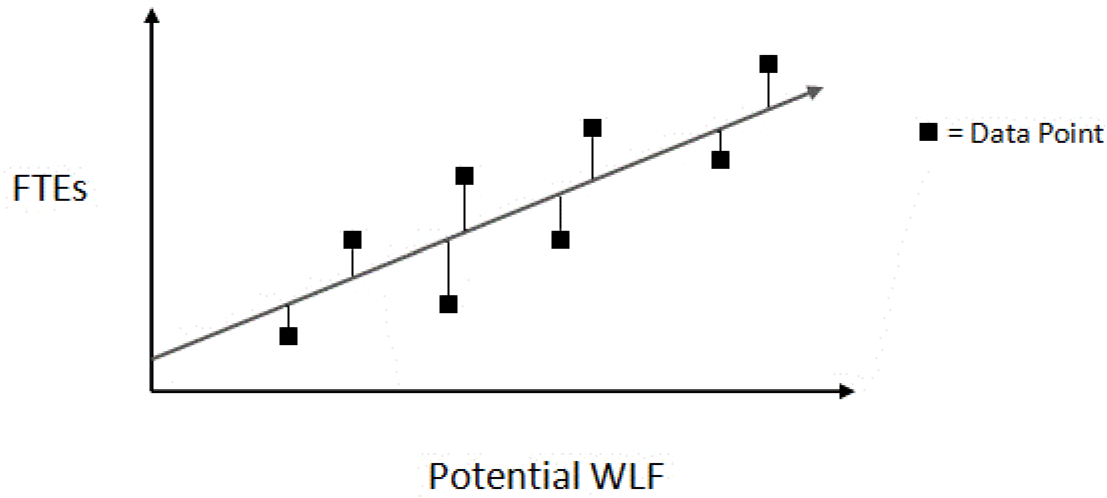
Figure 18.12. Graphically Depicting the SSR and Delta Between the Yc and the Mean ().



18.2.5. Sum of Squares Unexplained by Regression (SSE). The remaining variation in Y is defined as the SSE. Here, the word "unexplained" is used only to indicate that the relationship between X and Y is not completely explained mathematically by the calculated regression line. SSE computations for the data in Table 18.12 = 25.217.

Thus

Figure 18.13. Graphically Depicting the SSE and Delta Between the Measured Data (Ym) and the Regression Line (Yc).



18.2.5.1. Relationships between TSS, SSR, and SSE. Finally, there is an important relationship that should be stressed at this point before performing any of the correlation statistics. That is, the sum of SSE and SSR equals TSS. This can be expressed mathematically as:

$$\Sigma(Y_m - \bar{Y})^2 = \Sigma(Y_m - \bar{Y}_c)^2 + \Sigma(Y_c - \bar{Y})^2,\ or$$
$$TSS = SSE + SSR$$

18.2.5.2. By dividing both sides of the equation by the TSS, two proportions result that sum to one.

$$\frac{TSS}{TSS} = \frac{SSE}{TSS} + \frac{SSR}{TSS}$$
$$1 = \frac{SSE}{TSS} + \frac{SSR}{TSS}$$

18.2.6. Determining the R2. (Note: The term Coefficient of Determination (R2) is used when performing a multivariate regression analysis.) When the regression coefficients in the equation are estimated with the "least squares" method, a relationship needs to be calculated to continue the ME analyst's understanding of the equation's goodness of fit.

18.2.6.1. Coefficient of Determination (R2) Defined. R2 is defined as the proportion of the explained variation (SSR) to the total variation (TSS) that is explained by the regression line. The regression equation explains 74.24% of the total variation as shown below:

$$r^2 = \frac{EXPLAINED\ VARIATION}{TOTAL\ VARIATION} = \frac{SSR}{TSS}$$

18.2.6.2. From the example using the data in Table 15.14, the ME analyst has calculated that SSR = 72.666 while TSS = 97.875. Therefore to determine R2:

$$r^2 = \frac{EXPLAINED\ VARIATION}{TOTAL\ VARIATION} = \frac{SSR}{TSS} = \frac{72.666}{97.875} = .7424$$

18.2.6.3. The R2 Values May Range From 0 to 1. When the regression line explains most of the variation, R2 approaches the value of 1. When there is a large amount of unexplained variation (that is, the regression line is a poor fit and thus predictor), R2 approaches 0. If none of the variation is explained, R2 = 0, this then indicates there is no correlation; visually on a scatter diagram this would appear as a shotgun pattern. However, logic and science ultimately determines the value of the final equation as even perfect (positive, in our case) correlation, does not indicate a cause-and-effect relationship between dependent and independent variables. Rather, the correlation coefficient is an indication of co-variation. The value of r may be due to chance, hence the necessity for applying tests of significance.

18.2.6.4. The Coefficient of Correlation (r). The square root of the R2 is defined as the coefficient of correlation (r), which ranges from a minus one to a plus one. The square root of the sample R2 is the sample coefficient (or index) of correlation r, where:

$$r = \pm\sqrt{1 - \frac{\Sigma(Ym - Y_c)^2}{\Sigma(Y_c - \bar{Y})^2}}$$

18.2.6.5. If all variation is explained, then correlation is perfect, and all the data points would fall on the regression line. The sign of r is the same as the sign of the slope of the regression equation, as determined by the sign of coefficient b in the linear model or as can be visually seen by inspection of the scatter diagram.

18.2.6.6. Adjusted R-Squared. For multivariate regression analysis and dealing with sampled data, an adjustment to the R-squared value needs to be made that takes into consideration the sample size (n) and the number of regression coefficient (m) being tested to compensate for a potentially inflated R2 value. This adjusted R-squared value is determined by the following formula:

$$\text{Adjusted } R^2 = 1 - (1 - R^2)\left(\frac{n-1}{n-m}\right)$$

18.2.6.7. For example, if a multivariate analysis yielded a coefficient of determination (R2) value of .8735 using 14 data inputs (n) and regressing 5 test potential WLFs, the adjusted R2 value would be:

$$\text{Adjusted } R^2 = 1 - (1 - R^2)\left(\frac{n-1}{n-m}\right) \xrightarrow{yields} 1 - (1 - 0.8735)\left(\frac{14-1}{14-5}\right) =$$
$$= 1 - (.1265)\left(\frac{13}{9}\right) = .7653$$

18.2.7. Standard Deviation of Y (Sy). The standard deviation of the measured man-hours (Ym) is estimated by the square root of TSS divided by the degrees of freedom (n-1).

$$S_y = \sqrt{\frac{\Sigma(Y_m - \bar{Y})^2}{n-1}} = \sqrt{\frac{TSS}{n-1}}$$

This expression can be put in a form that is easier to compute:

$$\Sigma(Y_m - \bar{Y})^2 = \frac{n\Sigma Y^2 - (\Sigma Y)^2}{n}$$

18.2.8. Standard Error of the Estimate (). Another key summary statistic that is computed and continues to assist ME analysts evaluate the measure of how the observed data are scattered about the regression line. That summary statistic is the Standard Error of the Estimate or Syx is defined as square root of the SSE divided by the degrees of freedom. The degrees of which is defined as the number of data samples taken (n) less the number of regression coefficient estimated m. Thus the number of degrees of freedom equals n-m. Thus the mathematically representation is:

$$S_{yx} = \sqrt{\frac{\Sigma(Ym - Y_c)^2}{(n-m)}} = \sqrt{\frac{SSE}{(n-m)}}$$

18.2.9. Continuing to use the example from Table 18.12, the ME analyst knows the following:

SSE = 25.217 and
n = 8

18.2.10. And since there are two regression coefficients (a and b) in the bivariate equation of Yc = 1.375 + .5333X with m = 2. That leaves 6 (8-2) degrees of freedom. Note: Two degrees of freedom (the "m” value) are lost here in estimating this equation; had this example been a multivariate equation with additional b coefficients, more degrees of freedom would be lost. Placing this information into the formula, Syx is calculated as:

$$S_{yx} = \sqrt{\frac{25.217}{8-2}} \xrightarrow{yields} 2.05$$

18.2.11. Determining the Coefficient of Variation (V). To compare the goodness of equation’s fit between different equations that a ME analyst might develop, a relative measure is needed.

18.2.11.1. The coefficient of variation yields a measure that has no dimension and is relative to the mean of the measured data, and can be used to set up criteria for the levels of acceptable variability in an equation. V is defined as the standard error of the estimate divided by the average measured man-hours.

$$V = \frac{S_{yx}}{\overline{Y_m}}$$

18.2.11.2. Continuing with the example started with Table 18.12, the ME analyst can determine the Coefficient of Variation for this data. Using the Syx determined in paragraph 18.2.8, and the average of the measured data from Table 18.8, V is calculated as:

$$V = \frac{S_{yx}}{\overline{Y_m}} = \frac{2.05}{7.375} = .278$$

18.2.11.3. Note: Thus, although this equation's coefficient of determination (R2) value (.7424) passed the minimum statistical criteria required for R2 (>.700), the V value fails the requirement (<.25). Without further analysis or additional data (this sample size is very small), the ME analyst might ultimately have to abandon this particular WLF as a good predictor of required manpower.

18.2.12. Significance Tests. Regression analysis incorporates significance testing which is used to measure the reliability of either the sample regression coefficients, the sample R2, or both. The reliability aspect is pertinent, because the input data (Ym) are only a sample of values usually taken from an infinitely large population. The sample values are subject to error, and as such may not be representative of the range and distribution of population values. Note: When the assumptions about the nature of the values (as described in paragraph 0) are not fulfilled, simple tests of significance such as the t and the F-tests may be unreliable.

18.2.13. The F-test. To be useful in prediction, an equation needs to explain or account for more of the variability in the man-hours than is left unexplained. The F-test is a significance test used for this determination the regression coefficients, and tests the hypothesis that the regression model and that the independent variable (i.e., WLF) in a bivariate regression analysis, or at least one of the independent variables in a multivariate regression analysis, is significantly different from 0. Thus, the null hypothesis becomes:

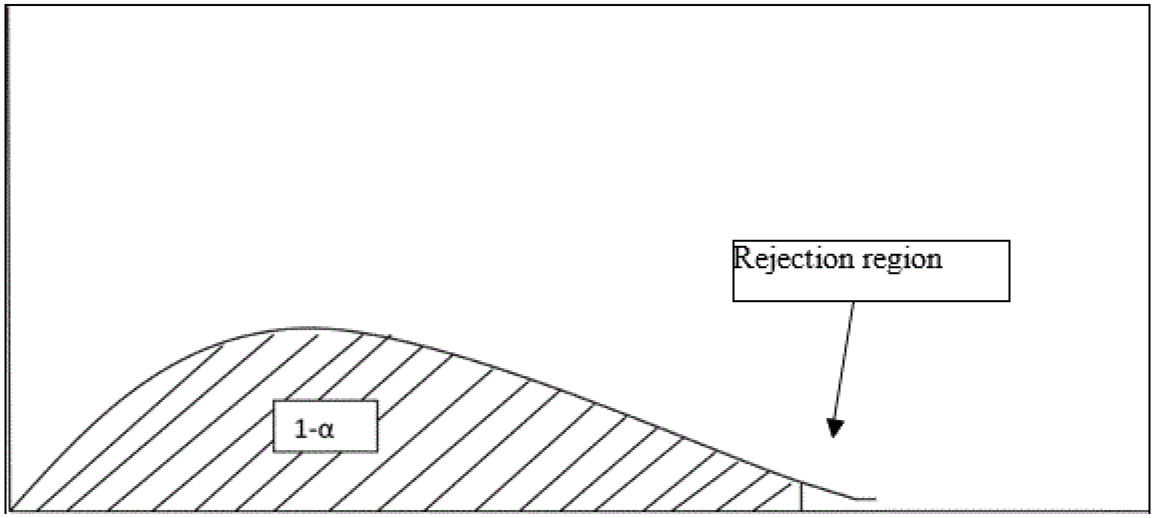
For a bivariate regression analysis:
H0 =b1 = 0
Or for multivariate analysis:
H0: b1 =b2=b3…bj = 0 in effect saying none of the regression coefficients is significant from 0

18.2.14. Where j is the total number of regression coefficients being tested in a particular multivariate regression run. Likewise, the Ha becomes:

For bivariate analysis:
H0 =b1 $\neq$ 0
Or for multivariate analysis:
Ha: Either b1, and/or b2, and/or b3, and/or...bj $\neq$ 0

18.2.15. To accomplish the F-test, two values are needed: the test statistic (F) that the ME analyst calculates, and the critical value (F*) that is obtained from our F-tables. Thus, if F > F*, enter the rejection region of H0 as shown in Figure 18.14, the ME analyst can reject the null hypothesis and know that at least one of our coefficients in a multivariate analysis (or the coefficient in a bivariate analysis) is significantly different than 0.

Figure 18.14. Showing the Rejection Region of the F-Test.



18.2.15.1. The test statistic (F) is the ratio of the variation explained by regression to the unexplained variation. Variations are obtained by dividing sum of squares with the respective degrees of freedom. Notice that because of the relationship between SSR and coefficient of determination (R2), this test statistic can be derived from either value. Notice also that when the double fraction is simplified (as in the first part of the relationship) the degrees of freedom for the numerator (m-1) appear in the denominator (as in the second part). The same switch occurs with the degrees of freedom for the denominator (n-m).

$$F = \frac{SSR/(m-1)}{SSE/(n-1)} = \frac{SSR(n-m)}{SSE(m-1)} = \frac{SSR/TSS(n-m)}{SSE/TSS(m-1)}$$

F, expressed as a function of R^2 is:

$$F = \left(\frac{r^2}{1-r^2}\right)\left(\frac{n-m}{m-1}\right)$$

18.2.15.2. It is the ratio of explained variation to unexplained variation, where:

$$explained\ variation = \frac{r^2}{m-1}$$, and

$$unexplained\ variation = \frac{1-r^2}{n-m}$$

18.2.15.3. The factors in the denominator of the latter two expressions are corrections for loss in degrees of freedom caused by making small sample estimates of explained and unexplained variance. It is important to note these are the equations to look at when determining degrees of freedom for the numerator and denominator of the F ratio in order to use the F table. Thus, it is (– 1) which determined the degrees of freedom for the numerator (df1), and (n-m) that determines the degrees of freedom for the denominator (df2). Note: The rearrangement of terms in the first equation is just for simplicity in doing the calculation rather than to indicate which correction goes with the numerator and which with the denominator.

18.2.15.4. The critical value for the F-test, $[\ast = (1-\propto, -1, -)]$, comes from the F-Table. First determine the confidence level desired. Note: C&R APPLICATION TOOL defaults to 80% confidence. To find the critical value, F*, read the F tables as follows: Table 18.15. F Table at 80% Confidence ($\alpha = .20$), Table 18.16. F Table at 90% Confidence ($\alpha = .10$), Table 18.17. F Table at 95% Confidence ($\alpha = .05$).

18.2.15.5. Find the degrees of freedom for the numerator (m-1) arrayed horizontally across the top of each of the tables. Find the degrees of freedom for the denominator (n-m) are vertically on the left hand side of the tables. Cross reference both the degrees of freedom for the numerator with the degrees of freedom with the denominator to obtain F*. For example, if the ME analyst wished to be 80% confident, and the data and regression analysis yielded 12 degrees of freedom in the numerator and 30 degrees of freedom in the denominator, the F* value from Table 18.15 = 1.446.

Table 18.15. F Table at 80% Confidence (α = .20).

80% Confidence (α = .20) Values for $F_{(.80,df1,df2)}$ Degrees of Freedom in the Numerator (m-1)—df_1													
	#	1	2	3	4	5	6	7	8	9	10	11	12
Degrees of Freedom in the Denominator (n-m)--df_2	1	9.472	12.000	13.064	13.644	14.008	14.258	14.439	14.577	14.685	14.772	14.844	14.904
	2	3.556	4.000	4.156	4.236	4.284	4.317	4.340	4.358	4.371	4.382	4.391	4.399
	3	2.682	2.886	2.936	2.956	2.965	2.971	2.974	2.976	2.978	2.979	2.980	2.981
	4	2.351	2.472	2.485	2.483	2.478	2.473	2.469	2.465	2.462	2.460	2.457	2.455
	5	2.178	2.259	2.253	2.240	2.228	2.217	2.209	2.202	2.196	2.191	2.187	2.184
	6	2.073	2.130	2.113	2.092	2.076	2.062	2.051	2.042	2.034	2.028	2.022	2.018
	7	2.002	2.043	2.019	1.994	1.974	1.957	1.945	1.934	1.925	1.918	1.911	1.906
	8	1.951	1.981	1.951	1.923	1.900	1.883	1.868	1.856	1.847	1.838	1.831	1.825
	9	1.913	1.935	1.901	1.870	1.846	1.826	1.811	1.798	1.787	1.778	1.771	1.764
	10	1.883	1.899	1.861	1.829	1.803	1.782	1.766	1.752	1.741	1.732	1.723	1.716
	11	1.859	1.870	1.830	1.796	1.768	1.747	1.730	1.716	1.704	1.694	1.685	1.678
	12	1.839	1.846	1.804	1.768	1.740	1.718	1.700	1.686	1.673	1.663	1.654	1.646
	13	1.823	1.826	1.783	1.746	1.717	1.694	1.676	1.661	1.648	1.637	1.628	1.620
	14	1.809	1.809	1.765	1.727	1.697	1.674	1.655	1.639	1.626	1.615	1.606	1.598
	15	1.797	1.795	1.749	1.710	1.680	1.656	1.637	1.621	1.608	1.596	1.587	1.578
	16	1.787	1.783	1.736	1.696	1.665	1.641	1.621	1.605	1.591	1.580	1.570	1.561
	17	1.778	1.772	1.724	1.684	1.652	1.628	1.608	1.591	1.577	1.566	1.555	1.547
	18	1.770	1.762	1.713	1.673	1.641	1.616	1.596	1.579	1.565	1.553	1.543	1.534
	19	1.763	1.754	1.704	1.663	1.631	1.605	1.585	1.568	1.554	1.542	1.531	1.522
	20	1.757	1.746	1.696	1.654	1.622	1.596	1.575	1.558	1.544	1.531	1.521	1.512
Degrees	21	1.751	1.739	1.688	1.646	1.614	1.588	1.567	1.549	1.535	1.522	1.511	1.502
	22	1.746	1.733	1.682	1.639	1.606	1.580	1.559	1.541	1.526	1.514	1.503	1.494

80% Confidence (α = .20) Values for $F_{(.80,df1,df2)}$
Degrees of Freedom in the Numerator (m-1)—df_1

	#	1	2	3	4	5	6	7	8	9	10	11	12
	26	1.729	1.713	1.660	1.617	1.583	1.556	1.534	1.516	1.500	1.487	1.476	1.466
	27	1.726	1.709	1.656	1.612	1.578	1.551	1.529	1.510	1.495	1.482	1.470	1.461
	28	1.723	1.706	1.652	1.608	1.573	1.546	1.524	1.505	1.490	1.477	1.465	1.455
	29	1.720	1.702	1.648	1.604	1.569	1.542	1.519	1.501	1.485	1.472	1.461	1.451
	30	1.717	1.699	1.645	1.600	1.565	1.538	1.515	1.497	1.481	1.468	1.456	1.446
	35	1.706	1.686	1.630	1.585	1.550	1.521	1.499	1.480	1.464	1.450	1.438	1.428
	40	1.698	1.676	1.620	1.574	1.538	1.509	1.486	1.467	1.451	1.437	1.424	1.414
	45	1.692	1.668	1.611	1.565	1.529	1.500	1.476	1.457	1.440	1.426	1.414	1.403
	50	1.687	1.662	1.605	1.558	1.522	1.492	1.469	1.449	1.432	1.418	1.405	1.394
	55	1.683	1.657	1.599	1.552	1.516	1.486	1.462	1.443	1.426	1.411	1.399	1.387
	60	1.679	1.653	1.595	1.548	1.511	1.481	1.457	1.437	1.420	1.406	1.393	1.382
	65	1.676	1.650	1.591	1.544	1.507	1.477	1.453	1.433	1.416	1.401	1.388	1.377
	70	1.674	1.647	1.588	1.540	1.503	1.473	1.449	1.429	1.412	1.397	1.384	1.372
	75	1.672	1.644	1.585	1.538	1.500	1.470	1.446	1.425	1.408	1.393	1.380	1.369
	80	1.670	1.642	1.583	1.535	1.497	1.467	1.443	1.422	1.405	1.390	1.377	1.366
	85	1.668	1.640	1.581	1.533	1.495	1.465	1.440	1.420	1.402	1.387	1.374	1.363
	90	1.667	1.639	1.579	1.531	1.493	1.463	1.438	1.418	1.400	1.385	1.372	1.360
	95	1.665	1.637	1.577	1.529	1.491	1.461	1.436	1.415	1.398	1.383	1.370	1.358
	100	1.664	1.636	1.576	1.527	1.489	1.459	1.434	1.414	1.396	1.381	1.368	1.356
	105	1.663	1.634	1.574	1.526	1.488	1.458	1.433	1.412	1.394	1.379	1.366	1.354
	110	1.662	1.633	1.573	1.525	1.487	1.456	1.431	1.410	1.393	1.378	1.364	1.352
	115	1.661	1.632	1.572	1.523	1.485	1.455	1.430	1.409	1.391	1.376	1.363	1.351
	120	1.661	1.631	1.571	1.522	1.484	1.454	1.429	1.408	1.390	1.375	1.361	1.350
	125	1.660	1.630	1.570	1.521	1.483	1.453	1.428	1.407	1.389	1.374	1.360	1.348
	130	1.659	1.630	1.569	1.520	1.482	1.452	1.426	1.406	1.388	1.372	1.359	1.347

80% Confidence (α = .20) Values for $F_{(.80,df1,df2)}$ Degrees of Freedom in the Numerator (m-1)—df_1													
	#	1	2	3	4	5	6	7	8	9	10	11	12
	135	1.659	1.629	1.568	1.519	1.481	1.451	1.426	1.405	1.387	1.371	1.358	1.346
	140	1.658	1.628	1.567	1.519	1.480	1.450	1.425	1.404	1.386	1.370	1.357	1.345
	145	1.657	1.627	1.567	1.518	1.480	1.449	1.424	1.403	1.385	1.369	1.356	1.344
	150	1.657	1.627	1.566	1.517	1.479	1.448	1.423	1.402	1.384	1.369	1.355	1.343
	155	1.656	1.626	1.566	1.517	1.478	1.447	1.422	1.401	1.383	1.368	1.354	1.342

Table 18.16. F Table at 90% Confidence (α = .10).

At 90% Confidence (α = .10)

Values for $F_{(.90,\, df1,\, df2)}$

Degrees of freedom in the numerator (m-1)--df_1

Degrees of Freedom in the Denominator (n-m)--df_2	1	2	3	4	5	6	7	8	9	10	11	12
1	39.863	49.500	53.593	55.833	57.240	58.204	58.906	59.439	59.858	60.195	60.473	60.705
2	8.526	9.000	9.162	9.243	9.293	9.326	9.349	9.367	9.381	9.392	9.401	9.408
3	5.538	5.462	5.391	5.343	5.309	5.285	5.266	5.252	5.240	5.230	5.222	5.216
4	4.545	4.325	4.191	4.107	4.051	4.010	3.979	3.955	3.936	3.920	3.907	3.896
5	4.060	3.780	3.619	3.520	3.453	3.405	3.368	3.339	3.316	3.297	3.282	3.268
6	3.776	3.463	3.289	3.181	3.108	3.055	3.014	2.983	2.958	2.937	2.920	2.905
7	3.589	3.257	3.074	2.961	2.883	2.827	2.785	2.752	2.725	2.703	2.684	2.668
8	3.458	3.113	2.924	2.806	2.726	2.668	2.624	2.589	2.561	2.538	2.519	2.502
9	3.360	3.006	2.813	2.693	2.611	2.551	2.505	2.469	2.440	2.416	2.396	2.379
10	3.285	2.924	2.728	2.605	2.522	2.461	2.414	2.377	2.347	2.323	2.302	2.284
11	3.225	2.860	2.660	2.536	2.451	2.389	2.342	2.304	2.274	2.248	2.227	2.209
12	3.177	2.807	2.606	2.480	2.394	2.331	2.283	2.245	2.214	2.188	2.166	2.147
13	3.136	2.763	2.560	2.434	2.347	2.283	2.234	2.195	2.164	2.138	2.116	2.097
14	3.102	2.726	2.522	2.395	2.307	2.243	2.193	2.154	2.122	2.095	2.073	2.054
15	3.073	2.695	2.490	2.361	2.273	2.208	2.158	2.119	2.086	2.059	2.037	2.017
16	3.048	2.668	2.462	2.333	2.244	2.178	2.128	2.088	2.055	2.028	2.005	1.985
17	3.026	2.645	2.437	2.308	2.218	2.152	2.102	2.061	2.028	2.001	1.978	1.958
18	3.007	2.624	2.416	2.286	2.196	2.130	2.079	2.038	2.005	1.977	1.954	1.933
19	2.990	2.606	2.397	2.266	2.176	2.109	2.058	2.017	1.984	1.956	1.932	1.912
20	2.975	2.589	2.380	2.249	2.158	2.091	2.040	1.999	1.965	1.937	1.913	1.892
21	2.961	2.575	2.365	2.233	2.142	2.075	2.023	1.982	1.948	1.920	1.896	1.875
22	2.949	2.561	2.351	2.219	2.128	2.060	2.008	1.967	1.933	1.904	1.880	1.859
23	2.937	2.549	2.339	2.207	2.115	2.047	1.995	1.953	1.919	1.890	1.866	1.845
24	2.927	2.538	2.327	2.195	2.103	2.035	1.983	1.941	1.906	1.877	1.853	1.832
25	2.918	2.528	2.317	2.184	2.092	2.024	1.971	1.929	1.895	1.866	1.841	1.820
26	2.909	2.519	2.307	2.174	2.082	2.014	1.961	1.919	1.884	1.855	1.830	1.809
27	2.901	2.511	2.299	2.165	2.073	2.005	1.952	1.909	1.874	1.845	1.820	1.799
28	2.894	2.503	2.291	2.157	2.064	1.996	1.943	1.900	1.865	1.836	1.811	1.790
29	2.887	2.495	2.283	2.149	2.057	1.988	1.935	1.892	1.857	1.827	1.802	1.781
30	2.881	2.489	2.276	2.142	2.049	1.980	1.927	1.884	1.849	1.819	1.794	1.773
35	2.855	2.461	2.247	2.113	2.019	1.950	1.896	1.852	1.817	1.787	1.761	1.739
40	2.835	2.440	2.226	2.091	1.997	1.927	1.873	1.829	1.793	1.763	1.737	1.715
45	2.820	2.425	2.210	2.074	1.980	1.909	1.855	1.811	1.774	1.744	1.718	1.695
50	2.809	2.412	2.197	2.061	1.966	1.895	1.840	1.796	1.760	1.729	1.703	1.680
55	2.799	2.402	2.186	2.050	1.955	1.884	1.829	1.785	1.748	1.717	1.691	1.668
60	2.791	2.393	2.177	2.041	1.946	1.875	1.819	1.775	1.738	1.707	1.680	1.657
65	2.784	2.386	2.170	2.033	1.938	1.867	1.811	1.767	1.730	1.699	1.672	1.649
70	2.779	2.380	2.164	2.027	1.931	1.860	1.804	1.760	1.723	1.691	1.665	1.641
75	2.774	2.375	2.158	2.021	1.926	1.854	1.798	1.754	1.716	1.685	1.658	1.635
80	2.769	2.370	2.154	2.016	1.921	1.849	1.793	1.748	1.711	1.680	1.653	1.629
85	2.765	2.366	2.149	2.012	1.916	1.845	1.789	1.744	1.706	1.675	1.648	1.624

		1	2	3	4	5	6	7	8	9	10	11	12
	90	2.762	2.363	2.146	2.008	1.912	1.841	1.785	1.739	1.702	1.670	1.643	1.620
	95	2.759	2.359	2.142	2.005	1.909	1.837	1.781	1.736	1.698	1.667	1.640	1.616
	100	2.756	2.356	2.139	2.002	1.906	1.834	1.778	1.732	1.695	1.663	1.636	1.612
	105	2.754	2.354	2.137	1.999	1.903	1.831	1.775	1.729	1.692	1.660	1.633	1.609
	110	2.752	2.351	2.134	1.997	1.900	1.828	1.772	1.727	1.689	1.657	1.630	1.606
	115	2.750	2.349	2.132	1.994	1.898	1.826	1.770	1.724	1.687	1.655	1.627	1.604
	120	2.748	2.347	2.130	1.992	1.896	1.824	1.767	1.722	1.684	1.652	1.625	1.601
	125	2.746	2.346	2.128	1.990	1.894	1.822	1.765	1.720	1.682	1.650	1.623	1.599
	130	2.745	2.344	2.126	1.989	1.892	1.820	1.764	1.718	1.680	1.648	1.621	1.597
	135	2.743	2.342	2.125	1.987	1.890	1.818	1.762	1.716	1.678	1.646	1.619	1.595
	140	2.742	2.341	2.123	1.985	1.889	1.817	1.760	1.714	1.677	1.645	1.617	1.593
	145	2.740	2.340	2.122	1.984	1.887	1.815	1.759	1.713	1.675	1.643	1.616	1.592
	150	2.739	2.338	2.121	1.983	1.886	1.814	1.757	1.712	1.674	1.642	1.614	1.590
	155	2.738	2.337	2.119	1.981	1.885	1.812	1.756	1.710	1.672	1.640	1.613	1.589

Table 18.17. F Table at 95% Confidence (α = .05).

At 95% Confidence (α = .05) Values for $F_{(.95, df1, df2)}$												
Degrees of freedom in the numerator (m-1)--df_1												
Degrees of Freedom in the Denominator (n-m)--df_2	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	161.448	199.500	215.707	224.583	230.162	233.986	236.768	238.883	240.543	241.882	242.983	243.906
2	18.513	19.000	19.164	19.247	19.296	19.330	19.353	19.371	19.385	19.396	19.405	19.413
3	10.128	9.552	9.277	9.117	9.013	8.941	8.887	8.845	8.812	8.786	8.763	8.745
4	7.709	6.944	6.591	6.388	6.256	6.163	6.094	6.041	5.999	5.964	5.936	5.912
5	6.608	5.786	5.409	5.192	5.050	4.950	4.876	4.818	4.772	4.735	4.704	4.678
6	5.987	5.143	4.757	4.534	4.387	4.284	4.207	4.147	4.099	4.060	4.027	4.000
7	5.591	4.737	4.347	4.120	3.972	3.866	3.787	3.726	3.677	3.637	3.603	3.575
8	5.318	4.459	4.066	3.838	3.687	3.581	3.500	3.438	3.388	3.347	3.313	3.284
9	5.117	4.256	3.863	3.633	3.482	3.374	3.293	3.230	3.179	3.137	3.102	3.073
10	4.965	4.103	3.708	3.478	3.326	3.217	3.135	3.072	3.020	2.978	2.943	2.913
11	4.844	3.982	3.587	3.357	3.204	3.095	3.012	2.948	2.896	2.854	2.818	2.788
12	4.747	3.885	3.490	3.259	3.106	2.996	2.913	2.849	2.796	2.753	2.717	2.687
13	4.667	3.806	3.411	3.179	3.025	2.915	2.832	2.767	2.714	2.671	2.635	2.604
14	4.600	3.739	3.344	3.112	2.958	2.848	2.764	2.699	2.646	2.602	2.565	2.534
15	4.543	3.682	3.287	3.056	2.901	2.790	2.707	2.641	2.588	2.544	2.507	2.475
16	4.494	3.634	3.239	3.007	2.852	2.741	2.657	2.591	2.538	2.494	2.456	2.425
17	4.451	3.592	3.197	2.965	2.810	2.699	2.614	2.548	2.494	2.450	2.413	2.381
18	4.414	3.555	3.160	2.928	2.773	2.661	2.577	2.510	2.456	2.412	2.374	2.342
19	4.381	3.522	3.127	2.895	2.740	2.628	2.544	2.477	2.423	2.378	2.340	2.308
20	4.351	3.493	3.098	2.866	2.711	2.599	2.514	2.447	2.393	2.348	2.310	2.278
21	4.325	3.467	3.072	2.840	2.685	2.573	2.488	2.420	2.366	2.321	2.283	2.250
22	4.301	3.443	3.049	2.817	2.661	2.549	2.464	2.397	2.342	2.297	2.259	2.226
23	4.279	3.422	3.028	2.796	2.640	2.528	2.442	2.375	2.320	2.275	2.236	2.204
24	4.260	3.403	3.009	2.776	2.621	2.508	2.423	2.355	2.300	2.255	2.216	2.183
25	4.242	3.385	2.991	2.759	2.603	2.490	2.405	2.337	2.282	2.236	2.198	2.165
26	4.225	3.369	2.975	2.743	2.587	2.474	2.388	2.321	2.265	2.220	2.181	2.148
27	4.210	3.354	2.960	2.728	2.572	2.459	2.373	2.305	2.250	2.204	2.166	2.132
28	4.196	3.340	2.947	2.714	2.558	2.445	2.359	2.291	2.236	2.190	2.151	2.118
29	4.183	3.328	2.934	2.701	2.545	2.432	2.346	2.278	2.223	2.177	2.138	2.104
30	4.171	3.316	2.922	2.690	2.534	2.421	2.334	2.266	2.211	2.165	2.126	2.092

	35	4.121	3.267	2.874	2.641	2.485	2.372	2.285	2.217	2.161	2.114	2.075	2.041
	40	4.085	3.232	2.839	2.606	2.449	2.336	2.249	2.180	2.124	2.077	2.038	2.003
	45	4.057	3.204	2.812	2.579	2.422	2.308	2.221	2.152	2.096	2.049	2.009	1.974
	50	4.034	3.183	2.790	2.557	2.400	2.286	2.199	2.130	2.073	2.026	1.986	1.952
	55	4.016	3.165	2.773	2.540	2.383	2.269	2.181	2.112	2.055	2.008	1.968	1.933
	60	4.001	3.150	2.758	2.525	2.368	2.254	2.167	2.097	2.040	1.993	1.952	1.917
	65	3.989	3.138	2.746	2.513	2.356	2.242	2.154	2.084	2.027	1.980	1.939	1.904
	70	3.978	3.128	2.736	2.503	2.346	2.231	2.143	2.074	2.017	1.969	1.928	1.893
	75	3.968	3.119	2.727	2.494	2.337	2.222	2.134	2.064	2.007	1.959	1.919	1.884
	80	3.960	3.111	2.719	2.486	2.329	2.214	2.126	2.056	1.999	1.951	1.910	1.875
	85	3.953	3.104	2.712	2.479	2.322	2.207	2.119	2.049	1.992	1.944	1.903	1.868
	90	3.947	3.098	2.706	2.473	2.316	2.201	2.113	2.043	1.986	1.938	1.897	1.861
	95	3.941	3.092	2.700	2.467	2.310	2.196	2.108	2.037	1.980	1.932	1.891	1.856
	100	3.936	3.087	2.696	2.463	2.305	2.191	2.103	2.032	1.975	1.927	1.886	1.850
	105	3.932	3.083	2.691	2.458	2.301	2.186	2.098	2.028	1.970	1.922	1.881	1.846
	110	3.927	3.079	2.687	2.454	2.297	2.182	2.094	2.024	1.966	1.918	1.877	1.841
	115	3.924	3.075	2.683	2.451	2.293	2.178	2.090	2.020	1.962	1.914	1.873	1.837
	120	3.920	3.072	2.680	2.447	2.290	2.175	2.087	2.016	1.959	1.910	1.869	1.834
	125	3.917	3.069	2.677	2.444	2.287	2.172	2.084	2.013	1.956	1.907	1.866	1.830
	130	3.914	3.066	2.674	2.441	2.284	2.169	2.081	2.010	1.953	1.904	1.863	1.827
	135	3.911	3.063	2.672	2.439	2.281	2.166	2.078	2.008	1.950	1.901	1.860	1.825
	140	3.909	3.061	2.669	2.436	2.279	2.164	2.076	2.005	1.947	1.899	1.858	1.822
	145	3.906	3.058	2.667	2.434	2.277	2.162	2.073	2.003	1.945	1.897	1.855	1.819
	150	3.904	3.056	2.665	2.432	2.274	2.160	2.071	2.001	1.943	1.894	1.853	1.817
	155	3.902	3.054	2.663	2.430	2.273	2.158	2.069	1.999	1.941	1.892	1.851	1.815

18.2.16. If the test statistic is larger or equal to the critical value such that $F \geq$, F * the equation's coefficient(s) are significantly different from 0, and the equation does explain a significant amount of variation in the sampled man-hours.

18.2.17. For example, suppose a ME analyst has performed an initial C&R analysis using 30 samples (n) and three potential WLFs (m=4), and achieved a coefficient of determination (R2) value of .8728.

Step 1. First, calculate the F-value

$$F = \left(\frac{r^2}{1-r^2}\right)\left(\frac{n-m}{m-1}\right) \xrightarrow{yields} \left(\frac{0.8728}{1-0.8728}\right)\left(\frac{30-4}{4-3}\right) = 59.461$$

18.2.18. Step 2. Using Table 18.15 (at 80% statistical confidence, $\propto = .20$), with 3 (m-1) degrees of freedom in the numerator, and 26 (n-m) degrees of freedom in the denominator, to get an F* value of 1.660.

18.2.19. Step 3. Since $F \geq F$ * (59.461 ≥ 1.660), the ME analyst can state that at least one or more of the coefficients is significantly different from 0, and the equation does explain a significant amount of variation in the sampled man-hours.

18.2.20. The t-test. With completion of the F test, the ME analyst knows at least one of its regression coefficients in a multivariate analysis is significantly different from 0. However, this begs the question: are all of the coefficients significantly different from 0? Generally data is not collected for a WLF if its coefficient was not significant, another set of tests is performed: the t-test. Note: There may be situations, for a given manpower study, that favor keeping in the manpower model a WLF that does not pass the t-test. For example, a functional community may be very concerned specific workload be part of the final manpower model. At the discretion of the ME analyst, a WLF that fails the t-test may be retained in the final manpower model; however, this practice should be kept to a minimum. The worst consequence of such a decision is the retention of a variable contributing very little statistically to the equation, and manpower is later expended to collect WLF data each time the equation is applied.

18.2.20.1. Thus, for parabola and multivariate equations, in addition to the "F" test, each regression coefficient is tested for significance using a "t" test in order to be kept in the final man-hour equation. The t-test determines if each of the individual coefficients of a multivariate (or parabolic) equation are significantly different from zero. A value whose coefficient is not significantly different from zero contributes little to the prediction equation and should not normally be retained.

18.2.20.2. As with the F-test, a test statistic and a critical value are needed to perform this test. The critical value, [$\mathbf{t}^* = \mathbf{t}_{(1-\propto/2, n-1)}$], comes from the t-Table at Table 18.18. Because the t-test is two tailed (concerned with values positively and negatively different from zero (See Figure 18.15.) the alpha-level is split evenly between the upper and lower tails. The degrees of freedom for the t-test are the number of measurement samples less one (n-1).

Table 18.18. t-Tables—Columns Representing 80, 90, 95% Confidence Levels.

df	80%	90%	95%	df	80%	90%	95%
1	3.0777	6.3138	12.7062	17	1.3334	1.7396	2.1098
2	1.8856	2.9200	4.3027	18	1.3304	1.7341	2.1009
3	1.6377	2.3534	3.1824	19	1.3277	1.7291	2.0930
4	1.5332	2.1318	2.7764	20	1.3253	1.7247	2.0860
5	1.4759	2.0150	2.5706	21	1.3232	1.7207	2.0796
6	1.4398	1.9432	2.4469	22	1.3212	1.7171	2.0739
7	1.4149	1.8946	2.3646	23	1.3195	1.7139	2.0687
8	1.3968	1.8595	2.3060	24	1.3178	1.7109	2.0639
9	1.3830	1.8331	2.2622	25	1.3163	1.7081	2.0595
10	1.3722	1.8125	2.2281	26	1.3150	1.7056	2.0555
11	1.3634	1.7959	2.2010	27	1.3137	1.7033	2.0518
12	1.3562	1.7823	2.1788	28	1.3125	1.7011	2.0484
13	1.3502	1.7709	2.1604	29	1.3114	1.6991	2.0452
14	1.3450	1.7613	2.1448	30	1.3104	1.6973	2.0423
15	1.3406	1.7531	2.1314	> 30	1.2820	1.6450	1.9600
16	1.3368	1.7459	2.1199				

18.2.20.3. If the test statistic (t) calculated from the data (considering it as an absolute value) is greater than or equal to the critical value ($t \geq t^*$) or ($t \leq -t^*$), the coefficient in question is significantly different from zero and should be used in the equation. The t test statistic is calculated as:

$$t_{b_i} = \frac{b_i}{s_{b_i}}$$

Where:
t_{bi} = the t test statistic
b_i = the particular regression coefficient in equation being tested
s_{bi} = standard error of the slope of the equation for the individual coefficient being test, which can be determined as:

$$s_{b_i} = \sqrt{\frac{\frac{\Sigma(Y_m - Y_c)^2}{n-2}}{\Sigma(X_i - \bar{X})^2}}$$

Where X_i represents the particular tested coefficient's potential WLF values.

18.2.20.4. For example, suppose an ME analyst is now given 4 WLFs, with 10 samples for the data shown in Table 18.19. Example Data—t Test Example. This data yields the man-hour equation using multivariate regression of:

$Y_c = -112.05 + 30.913X_1 + .008916X_2 - 2.668X_3 + .1986X_4$

Table 18.19. Example Data—t Test Example.

Ym	X1	X2	X3	X4
798.7	36	5431	88	645
1124.6	41	16342	210	1276
608.7	24	3839	62	389
491.2	24	16118	185	1034
576.8	32	6393	108	1100
1607.5	48	3217	72	1284
889.7	35	3012	95	753
363.3	12	2014	48	239
704	33	6932	91	480
1300	44	4102	81	799

18.2.20.5. From the above equation, the ME analyst has determined the coefficients of:

$b_1 = 30.913$
$b_2 = .008916$
$b_3 = -2.668$
$b_4 = 0.1986$

18.2.20.6. Through previous calculations, the ME analyst has also found an SSE of:

$SSE = \sum(Y_m - Y_c)^2 = 189562$

18.2.20.7. Now the ME analyst has all the necessary information to conduct calculations to find the t-test statistic for each individual coefficient being tested:

18.2.20.8. Step 1. Find the standard error of the slope of the equation for the first coefficient tested, with

n =10:

$$S_{b_1} = \sqrt{\frac{\frac{\sum(Y_m - Y_c)^2}{n-2}}{\sum(X_1 - \bar{X})^2}} \xrightarrow{yields} \sqrt{\frac{\frac{189562}{8}}{1026.9}} = 4.8036$$

18.2.20.9. Step 2. Now calculate the t-test statistic for the first coefficient being tested, the calculations are as follows:

$$t_{b_1} = \frac{b_1}{S_{b_1}} \xrightarrow{yields} \frac{30.913}{4.8036} = 6.4354$$

18.2.20.10. Step 3. Using Table 18.15 (at 80% statistical confidence), and with 9 (i.e., n-1) degrees of freedom, the value = 1.3830.

18.2.20.11. Step 4. Since $t_{b1} \geq t^*$ (6.4354 ≥ 1.3830), the coefficient is significantly different from zero and should be used in the equation.

18.2.20.12. Step 5. Now following steps 1- 4, repeat calculations to find the t-test statistic for the second coefficient being tested:

$$S_{b_2} = \sqrt{\frac{\frac{\sum(Y_m - Y_c)^2}{n-2}}{\sum(X_1 - \bar{X})^2}} \xrightarrow{yields} \sqrt{\frac{\frac{189562}{8}}{246035476}} = 0.009814$$

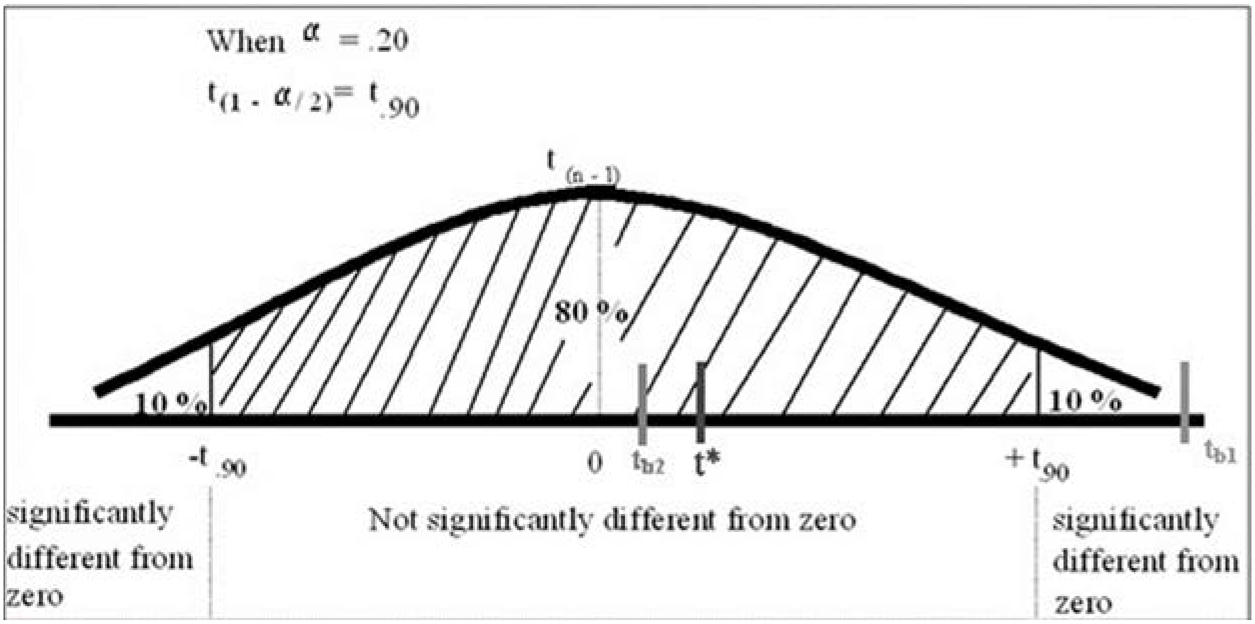
$$t_{b_2} = \frac{b_2}{S_{b_2}} \xrightarrow{yields} \frac{0.008916}{0.009814} = 0.9085$$

18.2.20.13. Step 6. Since $t_{b2} \geq t^*$, (.9085 ≥ 1.3830), the coefficient b2 is not significantly different from zero and should not be used in the manpower equation. (**Note:** Recall in some instances, a functional community may be concerned a specific WLF be in the final equation even if the coefficient failed the t-test. At the discretion of the ME analyst, the failed coefficient can be kept in the equation; however, this practice should be kept at a minimum since it drives additional cost of data collection for determinants application with little effect.)

18.2.20.14. Step 7. Repeat, steps 1- 4, for the remaining test coefficients b3 and b4.

18.2.20.15. Figure 18.15 shows the two tailed test and rejection areas for the null hypothesis when performing the t-test. (**Note:** The calculations of the t-test statistics for b1 and b2 for the example in Steps 1 through 6 are shown below placed on the figure.)

Figure 18.15. Decision Rule for the t-Test.



18.2.20.16. Equations that do not satisfy the realistic and economy criteria are not acceptable as manpower models. Reasons why a model may not have the desired attributes include such things as incorrect input data, non-representative input data, limited range of workload values, two or more distinct levels of operation included in the data, non-standardization of the system, extreme values included in the data, and inappropriate model selection. Man-hour equation coefficients meet both the realistic and economic criteria when in: The linear model (Y = a + bX) b-coefficient is positive. Increases in workload result in a constant positive increase in manpower. In a multivariate model, a given "b" value may be negative; however, in all realistic scenarios, an increase in workload should yield a total increase in required man-hours. The parabolic model ($Y = a + bX + cX^2$) b-coefficient is positive, and the value of cX2 is negative, and workload values do not exceed the point where X = -b/2c (i.e., the parabola's apex). If the "b" and "c" conditions are met and workload is greater than -b/2c, increasing workload after the apex results in decreasing manpower and the model is not realistic. The power model (Y = aXb) a-coefficient is positive and b-coefficient is between zero and one. This restricts the model to an increasing function where Y increases more slowly as X increases. The ratio model [Y = X/(a + bX)] a-coefficient and b-coefficient are greater than zero.

18.2.20.17. Potential Problems Encountered When Doing C&R. Sometimes during multivariate C&R analysis, two or more of the independent variables may be highly correlated with each other. This situation is called multicollinearity, and it is an undesirable condition. This means there are correlated independent X-variables adding similar (thus, little additional) information to the model.

18.2.20.18. Note: In some instances, there is not always a clear distinction between variables as to which is the dependent and which is the independent variable. For example, regressing a function's manpower against the WLFs of PAI and aircrew positions earned, API codes 1 and 2 shown on the UMD may yield a multicollinearity situation since API codes 1 and 2 are earned through a constant aircrew to aircraft ratio. Thus, in this situation, these WLFs are likely to create multicollinearity and add little additional significance to the model. Would there ever be a situation where, in the above example, the ME analyst might still wish to regress both PAI and API codes 1 and 2? Possibly, for example, Aircrew Flight Equipment has separate and distinct workload driven by both aircraft and aircrew, and thus a ME analyst may wish to explore both WLFs. Pairwise Analysis of X WLF Values. The C&R APPLICATION TOOL provides a pairwise analysis of WLFs to assist the ME analyst analyze the C&R results. This pairwise analysis regresses each X WLF against each of the other WLFs showing the R-value (Coefficient of Correlation) as shown in the matrix in Figure 18.16. (Note: C&R APPLICATION TOOL also performs a bivariate analysis with each WLF with the Y value in the third column; here, high positive r values are desired.)

Figure 18.16. C&R APPLICATION TOOL Pairwise Analysis.

LFs HSD, ACP, PAI, MDS, FH, SORT, and MWS as shown reveal a high degree of multicollinearity occurring between the certain pairs.

Pairwise Analysis from MSDS

	Y						
X_1	0.5534						
X_2	0.7850	0.6138					
X_3	0.6315	0.4493	0.7246				
X_4	0.2532	-0.1334	0.0288	0.3046			
X_5	0.5903	0.5044	0.7950	0.8140	-0.0748		
X_6	0.5111	0.4323	0.8298	0.8157	0.0995	0.8016	
X_7	-0.1261	-0.1497	-0.1005	-0.0843	0.5998	-0.1199	-0.0387

Table 18.20. Selected Pairwise X Pairs Depicting a High Degree of Multicollinearity.

WLF Pair	R-Value
X1, X2	.6138
X2, X3	.7246
X2, X5	.7950
X3,X5	.8140
X2, X6	.8298
X3, X6	.8157
X5, X6	.8016
X5, X7	.5998

18.2.20.19. Although the best defense against multicollinearity is applying logic early on in the effort, the ME analyst can spot multicollinearity occurring by viewing and/or conducting the pairwise analysis and take appropriate action by not regressing these particular potential WLFs together.

18.2.20.20. Using only the statistic R^2, the coefficient of determination for bivariate regression analysis, or coefficient of multiple correlation for multivariate regression (R2), as a measure of absolute goodness can be misleading. When the data points collected comes closer to the number of potential WLFs used in regression analysis, R2 may be artificially high. For example, three data points fit exactly an equation with three coefficients ($Y = a + bX + cX^2$), thus producing a misleading R^2 value of 1 (perfect correlation). The objective is to find an equation that accurately explains most of the variation within a system not to achieve a perfect mathematical fit.

18.2.20.21. While evaluating C&R results, the ME analyst needs to understand the difference between measured man-hours that are fixed (man-hours that remain constant relative to changes in WLF counts) and those that are variable (man-hours that do vary (positively) with changes in WLF counts). It is possible the statistical R^2 value can be improved and made more relevant by regressing only the measured variable man-hours that relate to a potential WLF and adding back the fixed man-hours as constant man-hours to the final man-hour equation.

18.2.21. Guidelines for Final Manpower Model Selection. After creating multiple manpower models, the ME analyst is often left with the task of evaluating one or more manpower equations for final posting in a manpower determinant. The final acceptance selection a manpower model for that work center needs a balance between several different factors.

18.2.21.1. Absolute Minimum Criteria for Selection. Any given model is required to first pass the following minimum criteria for selection as a manpower model:

18.2.21.1.1. All equations, regardless of equation form, are required to meet minimum statistical criteria outlined in Table 18.3. No further consideration can be given to those models that do not meet this minimum statistical criteria.

18.2.21.1.2. All equations should not have a high resultant "a" value in a manpower model. A model is unacceptable when it's "a" value quantifies the majority of the work center's manpower requirement.

18.2.21.1.2.1. For example, let's examine the equation Y= 540 + .0015X (where X = base military population). The equation's b-value when combined with the WLF (X) results in relatively insignificant man-hours; that is, an increase of 10,000 military personnel (i.e., the X value) only creates 15 man-hours of additional required man-hours.

18.2.21.1.2.2. In this example, the slope of the regression line is basically flat, and therefore, the WLF has little effect on determining the work center's total man-hour requirement.

18.2.21.2. If one or more possible manpower equations remain after meeting the criteria outline in paragraphs 18.2.21.1.1 and 18.2.21.2.1.2, then the following criteria, in order of precedence, for selecting the final manpower model is as follows:

18.2.21.2.1. Model Impact. The prime consideration for any model selection is accuracy and if that accuracy is manifested through the equation's impact. (Note: Impact here normally means the ME analyst has considered all requirements, and all possible variances have been identified and already taken into consideration. However, sometimes a potential manpower equation's impact may lead to the further development of variances upon further analysis.) Generally, those models with the higher coefficient of determination (R2) and lower coefficient of variation (V) values generally have the more favorable impact. However, always check this assumption against an actual equation application, and the lead and functional team's insight into the logic of the by-location impact.

18.2.21.2.1.1. A manpower equation's impact is judged by each location and not in the aggregate. In other words, the model's impact is logical and reasonable at each location where the model applies.

18.2.21.2.1.2. Judging a manpower equation by its aggregate impact, i.e., adding together all the manpower increases and decreases together for all affected bases in an effort, means little to the true accuracy of the requirements model.

18.2.21.2.2. Ease of Manpower Determinant Application. If two or more equations still continue to pass acceptable impact, the next model selection criteria is focused on ease of application. Specifically, consider the total workload in applying the determinant:

18.2.21.2.2.1. First, select manpower equations with programmable WLFs (i.e., an equation with some or more programmable WLFs should be selected over equations with no or fewer programmable WLFs).

18.2.21.2.2.2. Next, if all is still equal, choose the equation with the fewest WLFs to further reduce the workload of installation and command manpower and functional communities involved with the collection of WLFs and equation application required.

18.2.21.3. Selecting the Simplest Regression Equation Form. If all other criteria still put the remaining potential manpower equations as equal, select the simplest equation beginning with bivariate linear, curvilinear bivariate, and finally multivariate linear.

18.2.21.4. Functional and MAJCOM Manpower Community Consideration. Finally, if all other criteria have been met and a final manpower equation still requires selection, consult with the Air Force and MAJCOM functional communities as well as the MAJCOM manpower communities for input on final man-hour equation selection.

18.3. Extrapolation Limits Determination.

18.3.1. General Concepts. Any man-hour equations developed via C&R analysis techniques as well as man-hour equations developed via ratio unit times equations, are bounded by extrapolation limits.

18.3.1.1. Upper and lower extrapolations limits are established, as the Air Force MEP would assume too much risk in further presupposing an equation's behavior remains the same beyond the established extrapolation limits. For example, a function's manpower initially determined by a bivariate linear equation may truly become non-linear beyond a certain point. Further, the extrapolation limits at the same time allow a certain amount of flexibility in they do allow extrapolation beyond the sampled workload data used to initially create the man-hour equation, thus extending and expanding the life and use of the newly-developed manpower determinant.

18.3.1.2. Man-hour equation extrapolation limits are established, as follows:

18.3.1.2.1. The upper extrapolation limit is established at 25% above the largest calculated man-hour value of the sample data used to create the man-hour equation.

18.3.1.2.2. The lower extrapolation limit is established at 25% below the smallest calculated man-hour value of the sample data used to create the man-hour equation.

18.3.1.2.3. Based upon the definition of the upper and lower extrapolation limits in paragraph 18.3.2, it is incumbent upon the ME analyst to sample large and small bases during equation selection. Getting large and small work centers in the original analysis allows for a wider (if not widest possible) application of the new manpower determinant across the USAF.

18.3.2. Calculating Extrapolation Limits.

18.3.2.1. Determining the Upper Extrapolation Limit. To determine the upper extrapolation limit of the man-hour equation, the following formula is used:

18.3.2.1.1. Upper Extrapolation Limit = max Y_c x 1.25.

Where Y_c = largest calculated value based upon the original sample data to create the equation.

18.3.2.2. Determining the Lower Extrapolation Limit. To determine the lower extrapolation limit of the man-hour equation, the following formula is used:

18.3.2.2.1. Lower Extrapolation Limit = x .75.

Where Y_c = smallest calculated value based upon the original sample data to create the equation.

18.3.2.2.2. Using the functional modeling data from Table 22.1, the last two columns of Table 18.21 show the lower and upper extrapolation limits. The Upper Extrapolation limit is 25% above the highest value (Base E) and equals 2718.55 man-hours. The lower extrapolation limit is 25% below above the smallest value (Base A) and equals 644.67 man-hours.

Table 18.21. Determining Extrapolation Limits Example.

Y = -327.4 + 1.604X r^2 = .954 V = .072				Lower Extrapolation Limit Calculation	Upper Extrapolation Limit Calculation
BASE	**(Y)**	**WLF (X)**	**CALCULATED (Yc)**	min Y_c x .75	max Y_c x 1.25
A	966.72	740	859.56	.75 x 859.56 = 644.67	1.25 x 2174.84 = 2718.55
B	1127.83	980	1244.52		
C	1772.31	1270	1709.68		
D	1450.07	1100	1437.00		
E	2094.55	1560	2174.84		
F	966.72	8905	1100.16		
G	2094.55	1500	2078.60		
H	1772.31	122	1637.50		

18.3.2.3. Final Manpower Determinant Range. The final applicability range of the manpower determinant is simply the range from the lower to the upper extrapolation limit.

18.3.3. Using C&R APPLICATION TOOL. C&R APPLICATION TOOL automatically calculates the extrapolation limits in accordance with this guidance.

18.4. Single-Location Regression Analysis. Single-location regression analysis uses time series regression when multiple data sets can be obtained by one of the following methods.

18.4.1. Use historical data when reliable monthly man-hour and workload accounting records exist. Establish a collection cycle to gather the necessary measurement data over a given time period. Regress a minimum of 6 months, preferably 12 months, historical man-hour data against monthly workload data for each of the monthly periods. Use simulation modeling to generate manpower estimates under varying simulated workloads. The ME analyst can simulate various workload volumes and record the amount of manpower expended to deliver each of these workloads. Once a minimum of seven different workload volume scenarios have been analyzed (meaning enough samples have been taken under a given workload volume to ensure statistical confidence and precision of each data point), the ME analyst can regress the different manpower required against the different simulated workloads to create the manpower equation. For example, suppose an installation has an accurate reporting system for flying hours(X) and productive man-hours (Ym). Use the historical data for the past year to get an equation that relates flying hours to productive man-hours. Evaluate the equation with the coefficient of determination (R2) and coefficient of variation (V) criteria and the F-test. Figure 18.17 shows how to use regression analysis to build a manpower determinant at a single location from historical data.

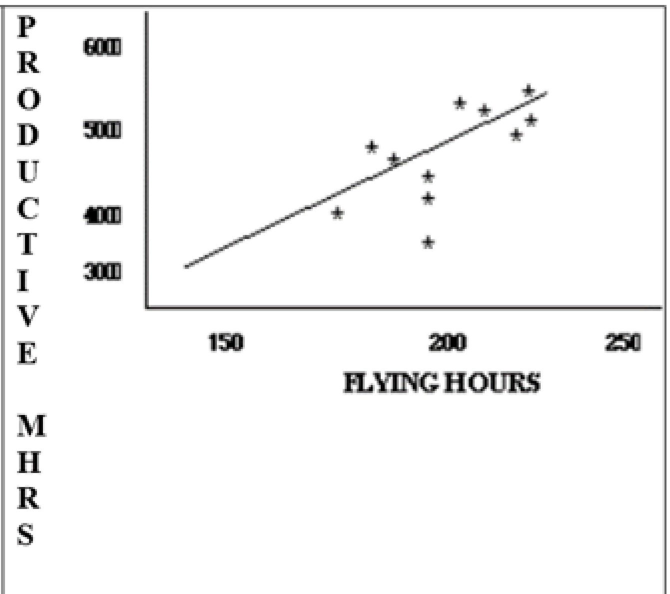
Figure 18.17. Example Using Regression Analysis and Historical Data for a Single Location Determinant.

MONTH	REPORTED FLYING HOURS (X)	REPORTED PRODUCTIVE MAN-HOURS (Y_m)
JAN	230	5500
FEB	190	4400
MAR	190	4800
APR	170	4100
MAY	190	3900
JUN	180	4300
JUL	170	4700
AUG	220	5500
SEP	200	5100
OCT	240	5500
NOV	230	5300
DEC	240	6000

$Y_c = 498.808 + 21.679X$

$R^2 = .755$

$V = .069$



Critical F* = F(.95,1,10) = 4.96

Critical F* = 30.964

30.964 > 4.96

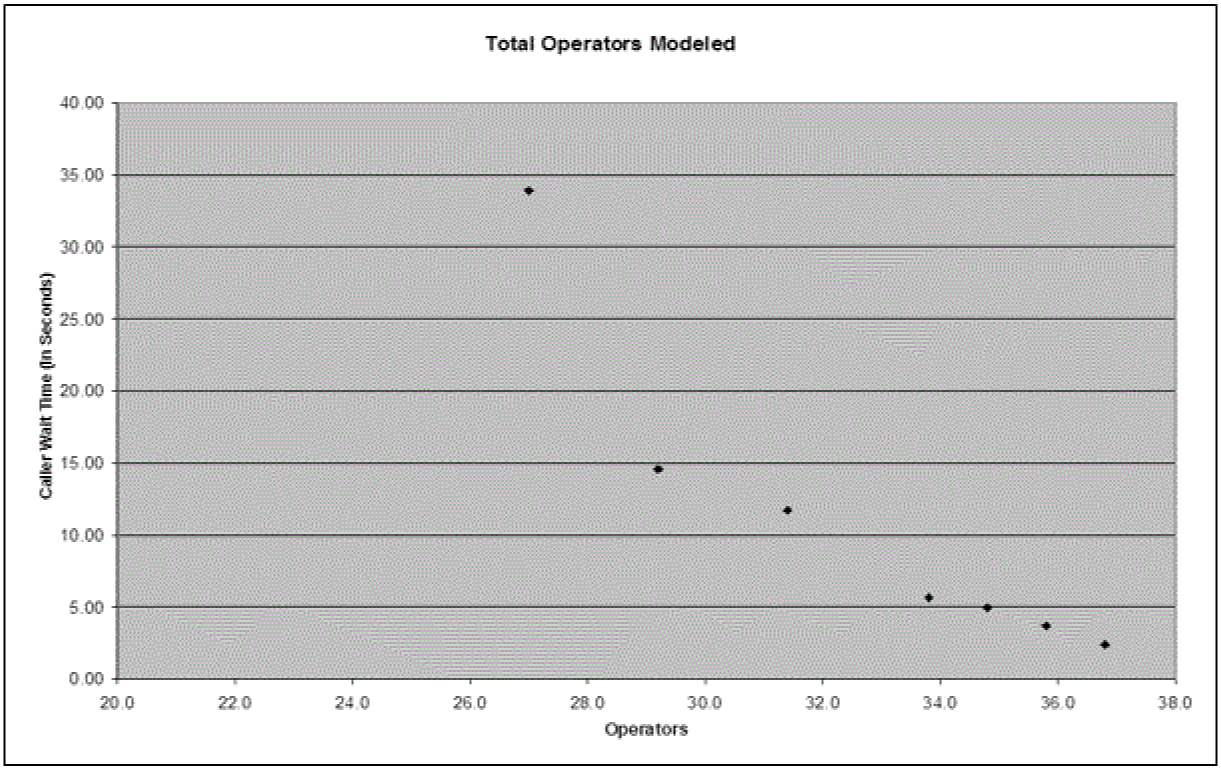
therefore, it passes the F-test

18.4.1.1. A scatter diagram of the data showed a strong linear trend and later regression analysis supported this initial indication. The computed value of F is larger than .95,1,10 = 4.96. This shows the regression model and WLF combination accounts for some of the variation in the man-hours. The sample coefficient of determination (R2) shows the model picked ($Y_c = a + bX$) and the independent variable used (reported flying hours) account for approximately 76% of the variation in the reported productive man-hours. The sample coefficient of variation shows the standard error of the estimate is approximately 6% as large as the average reported productive man-hours.

18.4.1.2. Other uses for C&R within the Air Force MEP. Although C&R has been primarily used to create man-hour forecasting equations with the Air Force's MEP, other pertinent uses exist for C&R's application. Levels of service and C&R. An ME analyst either deals with different levels of service because this situation occurs often in the field, or the ME analyst is asked by the functional community to explore different levels of service and the manpower impacts. For example, Figure 18.18., shows a scatter diagram used as the initial visual exploration of the relationship between the required manpower (in this case, Telephone Operators) and the time a caller waits to reach a live human operator at a single-point location. Logically, the more operators available to take caller phone calls (assuming the caller customer demands stays constant), the less time a caller has to wait to reach an available operator.

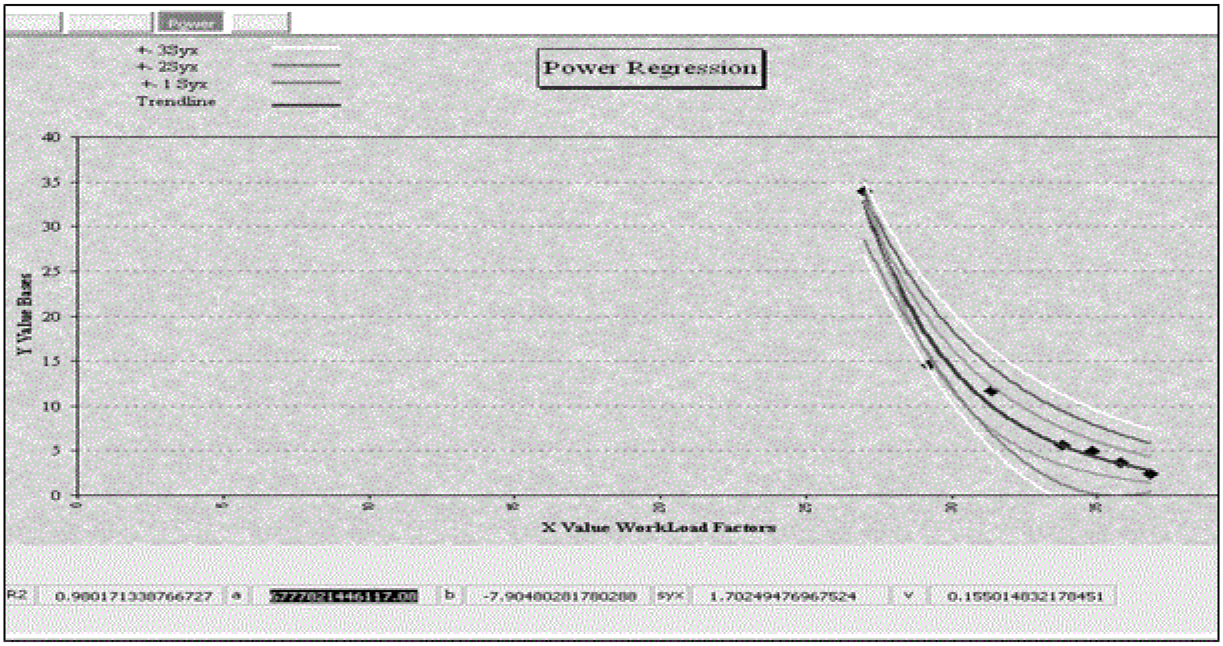
18.4.1.3. Note importantly in this case, the manpower required is on the x-axis, as the manpower required (again, logically) is considered the cause of the caller's resultant wait time (the effect) with the wait as a time-based performance measure for this function. Further, and as logically expected, the effect shows a negative correlation. (Here, a negative correlation is a good thing and logical, as the caller wait time is expected to decrease with an increase in the number of telephone operators.)

Figure 18.18. Plotting Telephone Operators and Caller Wait Time.



18.4.1.4. Performing C&R on this data would yield the results shown in Figure 18.19. Using the resulting equation derived via C&R, the ME analyst can now begin to use mathematical relationships defined by the equation to predict the performance measure's (i.e., caller wait time) impact against varying levels of telephone operator manpower.

Figure 18.19. Power Equation - Number of Telephone Operators and Resulting Caller Wait Time.



18.4.1.5. Another important lesson learned from this example is time-based, as well as throughput-based, functional performance measures are ideal measures to explore varying levels of manpower and the effect on performance. Again, C&R only quantifies the mathematical relationship (i.e., regression) and defines the goodness of fit of the data set explored (i.e., correlation) between the manpower and the resultant effect; logic and science proves the relationship.

18.4.1.6. Learning More About Statistics. The preceding information was provided to give the manpower ME analyst a very basic understanding of the computations needed to perform regression analysis for Air Force MEP efforts and how the statistics interrelate, to include specific criteria that apply to the Air Force MEP. This chapter was not intended to make one an expert statistician. In practice, computer programs are used to perform the mathematics, but the ME analyst is responsible for having the knowledge needed to understand and interpret results. A myriad of resources exist to help understand statistical information from the internet, books, and professional courses.

Chapter 19

CORE MODELING

19.1. General Concepts. Core modeling is a study technique designed to capture common core workload and related manpower requirements for a particular function. The process still allows for differences (variances) caused by mission, technological, or environmental factors. In the past, it was difficult to obtain our customer's or functional OPR's concurrence because of the uncertainty of whether or not credit was given for all work (including unique or peculiar situations) done by the function. Core modeling may be used with almost any measurement method, except WS. It is particularly suited to workshop measurement when using FP charting, OA, and staffing pattern methods to determine requirements. For our purposes, core workload is the most important part of a work center's or function's workload that is completed to accomplish the mission.

19.1.1. A depiction of core modeling would be:

19.1.1.1. Functional core man-hours with variance man-hours for individual differences. The total man-hours are then used to determine total work center man-hours.

19.1.1.2. Then, total work center man-hours are divided by the MAF to find the total work center requirements.

19.2. Specific Procedures.

19.2.1. The procedures for developing a core modeling manpower determinant are basically the same steps as any other determinant, but the sequence of the operations are different. The steps are as follows:

19.2.2. Develop the core SWD identifying only minimum requirements necessary to perform the work center's mission. This should be a coordinated effort between the functional and manpower communities, and all customers should give full participation.

19.2.3. Verify the SWD and obtain approval of the core SWD with all customers. Also request the customers start identifying differences (variances) and unique situations not included in the core SWD, but essential to mission completion. Keep in mind variances are only for environmental, technological, or mission differences, not for nice-to-have programs, indirect work, additional duties, etc.

19.2.4. The study team develops and measures the core model. Use whatever measurement method is most conducive for the function.

19.2.5. The study team prepares a final report with only the core model equations identified, and requests the customers identify and quantify any variance requirements. The manpower community normally quantifies the variances, as well as prices out the core model. Core man-hours and variance man-hours are used to find total work center requirements. The total package, including comments is sent to the study team.

19.2.6. The study team and the Senior Functional Manager review and analyze each variance to determine its validity.

19.2.7. The study team determines the overall impact of the manpower determinant, provides feedback to all customers relative to the variance disposition, revises the final report if necessary, and briefs the total estimated impact.

19.2.8. The MAJCOM M&O Directorate submits the core model and variances to AFMAA to be posted as the manpower determinant.

19.3. Benefits of Core Modeling.

19.3.1. One benefit of using the core modeling technique is the functional OPRs or customers view this type of technique as fair and equitable because unique workloads have been addressed as part of the formal study process.

19.3.2. Another benefit of using this technique is the study isn't bogged down during data analysis, trying to address outlying data points and individual base concerns. This normally reduces the overall study time.

19.3.3. Core Modeling gives our functional managers or customers a tool to decide what level of service each can afford.

19.3.4. This study technique is particularly useful in non-standardized functions where mode of operations differ, in functions with undefined levels of service, or in work centers where previous tries to develop manpower determinants proved unsuccessful. Examples would be Budget, Cost Analysis, and Operational Contracting.

19.3.5. Disadvantages of Core Modeling. The major disadvantage of core modeling is the additional workload taskings on the manpower community to collect and quantify the variance workload in the beginning. This can be alleviated if the manpower and functional communities are involved in the study process from the beginning, are briefed on what has been captured as core workload, and are briefed on what needs to be identified as variance workload. This allows them to get a head start on the process, and eliminates potential misunderstandings and confusion.

Chapter 20

MODULAR EQUATIONS

20.1. Modular Equations.

20.1.1. General Concepts. Modular equations are a series of separate equations rather than one single equation. These individual equations represent independent processes that comprise the required man-hours for the work center. While this type of representation is not right, nor needed for every work center, it does give visibility to the required man-hours for a work center by process. Attributes of the modular equation to consider are:

20.1.2. Develop modular equations for individual processes that represent different levels of service furnished to the customer. Based on these level of service modules, the OPR has the flexibility to choose the pertinent module for a given location or situation.

20.1.3. As work center requirements change (processes added, deleted, or modified), change the individual modules (insert or remove) to show the new work center requirements. This makes it relatively easy and cost-effective to maintain the determinant.

20.1.4. By virtue of design, calculate a man-hour cost associated with each process when using modular equations.

20.1.5. Modular equations make it easy to analyze a work center for what-ifs.

20.1.6. Represent individual processes not performed at all locations with a determinant at the process level. Development of variances is therefore eliminated.

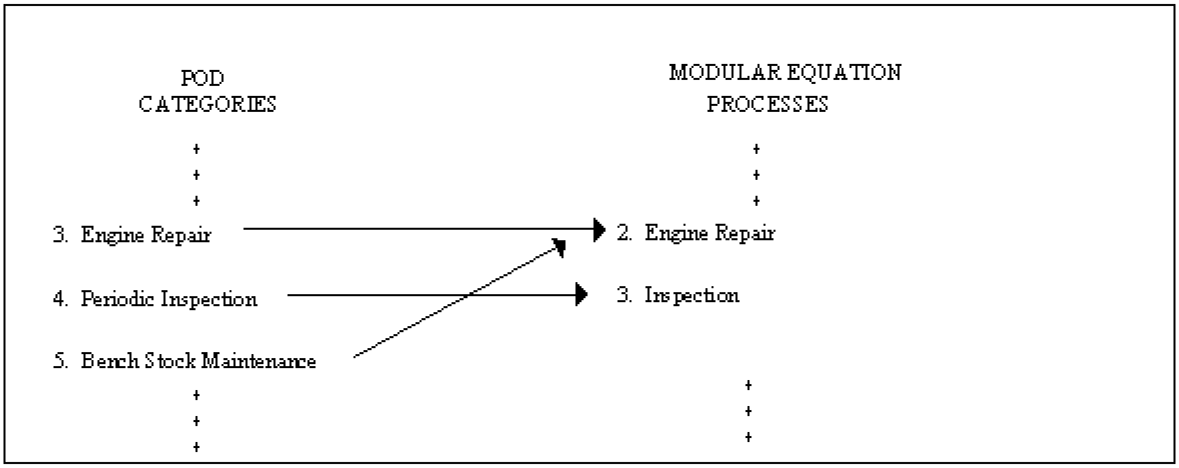
20.2. Specific Design Considerations.

20.2.1. The first and perhaps the most critical step in using a modular equation in determinants development is the initial research. Carefully research the nature and function of the work center to determine the suitability and feasibility of describing the work center as a composite of independent processes. Use the modular equations procedure only when the man-hours needed for a work center can be subdivided into independent modules of work that account for all man-hours. These modules may represent one or more processes as defined in a SWD. Limit the number of modules to a minimum to reduce the complexity involved in using such a determinant.

20.2.1.1. A module of work is independent if it can be added to or removed from the work center without imposing an increase or decrease in man-hours in another module. Thus, it can be considered a module in a modular equation. To rephrase this idea of independence, a work center that needs a given number of hours to do the work within module A is not expected to experience a change in these hours due to increases or decreases in the work in module B.

20.2.1.2. See Figure 20.1 for a simplistic example indicating a potential use for SWD processes in a modular equation.

Figure 20.1. Simplistic Example Relationship between SWD and Modular Equation Processes.



20.2.1.3. In Figure 20.1, SWD processes 3 and 5 are not independent because the amount of time needed to keep bench stock is related to the number of engines to be repaired. Therefore, if the workload is increased in process 3 (that is, more engines to be repaired), the work in both processes would increase. In a modular equation, consider these two processes (and possibly others) in one general process - engine repair.

20.2.1.4. SWD process 4 is independent of processes 3 and 5 since periodic inspections are done on all engines. The addition (or deletion) of the work would not change the hours needed to do engine repair or keep bench stock supplies. Represent this process with a different module in the modular equation.

20.2.2. Each module should have at least one WLF that is logically and statistically related to the work described.

20.3. Indirect Man-Hours.

20.3.1. When OA is the primary measurement method, use the IAF to credit indirect man-hours. Use the IAF to form a separate indirect module. Represent this with an equation that expresses the indirect man-hours as a function of the direct man-hours. This can either be a linear or parabolic equation. The indirect equation remains separate from the equations for direct work and is applied only after the direct work is computed. This procedure sets a relationship between indirect and direct work. Indirect man-hours (Y) are regressed against direct man-hours (X) for each of the input bases. You can develop your IAF factor as follows:

$Y = (a+bx)(1.0619)$

20.3.2. When WS is the primary measurement method in multi-location modular studies, use measured indirect man-hours to form a separate indirect module. Represent this with an equation that expresses the indirect man-hours as a function of the direct man-hours. Equation development and procedures outlined for OA also apply to WS.

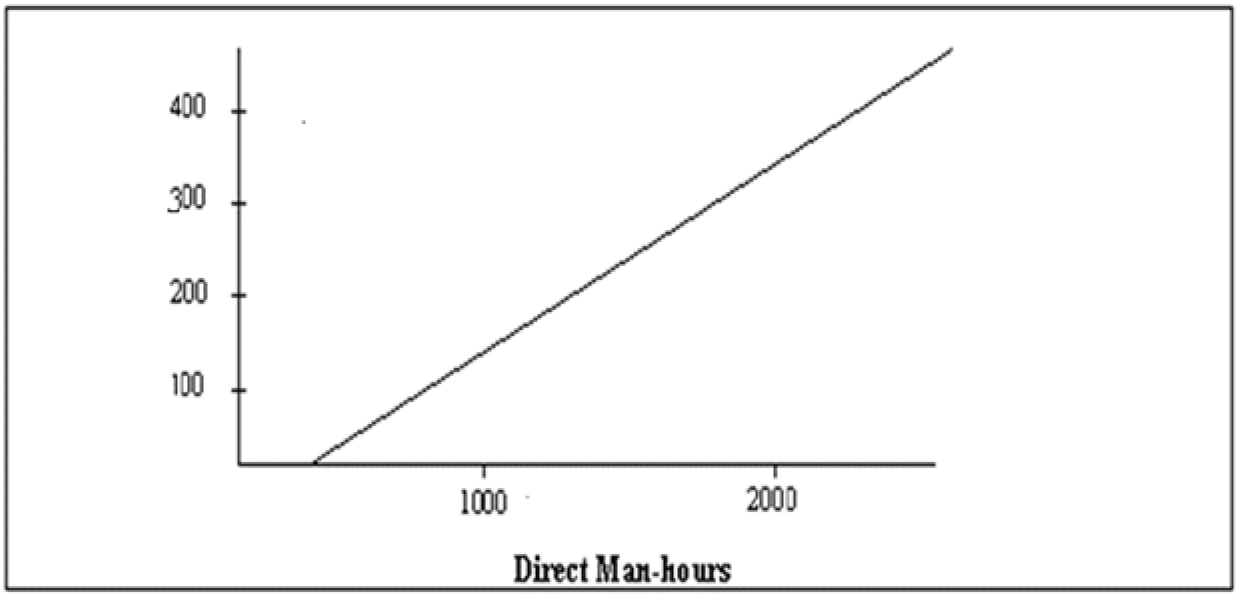
20.3.2.1. The b-value in the linear case represents the proportion of indirect time to direct time. Table 20.1 shows relationships between direct and indirect percentages. Use this information as a guide. In Figure 20.2, a typical indirect equation was computed to be:

Yind = -15.9354 + .1829 (Ydir). This allows an additional 18% (approximately) of the direct time for indirect work.

Table 20.1. Relationship of Indirect to Direct Man-Hours.

If total time is	Then the relationship of indirect to direct is:	
% Direct	% Indirect	Indirect/Direct
95	5	.0526
90	10	.1111
85	15	.1765
80	20	.2500
75	25	.3333
70	30	.4286

Figure 20.2. Graph of the Example Indirect Man-Hour Equation.



20.3.2.2. The a-value determines the line with this slope (the b-value) to use. A negative a-value (as in the example above) does not mean there is an automatic loss of man-hours. As in any equation, consider the a-value only in combination with the rest of the equation. For a given amount of direct work (for instance 950 hours), compute the hours added for indirect work from the indirect equation. Yc = -15.9354 + (.1829)(950.0) = 157.82

20.4. Developing Modular Equations. After a work center has met specific design considerations, develop a modular equation as follows:

20.4.1. Step 1. Identify all work center outputs (customer needed products or services). For each output, develop a task list of the process or processes needed to produce the unit of work (output). For each output, identify a WU (end item). Using the output task lists, develop a SWD so each independent process becomes a module and each module has its own WU. Structure the modules to account for all of the work described in the SWD. Be certain each process is included in one and only one module. Identify the relationship between the modules and the associated WLFs. To avoid confusion during equation computation, clearly specify all relationships from the beginning.

20.4.2. Step 2. Proceed with the measurement in the usual manner to collect all of the needed man-hours and workload counts. Use normal procedures for data collection and examination.

20.4.3. Step 3. Aggregate the data to the levels necessary for the separate modules.

20.4.4. Step 4. Do regression analysis for each module using procedures in Chapter 18. Keep the statistics (coefficient of determination (R^2), Syx, coefficient of variation (V)) with each equation.

20.4.5. Present the work center determinant as a set of individual equations (Table 20.2) that apply to each module of work. During application, compute only the modules that apply to a specific work center.

Table 20.2. Example of Modular Equation Construction.

BASE	Module 1			Module 2		TOTAL MAN-HOURS
	MAN-HOURS (Y1)	WORKLOAD 1 (X1)	WORKLOAD 2 (X2)	MAN-HOURS (Y2)	WORKLOAD 3 (X3)	
A	701.23	206.88	218.30	521.76	179.25	1222.99
B	891.48	227.94	960.90	448.87	181.53	1340.35
C	1692.71	343.42	1119.00	- -	- -	1692.71
D	1540.47	246.17	839.10	- -	- -	1540.47
E	941.23	151.03	343.80	420.57	148.23	1361.80
F	797.16	143.87	237.10	426.40	137.81	1223.56
G	990.63	184.05	595.30	411.57	133.32	1402.20
H	404.49	15.07	102.90	889.67	257.90	1294.16
I	638.83	162.31	25.20	281.30	102.69	920.13
J	479.16	30.60	669.50	478.92	181.97	958.08
K	718.42	47.90	1097.10	350.08	112.70	1068.50
$Y_1=227.8356+2.9830X_1+0.3286X_2$ Coefficient of determination (R^2) =.815 S_{YX}=193.5 V=.217				$Y_2=-81.5356+3.4575X_3$ R^2=.896 S_{YX}=59.42 V=.126 **Note:** Bases C and D are not regressed in Module 2 because the module does not apply to these two bases. Do not use zeros in the regression file.		
MODULAR EQUATION MODULE 1: $Y_1=227.8356+2.9830X_1+0.3286X_2$ MODULE 2: $Y_2=-81.5356+3.4575X_3$ COMBINED EQUATION: $Y = 146.3 + 2.9830X_1+0.3286X_2 + 3.4575X_3$ **Note:** An overall S_{yx} or coefficient of variation (V) is not applicable.						

Chapter 21

RATIO UNIT TIMES DETERMINANTS

21.1. General Concepts.

21.1.1. General Concepts. Ratio unit times for development of manpower determinants have been expanded to include large populations, as well as single location and small population determinants. The decision to use ratio unit times for large populations should be based on analysis of workload count variations. If the workload counts do not vary widely from one location to another, ratio unit times are appropriate. If there is a wide variation, consider breaking the large population into smaller ones (e.g., small workload count, medium workload count, large workload count). If this is not feasible or desirable, then use regression analysis as outlined in Chapter 17. This chapter addresses development procedures to be followed when using ratio unit times.

21.1.2. Population Definition.

21.1.2.1. Single location is applicable when the function under study is peculiar to one location or the service furnished (mode of operation) is very different from other locations.

21.1.2.2. Small population is defined as a population consisting of two, three, or four locations.

21.1.2.3. Large population is defined as a population of five or more locations. (Note: it is possible that large populations can be broken down to smaller populations based on analysis of workload data).

21.1.3. Input Data.

21.1.3.1. The quality of the input data is important in any study. However, it becomes increasingly important for small populations and single location studies because of the limited amount of data available. Accuracy is of great importance when limited measurement is possible. Since it is the only information available, it is essential to get the best estimate(s) possible.

21.1.3.2. When using OA as the primary measurement method, get multiple time estimates to find the best representation of the per accomplishment times. Procedures for handling multiple readings are in Chapter 6. Evaluate these measurements carefully, using available statistical analysis techniques.

21.1.4. Accuracy is also critical when WS is selected as the prime measurement method. Do WS as prescribed in Chapter 11.

21.2. Ratio Unit Times.

21.2.1. The ratio (b-value) is the result of measured direct man-hours divided by the associated workload. It represents the direct man-hours needed to produce one unit of work. The ratio development process is similar for both OA and WS except for one distinct difference: The IAF is not used in WS; therefore, the final equation developed using WS doesn't need adjustment.

21.2.1.1. Equations developed by ratio unit times takes one of two forms, depending on whether or not the fixed man-hours are separated from the variable man-hours (See Table 21.1).

21.2.1.2. The first equation form is: Y = a + b1X1 + b2X2 + … + bnXn where the a-value represents the sum of the fixed man-hours and the b-values represent the ratios of the variable man-hours to the respective WLFs.

21.2.1.3. The second equation form is Y = b1X1 + b2X2 + … +bnXn and is the same as the first equation except there is no a-value. Use of the second equation is optional.

21.2.1.4. Associate variable man-hours with processes or steps that are expected to show a relationship with the selected WLF.

21.2.1.5. An example of using ratio unit times for a single location determinant with the first equation form is shown in Table 21.1.

Table 21.1. Instructions for the Single Location Ratio Unit Times.

STEP	A Action	B Example			
1	CLASSIFY MEASURED DIRECT MAN-HOURS AS FIXED OR VARIABLE	WLF	AVG WUC	MAN-HOURS FIXED	MAN-HOURS VARIABLE
		1	10.20		65.07
		2	15.50		199.00
		3	5.00		134.65
		TOTAL MAN-HOURS		47.00	398.72
2	DIVIDE THE VARIABLE MAN-HOURS (V_i)BY THEIR ASSOCIATED WUC (X_i) TO DETERMINE A RATIO (b_i) FOR EACH WLF $b_i = \frac{V_i}{X_i}$	$b_1 = \frac{V_1}{X_1} = \frac{65.07}{10.20} = 6.379$ $b_2 = \frac{V_2}{X_2} = \frac{199.00}{15.50} = 12.839$ $b_3 = \frac{V_3}{X_3} = \frac{134.65}{5.00} = 26.93$			
3	COMBINE VALUES INTO THE APPROPRIATE EQUATION AND APPLY THE IAF	$Y = (a + b_1X_1 + b_2X_2 + b_3X_3)IAF$ $Y = (47.00 + 6.379X_1 + 12.84X_2 + 26.93X_3)IAF$			

21.2.1.6. The ratio unit times procedure can be extended to develop small population and large population determinants. To do so:

21.2.1.7. When only one WLF is used, sum the variable man-hours for that WLF for each location. Divide this sum by the sum of WLF values to form a ratio. (See Table 21.2)

Table 21.2. Instructions For Small & Large Population Ratio Unit Times - Single WLF.

STEP	ACTION	EXAMPLE
1	SELECT THE MAN-HOUR MODEL	$Y = a + b_1X_1$
2	CLASSIFY MEASURED MAN-HOURS AS FIXED OR VARIABLE	<table><tr><th></th><th>AVG WLF COUNT</th><th>MAN-HOURS FIXED</th><th>VARIABLE</th></tr><tr><td>Base A</td><td>20</td><td>120.50</td><td>350.75</td></tr><tr><td>Base B</td><td>15</td><td>95.60</td><td>275.90</td></tr><tr><td>Base C</td><td>25</td><td>130.70</td><td>395.65</td></tr><tr><td>Base D</td><td>29</td><td>125.60</td><td>397.35</td></tr><tr><td>TOTAL</td><td>89</td><td>472.40</td><td>1,419.65</td></tr></table>
3	COMPUTE THE VARIABLE MAN-HOURS RATIO $b_i = \frac{V_i}{X_i}$	$b_i = \frac{V_i}{X_i} = \; b_i = \frac{1{,}419.65}{89} = 15.951$
4	COMPUTE THE A-VALUE $A = \frac{FIXED\ MAN - HOURS}{NUMBER\ OF\ LOCATIONS}$	$A = \frac{FIXED\ MAN-HOURS}{NUMBER\ OF\ LOCATIONS} = \frac{472.40}{4} = 118.10$
5	COMBINE VALUES INTO THE APPROPRIATE EQUATION AND ADD IAF	$Y = 118.10 + 15.951X_1 + IAF$

21.2.1.8. When more than one WLF is used, develop a ratio for each WLF (See Table 21.3).

Table 21.3. Instructions For Small & Large Population Ratio Unit Times - Multiple WUC.

STEP	A Action	B Example
1	CLASSIFY MEASURED MAN-HOURS AS FIXED OR VARIABLE	AVG WUC / MAN-HOURS: FIXED / VARIABLE Base A: $X_1 = 50$; $X_2 = 15$; $X_3 = 300$ Base B: $X_1 = 55$; $X_2 = 22$; $X_3 = 295$ Base C: $X_1 = 43$; $X_2 = 20$; $X_3 = 305$ Base D: $X_1 = 51$; $X_2 = 17$; $X_3 = 285$ VARIABLE: 197.65, 254.85, 650.35, 205.20, 260.70, 635.75, 190.45, 254.65, 670.50, 195.90, 259.25, 615.75
2	TOTAL THE WORKLOAD VALUES AND ASSOCIATED VARIABLE MAN-HOURS	WUC / TOTAL (X) / MAN-HOURS (V) X_1 / 199 / 789.2 X_2 / 74 / 1029.45 X_3 / 1185 / 2572.35
3	COMPUTE THE VARIABLE MAN-HOURS RATIO(S) $b_i = \frac{V_i}{X_i}$	$b_1 = \frac{V_1}{X_1} = 789.20 \div 199 = 3.966$ $b_2 = \frac{V_2}{X_2} = 1029.45 \div 74 = 13.911$ $b_3 = \frac{V_3}{X_3} = 2572.35 \div 1185 = 2.171$
4	COMPUTE THE A-VALUE A = FIXED MAN-HOURS NUMBER OF LOCATIONS	Not applicable to example data
5	COMBINE VALUES INTO THE APPROPRIATE EQUATION AND APPLY THE IAF	$Y = (3.966X_1 + 13.911X_2 + 2.171X_3)IAF$

Chapter 22

FUNCTIONAL MODELING DETERMINANTS

22.1. General Concepts.

22.1.1. Functional Model Uses.

22.1.1.1. The functional model is a mathematical equation that relates the current distribution of manpower to a specific workload. The relationship may not provide accurate manpower requirements since the current distribution of manpower may not be correct.

22.1.1.2. The functional model is a method used to develop manpower equations, estimate wartime requirements, and analyze potential WLFs.

22.1.2. Determinants Development.

22.1.2.1. Before model construction, analyze and adjust authorized and assigned data to reflect approved initiatives. An example of constructing a model and incorporating initiatives is shown in Table 22.1.

Table 22.1. Functional Model Determinant Development.

Step 1. Develop model equation using assigned man-hours as the dependent variable (Y). Y = MAF times overload (for military) times assigned strength. Select a program variable which logically relates to man-hours expended, and regress this variable against six to twelve months of average workload.				
MAF	BASE	ASGN	(Y)	WLF (X)
150.7	A	6	966.72	740
(1.077)	B	7	1127.83	980
(Overload	C	11	1772.31	1270
Factor)	D	9	1450.07	1100
	E	13	2094.55	1560
	F	6	966.72	890
	G	13	2094.55	1500
	H	11	1772.31	1225
TOTAL:		76	12245.06	
BASE	(Y)		CALCULATED (Yc)	
A	966.72		859.56	
B	1127.83		1244.52	
C	1772.31		1709.68	
D	1450.07		1437.00	
E	2094.55		2174.84	
F	966.72		1100.16	
G	2094.55		2078.60	
H	1772.31		1637.50	
BASE	(Y)		CALCULATED (Yc)	
A	250			
B	300			
C	275			
D	410			
E	360			
F	380			
G	290			
H	335			
BASE	AUTH M-HRS		WLF (X)	CALCULATED
A	859.56		740	764.36
B	1244.52		980	1148.12
C	1709.68		1270	1611.83
D	1437.00		1100	1340.00
E	2174.84		1560	2075.54
F	1100.16		890	1004.21
G	2078.60		1500	1979.60
H	1637.50		1225	1539.88

22.1.2.2. The dependent variable (Y) used in the functional model may be either assigned or authorized man-hours. Convert assigned or authorized strength to man-hours by multiplying by the pertinent MAF and overload factor.

22.1.2.3. Consult with the OPR and decide whether to use authorized or assigned man-hours. When there is a large difference between the two, discuss this disparity with the OPR, and select the proper dependent variable. Correlate the dependent variable with the independent workload variables.

22.1.2.4. In situations where authorized and assigned man-hours are closely compatible, use the analysis of variation and correlation criteria to select the best dependent variable (Y). When these statistical criteria are used, assigned strengths should not differ from authorized strengths by more than 10 percent when input points are totaled.

22.1.2.5. Make sure the minimum number of input locations is satisfied when developing the functional model.

22.1.2.6. Use the selected equation to calculate required man-hours. Make sure a representative period of workload data is used to apply the equation. This sets up the man-hour data base for the first equation. After setting up the data base, subtract the man-hours saved due to initiatives. Regress adjusted man-hours against workload (same x-values) to develop the final man-hour equation.

22.1.3. Wartime Requirements Modeling.

22.1.3.1. Periodically, wartime manpower requirements are estimated for each Air Force support activity. MAJCOMs identify and document deployment requirements, in-place requirements, shortfalls, and untasked resources. Deployment requirements are based on force requirements identified in a force sizing exercise (such as Total Force Assessment) Time Phased Force Deployment Document. In-place manpower requirements are based on programmed wartime workload and wartime MAFs. The requirement data is grouped by specialty, skill, and manpower resource category.

22.1.3.2. Construct a functional model for wartime based on the above manpower requirements and workload available from each MAJCOM. Follow the same procedures and sequence used for analyzing peacetime requirements.

22.1.3.3. Use wartime-related workload values as the independent variable.

22.1.3.4. Analyze separate models for the two wartime populations.

22.1.3.4.1. In-place units not deploying to a combat theater.

22.1.3.4.2. Combat theater units and units deploying to a combat theater under a force sizing scenario.

22.1.3.5. When using a functional model for wartime requirements pending determinants development, furnish this additional information.

22.1.3.5.1. Specialty and skill requirements.

22.1.3.5.2. Functional statement of wartime responsibilities. Get responsibilities from the functional guidance included in the USAF War and Mobilization Plan, Volume 1; Base Support Plan, Volumes 1 and 2; and Total Force Assessment guidance.

22.1.4. Using a Functional Model to Analyze Potential WLFs.

22.1.5. During study familiarization, use the functional model to analyze potential WLFs. The size of the standard error and the number of extreme deviations from the line often show the degree of relatability. Other means of evaluation such as activity analysis charts, discussions with the functional OPR, and logical analysis help refine the list of potential WLFs.

22.1.5.1. The following steps identify the procedures which should be followed when using a functional model to analyze potential WLFs:

22.1.5.1.1. Step 1. Pick the work center or functional area to be analyzed.

22.1.5.1.1.1. Step 2. Pick candidate workload and program variables that logically relate to manpower authorizations in the UMD and for data available from programming documents or formal reports.

22.1.5.1.1.2. Step 3. Get the manpower data from the UMD for each location and time period under consideration. Use the volume of the selected variables for the same time periods.

22.1.5.1.1.3. Step 4. Analyze data.

22.1.5.1.1.3.1. Check manpower and workload data with the functional OPR and revise any data that both parties agree is incorrect.

22.1.5.1.1.3.2. Plot the data pairs on a scatter gram and analyze the relative position of each plot with respect to a trend or pattern of the overall display. Prepare the plot manually or by computer.

22.1.5.1.1.3.3. Do regression analysis to find the relationship between manpower authorizations and the candidate workload variables. Regression analysis procedures and interpretation of the results are in **Chapter 18.**

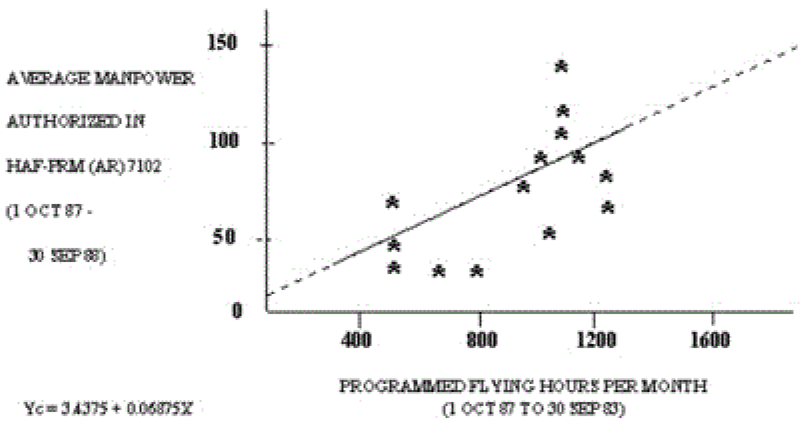
22.1.5.1.1.3.4. Investigate any extreme deviation in the data points. The purpose of this investigation is to find whether a high standard error (deviation) is due to management design or well-documented reasons. If so, include those reasons as part of the functional model backup data. Typical reasons are: mixed data from different organizational levels, incorrectly defined FACs, and organizational structure codes, geographic population differences, use of contract services at some locations, differences in management philosophy and personnel utilization, organizational structure differences, and lack of a quantitative relationship between manpower and the tested workload variables. The investigation should give some clues to the expected benefit of alternative approaches. A full study of the functions at selected locations may be needed to identify the reasons for large deviations. Separate determinants may be needed to show multiple populations that are shown by the scatter gram.

22.1.5.1.1.4. Step 5. Repeat steps 2 through 4 to evaluate alternative workload variables. Additional models using assigned strength or wartime manpower distributions instead of authorizations may give more insight into manpower requirements, variations by location or condition, and potential WLFs. For example, analysis of assigned strength and the historical workload relate to a productivity index and show the work done by expended manpower. Given consistent workload and efficient operations, expended resources should relate to future requirements. Models are also valuable for analyzing the potential differences that may need different populations for determinant coverage.

22.1.5.1.1.4.1. Figure 22.1 is an example of a functional model. Note the equation and all data points are plotted for ease of analysis. The functional model shown doesn't show a good relationship between manpower and the tested workload variable. Although this relationship doesn't require discarding the potential WLF, it does show the absence of a strong relationship.

Figure 22.1. Functional Model Example of Manpower and Flying Hours.

BASE	MANPOWER (Y)	FLYING HOURS (X)
1	28	500
2	35	500
3	55	500
4	33	700
5	59	850
6	30	800
7	40	950
8	80	900
9	130	1000
10	100	1000
11	65	1200
12	60	1200
13	70	1000
14	95	1000



Chapter 23

FUNCTIONAL ESTIMATING EQUATIONS

23.1. Forecasting Manpower Requirements.

23.1.1. General Concepts. The purpose of this chapter is to show how work center manpower determinants form the basis for FEEs and how FEEs are built. These equations are quantitative tools designed to be used at all organizational levels to forecast manpower requirements. FEEs are optional and are used to supplement other forecasting methods.

23.1.2. Air Force Program Element Structure.

23.1.2.1. Manpower management personnel build the quantitative tools (models) needed to develop the manpower programming part of the planning, programming, and budgeting system. To be effective, these models parallel the DoD programming system embodied in the Air Force part of the Future Years Defense Program (FYDP).

23.1.2.2. The broadest and most basic structural element of the FYDP is the major force program (MFP). MFP in Table 23.1 represents broad aggregations of smaller or specific missions that are closely related.

Table 23.1. MAJOR FORCE PROGRAMS (MFP).

MAJOR FORCE PROGRAMS (MFP)	
PROGRAM	**TITLE**
1	Strategic Forces
2	General Purpose Forces
3	C3I and Space
4	Airlift/Sealift
5	Guard and Reserve Forces
6	Research and Development
7	Central Supply and Maintenance
8	Training, Medical, and Other General Personnel Activities
9	Administration and Associated Activities
10	Support of Other Nations
11	Special Operations Forces

23.1.2.3. Each MFP is subdivided into more specific mission breakdowns called program elements.

23.1.2.3.1. Program elements represent a combination of manpower, equipment, and facilities that constitute a military capability or support activity. Program elements give full descriptions of the mission and are the smallest program cost-collection unit that OSD requires DoD components to furnish information on a regular basis. Program elements are used throughout DoD and identify every type of organization.

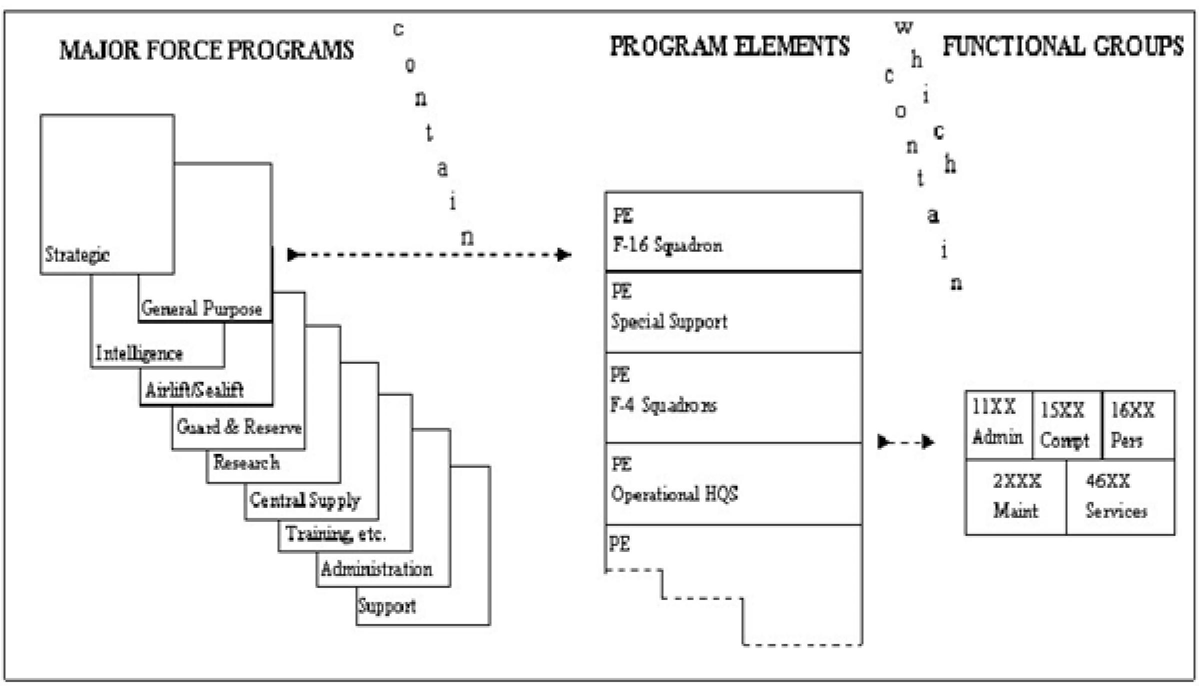
23.1.2.3.2. Each program element is identified by a program element code (PEC) consisting of six characters. The first character represents the MFP. The first five characters are always numeric (for example, 41896) except "a” used for MFP 10 and "b" used for MFP 11. The sixth is always alphabetic. At the DoD level, this sixth character identifies the DoD component (F means Air Force) (See Table 23.2). When used within the Air Force, this sixth character is replaced by other alphabetic characters (for example, 41896A, 41896B) other than F that is reserved for DoD use. This is done when it is necessary to shred-out the DoD PEC to account for resources at a lower level. PEC shreds are established by HQ USAF/A1M.

Table 23.2. Air Force PECs Within Major Force Program 2.

MAJOR FORCE PROGRAM 2 (partial list)			
PROGRAM ELEMENT CODES	TITLE	PROGRAM ELEMENT CODES	TITLE
21006A	Special Support (Spt)	27596A	Base Ops-TAC AF
21114A	PACOM - Service Spt	27596D	Manpower Office
21115A	USSOUTHCOM - Service Spt	27969E	Cbt Spt EAF Support Backfill
27133H	Aircrew Tng Devices	27597A	TAF-Lead-In Misc Pipeline Student
27133A	F-16 Squadrons	28038A	Contingency Hospital
27236A	Operational Hqs (TAF)	28090A	Instl Audiovisual Spt (Tactical)
27581A	Joint Stars Ops	28719A	Child Development
27588A	Air Base Gnd Def	28720A	Family Center
		28720R	Family Center (REIMB)

23.1.2.3.3. Within a program element, there can be one or more functional groups. A functional group is defined by the first two digits of a functional account code (FAC). For example, PEC 27236A includes work centers in 11XX Administration, 15XX Comptroller, 16XX Personnel, 2XXX Maintenance, and 46XX Services (Figure 23.1).

Figure 23.1. Relationship Between Major Force Program, Program Elements, and Functional Groups.



23.1.2.4. To meet the objective of building manpower forecasting tools, a FEE is built for each functional group within each MAJCOM.

23.2. FEE Development.

23.2.1. Building a FEE.

23.2.1.1. Each FEE is made up of two major parts.

23.2.1.2. A mathematical equation showing the relationship between the function's total manpower requirement and a selected program estimating factor (PEF). All of the PEFs are variables specifically programmed in the FYDP. The PEFs used to build FEEs are:

PEF	
Flying hours.	Students.
Number of aircraft.	Base population.
Number of missiles.	Number of vehicles.

23.2.1.3. Percentage factors break a function's total manpower requirements into various PECs and manpower categories at MAJCOM, base, and work center levels. These percentage factors identify what part of a function's total manpower requirements, as shown by application of the mathematical equation, are in various PECs. There are also factors that further identify what part of a PEC's manpower requirements are in various manpower categories. These categories include officers, airmen, United States direct-hire civilians, foreign national direct-hire civilians, foreign national indirect-hire civilians, non-chargeable civilians on UAF but not in FYDP, and CFTEs.

23.2.2. Build at least one FEE for each functional area. Functional areas are defined by the first or first and second digit of Air Force FACs (for example, 5XXX defines the medical functional area while 41XX defines the supply functional area). However, if manpower resources need to be programmed at a lower functional level (for example, 44EX), then build FEEs at these levels.

23.2.3. Normally use regression analysis to build the mathematical equation of a FEE. This analysis uses the function's total required manpower and actual historical values for selected PEFs from each relevant location in the MAJCOM.

23.2.3.1. Make sure all mathematical equations are linear (bivariate or multivariate).

23.2.3.2. Get the function's required manpower total at each location by applying all manpower determinants covering work centers in the function (use whole numbers for the manpower values).

23.2.3.2.1. The monthly WLF values used in these applications are the result of analysis done on the 12 most current months of historical data. If 12 months of data is not available, use 6 months of data at the minimum.

23.2.3.2.2. Include in the function's total manpower requirements any CFTEs that are relevant. Track these numbers separately on the UMD. CFTEs are eventually identified as a CFTE percentage factor.

23.2.3.3. Use PEFs in FEEs like WLFs are used in work center manpower determinants. PEF values are average monthly values obtained from analysis of historical data for each location in the MAJCOM. Take this historical data from the same time period as the workload data used to apply the determinants. See Table 23.3 for specific instructions for building the mathematical equation of a FEE by using regression analysis.

Table 23.3. Construction of the Mathematical Equation for a FEE.

STEP	Action	Example
1	Identify all work centers within a functional area.	Within functional area 81XX there are four work centers: 81A1, 81B1, 81C1, and 81D1.
2	Identify all locations in the MAJCOM which have work centers from this functional area.	There are twenty locations in command ABC that have this functional area.
3	Identify which of the locations identified in step 2 can be grouped together to build a FEE. However, if circumstances dictate more than one grouping of bases (e.g., locations where the MAJCOM is host versus locations where the MAJCOM is a tenant) build a FEE for each grouping. Each location can be in only one grouping.	Assume all twenty locations in command ABC can be treated as one group. This results in the building of only one FEE.
4	Select the PEFs to be tested for each of the groupings of locations identified in step 3.	Base population is tested for this function.
5	At each MAJCOM location, obtain the manpower requirements for each work center in the function by applying its manpower determinant.	At base 1, the following requirements were obtained. WORK CENTER REQUIREMENTS A 22 B 15 C 10 D 18
6	At each location, sum the results of step 5 to get the total functional requirements.	Base 1 total functional requirements = 22 + 15 + 10 + 18 = 65.
7	At each location, determine a monthly PEF value from analysis of actual values experienced during the same time period as the workload data used to apply the determinants.	For base 1, the monthly base population value is 2528.
8	Fit the regression line to the data.	

Table 23.4. Example of Data Used to Build a FEE.

TITLE: FEE DATA PAIRS
MAJCOM: ABC
PEF AND WLF TIME FRAME:
JANUARY 2007 - DECEMBER 2008
PEF SOURCE: PERFOMANCE MEASURE (31 December 2008)

BASE	REQUIRED MANPOWER	PEF VALUE
1	65	2528
2	47	2171
3	67	4145
4	64	4270
5	39	1360
6	71	4894
7	51	1603
8	64	2420
9	71	5214
10	49	1850
11	53	3004
12	106	10551
13	39	1586
14	72	3498
15	62	4216
16	61	403
17	64	4493
18	82	4829
19	37	1231
20	43	2147

EQUATION:
$Y = 38.83 + .006482(X)$
$R^2 = .751$
$S_{YX} = 8.505$
$V = .140$

23.2.4. A FEE built using regression analysis should satisfy the statistical criteria of the measurement method selected. If it does not, then use an equation in the form of Y = bX, where:

23.2.4.1. Y = Manpower Requirements for a Functional Area

23.2.4.2. b = Determinant Application Requirements Historical Monthly PEF Value

23.2.4.3. X = Programmed PEF Value

23.2.5. When a FEE applies to four or less locations in a MAJCOM, build the mathematical equation for the FEE using instructions for the single location and small population determinant.

23.2.6. Build the adjustment and percentage factors of a FEE using information from application of the work center determinants, data found in the UMD, and values resulting from the development of the FEE's mathematical equation.

23.2.7. Compute the adjustment factor for each location in the MAJCOM (See Table 23.5). This value identifies how much each location's manpower requirement total, obtained from application of the function's manpower determinants, is different from the manpower requirement total obtained from application of the FEE. Apply both the FEE and the determinant to get this factor. Round the adjustment factor to three decimal places.

Table 23.5. Computation of Base Adjustment Factors for a FEE.

TITLE: FEE ADJUSTMENT FACTOR CALCULATION MAJCOM: ABC					
BASE	DETERMINANT APPLICATION REQUIREMENTS	minus	FEE REQUIREMENTS	equals	ADJUSTMENT FACTOR
1	65.000	-	55.212	=	+9.788
2	47.000	-	52.897	=	-5.897
3	67.000	-	65.694	=	+1.306
4	64.000	-	66.504	=	-2.504
5	39.000	-	47.640	=	-8.640
6	71.000	-	70.549	=	+.451
7	51.000	-	49.215	=	+1.785
8	64.000	-	54.512	=	+9.488
9	71.000	-	72.624	=	-1.624
10	49.000	-	50.817	=	-1.817
11	53.000	-	58.297	=	-5.297
12	106.000	-	107.220	=	-1.220
13	39.000	-	49.105	=	-10.105
14	72.000	-	61.500	=	+10.500
15	62.000	-	66.154	=	-4.154
16	61.000	-	41.436	=	+19.564
17	64.000	-	67.950	=	-3.950
18	82.000	-	70.128	=	+11.872
19	37.000	-	46.804	=	-9.804
	43.000	-	52.742	=	-9.742

23.2.7.1. The remaining FEE factors are percentages that show what percent of the total functional area requirements is in each PEC and what percent is in other various manpower categories. Compute different factors for the work center, base, and MAJCOM levels. There are three kinds of percentage factors needed for each base in a MAJCOM.

23.2.7.2. The first are percentages of the total manpower requirements represented by each PEC. Percentages are needed for the overall function as well as for each work center in the function. Instructions for building these percentages are shown in Table 23.6. PEC Percentage Factor Calculation example is shown in Table 23.7. Example of Base Level PEC Percentages and the Overall MAJCOM PEC Percentages.

Table 23.6. PEC Percentage Factor Calculation.

<table>
<tr><th>STEP</th><th>Action (See note)</th><th>Example</th></tr>
<tr><td>1</td><td>Within each work center at a location, identify the PECs that cover the requirements shown in the UMD.</td><td>At base 16, all requirements fall into either PEC 91212A or PEC 27596A.</td></tr>
<tr><td>2</td><td>For the fiscal quarter in which the determinant applications are done, identify the number of requirements in each PEC for each work center.</td><td>
<table>
<tr><th>WORK CENTER</th><th>PEC</th><th>REQUIREMENTS</th></tr>
<tr><td>A</td><td>27596A</td><td>4</td></tr>
<tr><td>A</td><td>91212A</td><td>16</td></tr>
<tr><td>B</td><td>91212A</td><td>12</td></tr>
<tr><td>C</td><td>91212A</td><td>17</td></tr>
<tr><td>D</td><td>91212A</td><td>12</td></tr>
</table>
</td></tr>
<tr><td>3</td><td>Determine the PEC percentages for each work center. Divide each PEC requirement total by the work center's total requirements (all PECs added together). Keep the percentages in terms of decimals rounded to three decimal places.</td><td>
<table>
<tr><td colspan="3">(BASE LEVEL)</td></tr>
<tr><th>WORK CENTER</th><th>PEC</th><th>PERCENTAGE</th></tr>
<tr><td>A</td><td>27596A</td><td>$\frac{4}{20} = 0.200$</td></tr>
<tr><td>A</td><td>91212A</td><td>$\frac{164}{20} = 0.800$</td></tr>
</table>
</td></tr>
<tr><td>4</td><td>For each location, compute the function's total requirements by PEC by adding the work center results in step 2.</td><td>
<table>
<tr><th>WORK CENTER</th><th>27596A</th><th>91212A</th><th>TOTAL FUNCTIONAL REQUIREMENTS</th></tr>
<tr><td>A</td><td>4</td><td>16</td><td>20</td></tr>
<tr><td>B</td><td></td><td>12</td><td>12</td></tr>
<tr><td>C</td><td></td><td>17</td><td>17</td></tr>
<tr><td>D</td><td>_</td><td>12</td><td>12</td></tr>
<tr><td>TOTAL</td><td>4</td><td>57</td><td>61</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>STEP</th><th>Action (See note)</th><th>Example</th></tr>
<tr><td>5</td><td>Determine the PEC percentages for the function at each location. Divide each PEC requirement total by the function's total requirement (all PECs added together). Keep the results in terms of decimals rounded to three decimal places.</td><td>
<table>
<tr><th>LOCATION</th><th>PEC</th><th>FUNCTIONAL
(BASE LEVEL)
PEC PERCENTAGE</th></tr>
<tr><td>Base 16</td><td>27596A</td><td>$\frac{4}{61} = .066$</td></tr>
<tr><td></td><td>91212A</td><td>$\frac{57}{61} = .934$</td></tr>
</table>
</td></tr>
<tr><td>6</td><td>For the overall command, compute the function's total requirements within each PEC by adding the functional results obtained in step 4 for each location (See Table 23.6).</td><td>
<table>
<tr><th>PEC</th><th>FUNCTION'S TOTAL REQUIREMENT</th></tr>
<tr><td>27596A</td><td>1106</td></tr>
<tr><td>91212A</td><td>57</td></tr>
<tr><td>41896A</td><td>2</td></tr>
<tr><td>31196A</td><td>39</td></tr>
<tr><td>11896A</td><td>3</td></tr>
<tr><td>Overall Total</td><td>1207</td></tr>
</table>
</td></tr>
<tr><td>7</td><td>Determine the PEC percentages for the function at MAJCOM level. Divide each PEC UMD requirement total by the function's total UMD requirements (all PECs added together). Keep the percentages in terms of decimals rounded to three decimal places.</td><td>
<table>
<tr><th>MAJCOM</th><th>PEC</th><th>FUNCTIONAL
(MAJCOM LEVEL)
PEC PERCENTAGE</th></tr>
<tr><td>ABC</td><td>27596A</td><td>$\frac{1106}{1207} = .916$</td></tr>
<tr><td></td><td>91212A</td><td>$\frac{57}{1207} = .047$</td></tr>
<tr><td></td><td>41896A</td><td>$\frac{2}{1207} = .002$</td></tr>
<tr><td></td><td>31196A</td><td>$\frac{39}{1207} = 032$</td></tr>
<tr><td></td><td>11896A</td><td>$\frac{3}{1207} = .002$</td></tr>
</table>
</td></tr>
<tr><td colspan="3">Note: PEC percentage factors are determined for three levels; work center at base level, functional at base level, and functional at MAJCOM level.</td></tr>
</table>

Table 23.7. Example of Base Level PEC Percentages and the Overall MAJCOM PEC Percentages.

BASE	PEC 11896A		PEC 27596A		PEC 31196A		PEC 41896A		PEC 91212A		TOTAL
	RQMTS	%	RQMTS	%	RQMTS	%	RQMTS	%	RQMTS	%	RQMTS
1			65	1.000							65
2			47	1.000							47
3			67	1.000							67
4			64	1.000							64
5			39	1.000							39
6			71	1.000							71
7			51	1.000							51
8			64	1.000							64
9			71	1.000							71
10			49	1.000							49
11			53	1.000							53
12			104	.981			2	.019			106
13					39	1.000					39
14			72	1.000							72
15			62	1.000							62
16			4	.066					57	.934	61
17			64	1.000							64
18	3	.037	79	.963							82
19			37	1.000							37
20			43	1.000							43
MAJCOM FUNC-TIONAL TOTALS	3	.002	1106	.916	39	.032	2	.002	57	.047	1207

23.2.7.3. Next are percentages of the function's total manpower requirements represented by each work center. Instructions for building these percentages are shown in Table 23.8.

Table 23.8. Work Center Percentage Factor Calculation.

STEP	Action	Example
1	Identify all work centers within a functional area.	Within functional area 81XX there are four work centers: 81A1, 81B1, 81C1, and 81D1.
2	Identify all locations in the MAJCOM which have work centers in this functional area.	There are twenty locations in command ABC that have this functional area.
3	At each MAJCOM location, obtain the manpower requirements for each work center in the function by applying the manpower determinants.	At base 1, the following requirements were obtained. WORK CENTER – REQUIREMENTS A – 22 B – 15 C – 10 D – 18
4	At each location, sum the results of step 3 to get the total functional requirements.	Base 1 total functional requirements = $22 + 15 + 10 + 18 = 65$.
5	To get the work center percentage factors for each location in the MAJCOM, divide each work center requirement total found in step 3 by the total found in step 4. Keep the percentages in terms of decimals rounded to three decimal places.	WORK CENTER – PERCENTAGE A – $\frac{22}{65} = .338$ B – $\frac{15}{65} = .231$ C – $\frac{10}{65} = .154$ D – $\frac{18}{65} = .277$

23.2.7.4. The final kinds are percentages of officers, airmen, United States direct-hire civilians, foreign national direct-hire civilians, foreign national indirect-hire civilians, and CFTEs within each PEC at the overall functional level. Develop these percentages for each PEC in each work center. Instructions for building these percentages are shown in Table 23.8 and an example is shown in Table 23.6.

Table 23.9. Manpower Category Percentage Factor Calculation.

<table>
<tr><th>STEP</th><th>Action</th><th>Example</th></tr>
<tr><td>1</td><td>Identify the manpower categories that are present within each work center at a MAJCOM location. These categories include officers, airmen, United States Direct Hire (USDH) civilians, Foreign National Direct Hire (FNDH) civilians, and CFTEs.</td><td>At base 12, in work center C, there are officers, airmen, and USDH civilians.</td></tr>
<tr><td>2</td><td>Determine the total work center requirements for each of the manpower categories found in step 1. These requirements are obtained from application of the work center's determinant.</td><td>
<table>
<tr><td colspan="3">BASE 12</td><td colspan="2">USDH</td></tr>
<tr><td>WORK CENTER</td><td>OFF</td><td>ENL</td><td>CIV</td><td>TOTAL</td></tr>
<tr><td>C</td><td>1</td><td>21</td><td>1</td><td>23</td></tr>
</table>
</td></tr>
<tr><td>3</td><td>Determine the PECs that are in the work center of interest. This is the same as determined in Table 23.2.</td><td>In this work center there are two PECs:
<table>
<tr><td>PEC</td></tr>
<tr><td>27596A</td></tr>
<tr><td>41896A</td></tr>
</table>
</td></tr>
<tr><td>4</td><td>Multiply the total work center requirements found in step 2 by the work center (base level) PEC percentages found in Table 23.2, Step 3, to obtain the requirement for each PEC in the work center.</td><td>WORK CENTER REQUIREMENT (Base Level)
<table>
<tr><td colspan="3">WORK CENTER</td><td>USDH</td></tr>
<tr><td></td><td><u>PEC %</u></td><td><u>TOTAL</u></td><td><u>PER PEC</u></td></tr>
<tr><td>C</td><td>.913 *</td><td>23</td><td>21</td></tr>
<tr><td>C</td><td>.087 *</td><td>23</td><td>2</td></tr>
</table>
</td></tr>
<tr><td>5</td><td></td><td>The UMD shows all requirements in PEC 41896A are airmen. Maintaining this finding, the PEC split by manpower category becomes:
<table>
<tr><td colspan="5">MANPOWER CATEGORY TOTALS (BY BASE BY WORK CENTER)</td></tr>
<tr><td>PEC</td><td>OFF</td><td>ENL</td><td>USDH CIV</td><td>TOTAL</td></tr>
<tr><td>27596A</td><td>1</td><td>19</td><td>1</td><td>21</td></tr>
<tr><td>41896A</td><td></td><td>2</td><td></td><td>2</td></tr>
</table>
</td></tr>
<tr><td>6</td><td>Determine the manpower category percentages for each PEC within each work center. Divide each manpower category requirement within a PEC by that PEC's total work center requirement. Combine the officer and airmen requirements to compute a military percentage instead of a percentage for each. Keep the percentages in terms of decimals rounded to three decimal places.</td><td>
<table>
<tr><td colspan="4">MANPOWER CATEGORY PERCENTAGES (BY BASE BY WORK CENTER)</td></tr>
<tr><td>PEC</td><td>MILITARY</td><td>USDH CIV</td><td>TOTAL</td></tr>
<tr><td>27596A</td><td>1+19=.952</td><td>1=.048</td><td>21</td></tr>
<tr><td>41896A</td><td>2=1.000</td><td>N/A</td><td>2</td></tr>
</table>
</td></tr>
<tr><td>7</td><td>For each MAJCOM location, compute the function's requirements by manpower category within each PEC by adding the work center totals obtained in step 3.</td><td>
<table>
<tr><td colspan="5">MANPOWER CATEGORY TOTALS (BY BASE BY FUNCTION)</td></tr>
<tr><td>PEC</td><td>OFF</td><td>ENL</td><td>USDH CIV</td><td>TOTAL</td></tr>
<tr><td>27596A</td><td>6</td><td>96</td><td>2</td><td>104</td></tr>
<tr><td>41896A</td><td></td><td>2</td><td></td><td>2</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>S
T
E
P</th><th>Action</th><th>Example</th></tr>
<tr><td>1</td><td>Identify the manpower categories that are present within each work center at a MAJCOM location. These categories include officers, airmen, United States Direct Hire (USDH) civilians, Foreign National Direct Hire (FNDH) civilians, and CFTEs.</td><td>At base 12, in work center C, there are officers, airmen, and USDH civilians.</td></tr>
<tr><td>2</td><td>Determine the total work center requirements for each of the manpower categories found in step 1. These requirements are obtained from application of the work center's determinant.</td><td><table>
<tr><td colspan="3">BASE 12</td><td colspan="2">USDH</td></tr>
<tr><td>WORK CENTER</td><td>OFF</td><td>ENL</td><td>CIV</td><td>TOTAL</td></tr>
<tr><td>C</td><td>1</td><td>21</td><td>1</td><td>23</td></tr>
</table></td></tr>
<tr><td>3</td><td>Determine the PECs that are in the work center of interest. This is the same as determined in Table 23.2.</td><td>In this work center there are two PECs:<table>
<tr><td>PEC</td></tr>
<tr><td>27596A</td></tr>
<tr><td>41896A</td></tr>
</table></td></tr>
<tr><td>4</td><td>Multiply the total work center requirements found in step 2 by the work center (base level) PEC percentages found in Table 23.2, Step 3, to obtain the requirement for each PEC in the work center.</td><td>WORK CENTER REQUIREMENT (Base Level)<table>
<tr><td colspan="3">WORK CENTER</td><td>USDH</td></tr>
<tr><td></td><td><u>PEC %</u></td><td><u>TOTAL</u></td><td><u>PER PEC</u></td></tr>
<tr><td>C</td><td>.913 *</td><td>23</td><td>21</td></tr>
<tr><td>C</td><td>.087 *</td><td>23</td><td>2</td></tr>
</table></td></tr>
<tr><td>5</td><td></td><td>The UMD shows all requirements in PEC 41896A are airmen. Maintaining this finding, the PEC split by manpower category becomes:<table>
<tr><td colspan="5">MANPOWER CATEGORY TOTALS
(BY BASE BY WORK CENTER)</td></tr>
<tr><td>PEC</td><td>OFF</td><td>ENL</td><td>USDH CIV</td><td>TOTAL</td></tr>
<tr><td>27596A</td><td>1</td><td>19</td><td>1</td><td>21</td></tr>
<tr><td>41896A</td><td></td><td>2</td><td></td><td>2</td></tr>
</table></td></tr>
<tr><td>6</td><td>Determine the manpower category percentages for each PEC within each work center. Divide each manpower category requirement within a PEC by that PEC's total work center requirement. Combine the officer and airmen requirements to compute a military percentage instead of a percentage for each. Keep the percentages in terms of decimals rounded to three decimal places.</td><td><table>
<tr><td colspan="4">MANPOWER CATEGORY PERCENTAGES
(BY BASE BY WORK CENTER)</td></tr>
<tr><td>PEC</td><td>MILITARY</td><td>USDH CIV</td><td>TOTAL</td></tr>
<tr><td>27596A</td><td>1+19=.952</td><td>1=.048</td><td>21</td></tr>
<tr><td>41896A</td><td>2=1.000</td><td>N/A</td><td>2</td></tr>
</table></td></tr>
<tr><td>7</td><td>For each MAJCOM location, compute the function's requirements by manpower category within each PEC by adding the work center totals obtained in step 3.</td><td><table>
<tr><td colspan="5">MANPOWER CATEGORY TOTALS
(BY BASE BY FUNCTION)</td></tr>
<tr><td>PEC</td><td>OFF</td><td>ENL</td><td>USDH CIV</td><td>TOTAL</td></tr>
<tr><td>27596A</td><td>6</td><td>96</td><td>2</td><td>104</td></tr>
<tr><td>41896A</td><td></td><td>2</td><td></td><td>2</td></tr>
</table></td></tr>
</table>

Table 23.10. Example of Manpower Category Percentages for One PEC.

MANPOWER CATEGORY PERCENTAGES FOR PEC 27596A									
BASE	OFFICERS		AIRMEN		USDH CIVILIANS		FNDH CIVILIANS		TOTAL RQMTS
	RQMTS	%	RQMTS	%	RQMTS	%	RQMTS	%	
1	5	.077	56	.862	4	.062			65
2	4	.085	42	.894			1	.021	47
3	5	.075	61	.910	1	.021			67
4	5	.078	57	.891	2	.015			64
5	3	.077	35	.897	1	.031			39
6	5	.070	65	.915	1	.026			71
7	4	.078	45	.882	2	.014			51
8	5	.078	58	.906	1	.039			64
9	5	.070	64	.901	2	.016			71
10	4	.082	43	.878	2	.208			49
11	4	.075	45	.849	4	.041			53
12	6	.058	96	.923	2	.019			104
13*									
14	5	.069	65	.903	2	.028			72
15	5	.081	56	.903	1	.016			62
16			4	1.000					4
17	4	.078	58	.906	1	.016			64
18	5	.076	71	.899	2	.025			79
19	2	.054	34	.919	1	.027			37
20	4	.093	38	.884	1	.023			43
*Data not available									
MAJCOM FUNC-TIONAL TOTALS	82	.074	993	.898	30	.027	1	.001	1106

23.2.8. Using a FEE.

23.2.8.1. FEEs study manpower requirements for a function. FEEs can be applied at either base or MAJCOM level.

23.2.8.2. PEC data used to apply a FEE always represents the fourth quarter value for a given fiscal year.

23.2.8.3. How a FEE is applied depends on the level that the equation is used and whether zero-based or incremental requirements are being determined.

Chapter 24

AIR FORCE SPECIALTY SKILLS AND GRADES DETERMINATION

24.1. General Concepts. This chapter provides procedures for determining skills and grade requirements to use in the development of the determinant manpower table (MANTAB).

24.2. Guidelines for Determining Required Skills.

24.2.1. The overarching concept that workers spend the majority of work time at their highest skill level governs the determination of the required skills. Therefore, the ratios of high-to-low skill levels may vary depending on the function of the work center.

24.2.2. Give particular attention to selecting the proper category of authorizations. Officer authorizations are justified by responsibilities or duties specifically needing an officer.

24.2.3. Use special care to ensure rated specialties are authorized only when the duties involved clearly justify such action. A guiding principle is to use senior level enlisted in lieu of lower grade officers when practical and feasible.

24.3. Skill Level Criteria. The criteria below gives general guidance in finding the level of skill needed for each position:

Types of Specialties	Dominant Type of Duties
Commander	Commands a unit
Director	Administers sets of programs
Staff Officer	Administers a program
Managerial Officer	Manages an activity
Technical Officer	Performs professional tasks
Superintendent	Supervises a shop or office
Supervisor	Supervises a work team
Technician	Performs advanced tasks
Specialist/Apprentice	Performs skilled and semi-skilled tasks
Helper	Performs unskilled tasks

24.4. How Input Locations Determine Skills. In its broadest sense, identifying and distributing skills sorts the total manpower requirement into the proper types and qualifications of workers. The following steps provide a logical way to determine the skills needed:

24.4.1. To properly identify the skills that are needed, the ME analyst initially needs a thorough understanding of AFI 36-2101, Classifying Military Personnel (Officer and Enlisted).

24.4.2. Compare the composition of the work (for example, WS category definitions, WUs, or OA tasks) with the utilization and career field description in the Air Force Officer and Enlisted Classification Directories located on the HQ AFPC myPERS site. Identify the various specialties and associated fields with the total manpower requirement. For civilian requirements, pick the AFSCs that are most closely aligned with the positions in the work center. To aid in this, refer to the Standard Core Personnel Document (SCPD) library located on the HQ AFPC myPERS site.

24.4.3. Perform a similar comparative analysis within each of the utilization or career fields identified. Accomplish this analysis by referring to the specialty descriptions in the Air Force

Officer and Enlisted Classification Directories to identify appropriate officer and airman specialties (regardless of skill level) with the man-hours associated with each.

24.4.4. Find the best distribution of 3-, 5-, 7-, and 9-skill levels for each enlisted specialty identified. The applicable STS could provide assistance. The detail shown in many well-designed manpower determinants permit tasks to be associated with specific specialties and skill levels. In this case, the associated man-hours point out accurately the requirements for each AFSC.

24.4.5. List fractional requirements exactly as they are computed. As such the data are more useful for distributing the skill over the range of the determinant MANTAB.

24.5. How to Determine Skills. The ME analyst relies on the same specialty and skill criteria used previously by each of the measurement teams (the Air Force Officer and Enlisted Classification Directories and STS). The procedure is slightly revised, however; because the recommended specialty and skill distributions from the various input points are available. The following steps are suggested, either done separately or in conjunction with grade determination:

24.5.1. Prepare an array of the recommended specialty and skills distribution data. List all recommended AFSCs in the first column. List the workload value and the fractional manpower recommended for each listed AFSC in succeeding columns, beginning with the smallest interval and going to the largest. This aids in spotting any obvious inconsistencies. These may be explained in the team's comments; if not, talk to the appropriate input team to find and evaluate the rationale for their recommendation.

24.5.2. Plot a scatter diagram for each AFSC, (with workload values on the horizontal axis and recommended manpower on the vertical axis), and then fit a regression line to the data. This aids both in identifying "outliers" and in picking the phase points for increasing the manpower for each AFSC.

24.5.3. Analyze the data array and the scatter diagram to find the workload values where there are significant changes in either specialty or skill requirements. Some examples of these are: the point at which an officer requirement is first needed; the point at which a staff officer AFSC is first needed; similar points for 5-, 7-, or 9-skill level requirements; and the points at which multiple requirements for any of the foregoing are first encountered. Put these requirements in the appropriate workload columns of the MANTAB. Complete the required entries in each workload column by using these entries as firm "fixes" and refer to the trends shown by the data array and scatter diagrams.

24.5.4. When there is more than one AFSC, some judgment may be needed to solve fractional specialty problems. In many cases, recommend a "give-and-take" agreement with the functional OPR or develop whole-man requirements for each AFSC without increasing the requirements.

24.5.5. In the final analysis, the combined judgment of the ME analyst and the functional OPR representatives weigh heavily in integrating the input team recommendations. The results of array analyses and the specialty descriptions of the Air Force Officer and Enlisted Classification Directories are useful in finding the most realistic distribution of requirements. This task cannot be treated lightly. Quality is just as important as quantity in stating a manpower requirement.

24.6. Guidelines for Determining Required Military Grades.

24.6.1. When skill requirements are determined, identify the specific grade for each position. Show the grade needed for each skill level in the MANTAB.

24.6.2. More than one grade for each qualification or skill level of an AFSC is allowed (See the Air Force Officer and Enlisted Classification Directories).

24.6.2.1. To determine a specific grade within an AFSC, place the more senior grades in positions that significantly need the most responsibility and experience.

24.6.2.2. Identify the more junior grades where less responsibility and experience is needed. Also, in determining grades, keep in mind that like jobs require like grades.

24.6.2.3. Use care in comparing with other grade structures. The ME analyst makes sure the comparison is made against an actual grade requirement versus a grade authorization that was substituted because of funding constraints. The manpower programming and execution system provides this visibility via the “required grade" and "funded grade" data fields. The “required grade” data field portrays grades that were determined by the ME process.

24.6.3. Manpower determinants reflect two enlisted grades per 7- and 5-skill levels (i.e., 7-level = E6 and E7, 5- level = E4 and E5), one grade for 9-level (E8) and 3-level (E3), and one grade for 0-level (Chief Enlisted Manager).

24.6.4. In determining grades, the ME analyst documents the actual grade requirements without the influence of the career progression group impact. The career progression group is a separate program to determine grade-funding allocations. External constraints or funding limitations do not affect the process of determining skill and associated grade requirements.

24.7. How Input Locations Determine Grades. Grades cannot be determined without the use of some subjective judgment. The process requires an extensive familiarity with AFI 36-2101 and the Air Force Officer and Enlisted Classification Directories. Two factors make the determinations of military grades a highly complex process, skill and work content.

24.7.1. Each skill level is normally associated with more than one grade.

24.7.2. Work content of the specific position, external contacts, and existing comparable grade structures, affect the grade determination.

24.7.3. Knowledge of the skills needed in a work center is essential. The following steps provide the most intensive process for grade determination; however, other techniques may be used:

24.7.3.1. Step 1. Compare AFSC descriptions from the Air Force Officer and Enlisted Classification Directories that match the AFSCs recommended in the effort and approved POD/SWD.

24.7.3.2. Step 2. Arrange or otherwise identify the tasks in a relative order as to the experience and ability needed to satisfactorily do each one. STS are helpful in ranking the tasks requiring enlisted skills. To rank order the officer tasks, the team has to rely primarily on its collective experience and best judgment. In either case, it may also be beneficial to get help from work center functional managers and classification specialists.

24.7.3.3. Step 3. Find those points in each task list where the transition is made from one grade to another. One such approach for doing this is:

24.7.3.3.1. Find the grade spread that corresponds with each AFSC concerned (See paragraph 24.6.). Assume that the lowest grade specified for each AFSC is needed to do the lowest ranking task identified on that AFSC's task list.

24.7.3.3.2. Refer to the rank-ordered task list for each AFSC. Using the lowest ranking task for each AFSC as the point of departure, estimate the amount of time in the functional area needed to get the necessary experience and ability to satisfactorily do the succeeding higher ranking tasks. Base these estimates on the anticipated experience of an average individual progressing through a typical technical education, OJT and career assignment pattern in the specialty concerned. Also, assume that this individual served in the same career field throughout his career. These tasks then make up those points on each AFSC's task list where the transition is made from one grade to another.

24.7.3.4. Step 4. Check each task list with the work measurement data to find the man-hours spent at the different levels of task difficulty. Based on this comparison, make the first decision for the recommended grades for each AFSC.

24.7.3.5. Step 5. Evaluate other pertinent factors to find if the initial grade needs adjusting. Specifically, consider the following:

24.7.3.5.1. The working relationship between the work center and other agencies (such as higher echelons, other units, or other work centers within the same organization). The scope and sensitivity of these interfaces may mean some degree of grade equality between working counterparts.

24.7.3.5.2. The grade structures of other activities at the same or equivalent level of organization. The grades of at least supervisory positions in the work center should, as a rule, be close to those in other activities having similar missions or a closely equal degree of responsibility. Because of the limited view of overall needs at a single location, reviewing and deciding on grade comparability may only be practicable at the MAJCOM HQ level or higher. In any event, grade comparability is not the sole basis for adjusting the original determination.

24.7.3.6. Step 6. Document fractional grade requirements as they are derived. The data, as such, are more accurate for use in finding the needed grades for an entire MANTAB.

24.7.4. Work processes are often written in broad terms. They do not always show in detail some of the tasks done in a work center by a specific AFSC. As a result, the man-hours cannot be measured at the various levels of task difficulty for an AFSC. Consequently, the following steps give a suggested approach for determining the required grades:

24.7.4.1. Step 1. Review the present manning to find the AFSCs assigned to each work center. Compare the skill descriptions from the Air Force Officer and Enlisted Classification Directories that match those AFSCs presently assigned.

24.7.4.2. Step 2. For each AFSC, build a task list made up of all the tasks that are in the corresponding skill description in the Air Force Officer and Enlisted Classification Directories.

24.7.4.3. Step 3. Give each of the work center personnel the task list which goes with the respective AFSC. Have each person check those tasks they actually do. Add any activities that are done but are not shown on the list. Show the approximate percentage of time spent on each.

24.7.4.3.1. Where there are large numbers of the same AFSC in a work center, not everyone need fill out a task list. Instead, have the work center supervisor(s) identify those personnel who essentially perform the same jobs.

24.7.4.3.2. Once these groupings are known, the task lists can then be sent to and completed by a representative portion of each group.

24.7.4.4. Step 4. For each AFSC, bring together the tasks added by work center personnel. Add these to the basic task list first built for each AFSC. Fix the relative order of the tasks and corresponding grades according to the experience and ability needed to satisfactorily do each one.

24.7.4.5. Step 5. Using the tasks lists filled out by work center personnel, find the average percentage of time spent by AFSC on each task that goes with that AFSC. Multiply these average percentage factors by the total man-hours identified for the corresponding AFSCs. This gives an approximation of the man-hours spent on all tasks done in the work center by each AFSC.

24.7.4.6. Step 6. Compare the man-hours for each task with the respective task-ordered task lists. Using this comparison, make an initial determination of the recommended grades for each AFSC.

24.7.4.7. Step 7. Look at other pertinent factors to decide if any change to the initial grade determinations is needed.

24.8. How to Determine Grades. To find the overall grade structure, use essentially the same method prescribed for developing the distribution of AFSCs for an entire MANTAB. One method is provided, but others may be used.

24.8.1. Prepare an array of the recommended AFSC and grade distribution data.

24.8.1.1. In the first column, list all recommend AFSCs.

24.8.1.2. In the second column, list the recommended grades that match each AFSC.

24.8.1.3. In succeeding columns, list the workload value and the manpower recommended for each grade and AFSC, beginning with the smallest interval and going to the largest.

24.8.1.4. This aids in spotting the more obvious inconsistencies between data points. These may be explained in the team comments; if not, talk with the applicable input team to get and evaluate the rationale for their recommendations.

24.8.2. For each AFSC, build a scatter diagram for each grade recommended for the AFSC. In other words, there are as many scatter diagrams for an AFSC as there are different grades recommended for that AFSC.

24.8.2.1. Plot workload values on the horizontal axis and the recommended numbers of each grade on the vertical axis.

24.8.2.2. Try fitting a regression line to the data. This is helpful in identifying "outliers" and picking the workload values where changes in manpower take place.

24.8.3. Apply the workload breakpoints to the regression line equations built for each grade by AFSC. This determines the corresponding grade requirements (normally in fractional form) for each AFSC.

24.8.3.1. Enter these in the determinant MANTAB exactly as derived. Do not leave out fractional requirements at this point.

24.8.3.2. Sum each column of these requirements to find out how their totals compare with the total manpower computed for each column using the determinant man-hour equation.

24.8.3.3. Where the totals do not match, adjust each fractional requirement so that there are no differences.

24.8.3.4. Find the whole-man requirements for each grade and AFSC. In doing this, two guidelines apply.

24.8.3.4.1. First, do not resolve the fractional requirements so that there are more or less whole-man requirements than the corresponding workload gives by the determinant man-hour equation.

24.8.3.4.2. Second, round any fractional requirement to the next whole-position in accordance with the rounding procedures found in AFI 38-201.

24.8.4. If the procedures shown in this chapter are not used, use a system that does not tend to layer supervisory grades.

24.8.4.1. For example, Table 24.1 shows the following distribution layers of supervisory grades. Supervisory grades are denoted by an *.

Table 24.1. Distribution Layers of Supervisory Grades.

SMSgt					1
MSgt			1	1	1*
TSgt	1	1	1*	1*	1
SSgt	1	1	1	1	1
SrA	2	2	2	3	2
A1C	2	3	3	3	4
Total	**6**	**7**	**8**	**9**	**10**

24.8.4.2. In this table, a TSgt is required for a seven-person work center, but at a threshold of eight, both a MSgt and TSgt are required. This is doubtful. Similarly, going from a work center size of nine, to one of 10, a SMSgt position is added and the MSgt grade is retained. Again, it is doubtful that both of these grades are needed.

24.8.4.3. A more real-life grade spread is depicted in Table 24.2.

Table 24.2. Real Life Grade Spread.

SMSgt					1
MSgt			1	1	
TSgt	1	1			1
SSgt	1	1	1	1	2*
SrA	2	2	3*	3	2
A1C	2	3	3	4*	4
Total	**6**	**7**	**8**	**9**	**10**
Note: * possible substitutions					

24.8.4.4. The same problem occurs with officer level positions. There may be a few cases where retaining the higher grades is justified. Grade analysis establishes that layering of higher grades is fully justified by job content and that shifting lower level responsibilities does not delete the need for the layered grades.

24.8.4.5. Make sure that the required skill level and grades are available to do the mission requirements in multi-shift operations. For example, the required man-hours in a work center requiring 9-level positions may give only one authorization. However, the true requirement may call for these duties during each shift of a three-shift operation. Teams should find the number, by grade and skill, by considering both total man-hours and minimum requirements to cover multi-shift operations.

24.8.4.6. Developing the MANTAB. Prepare the MANTAB IAW Table 24.3 and refer to the example in Table 24.4.

Table 24.3. Preparation Instructions for MANTAB.

	A	B
Item	**To Complete**	**Enter**
1	Work Center FAC	Appropriate title from the work center. If FAC and title do not specifically identify the work center, enter a unique title for identification.
2	Applicability Man-hour Range	The valid man-hour data range for this determinant. Boundaries are the lower and upper man-hour extrapolation values. For a determinant that yields a constant manpower requirement, enter the words, "Constant Manpower." When a parabola or ratio equation form is used for the determinant, specify the upper limit for the workload. Do this by putting the message "(Upper Workload Value = XXX)" under the man-hour range. When the determinant contains more than one equation, enter "See AFMD Application Instructions" in this block. Enter the man-hour data and upper workload, if applicable, in the applicability paragraph of the AFMD.
3	AFSC Title	All AFSC titles required in the function at any requirement level within the applicability range. Use the titles in the Air Force Officer and Enlisted Classification Directories to identify both military and civilian requirements. List officers first, then airmen. Group titles by career area and/or career progression group, within career specialty list in order of descending AFSC, and within each function when the AFMD covers an organization. Replace the AFSC title with the appropriate supervisory title (i.e., flight commander, flight chief, etc.) when the duties are primarily supervisory. This is intended to show key leadership positions, not every supervisory position.
4	AFSC	AFSC that corresponds to the specialty title. List both title and AFSC in descending order of AFSC within career area.
5	GRD	For a military requirement, the grade associated with the specified AFSC is based on the policy of two grades per skill level for enlisted requirements. For example, a 7-level is either a TSgt or MSgt. If any of the manpower requirements are military, treat all requirements as military. Within the AFSC, list grades in descending order. Show all grades below SRA as A1C, and show both 1st and 2d lieutenants as LT.
6	PAY PLAN/ SERIES/ GRD	Include Pay Plan, Series, and Grade.
7	Manpower Requirements	Appropriate distribution of whole manpower requirements by AFSC and grade for each level of requirements within the range bounded by the lower and upper extrapolation limits. To ensure that all levels of manpower are covered on the MANTAB, consider all of the MAFs that apply, then: (1) The smallest number of requirements shown on the table is the number required for the largest applicable MAF at the lower extrapolation limit. (2) The largest number of requirements shown on the table is the number required for the smallest applicable MAF at the upper extrapolation limit.
8	Total	The total requirement for AFSCs and grades in the column. The first and last total reflect the manpower associated with the extrapolation range.

Table 24.4. MANTAB Example.

WORK CENTER **Control Tower/13E300**					**APPLICABILITY MAN-HOUR RANGE** 966.60-4833.00								
AIR FORCE SPECIALTY CODE TITLE	**AFSC**	**GRD**	**PAY PLAN/ SERIES/ GRADE**	**SCPD NUMBER**	**MANPOWER REQUIREMENTS**								
Air Traffic Control Supt	1C191	SMSgt	GS-2152-XX								1	1	1
Air Traffic Control Craftsman	1C171	MSgt	GS-2152-XX		1	1	1	1	1	1	1	1	1
Air Traffic Control Craftsman	1C171	TSgt	GS-2152-XX		3	3	4	4	5	5	5	5	5
Air Traffic Control Journeyman	1C151	SSgt	GS-2152-XX		1	1	1	2	2	2	2	2	3
Air Traffic Control Journeyman	1C151	SRA	GS-2152-XX		1	2	2	2	2	3	3	4	4
TOTAL					**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**

Chapter 25

UPDATING AND MAINTAINING MANPOWER DETERMINANTS

25.1. General Concepts. The purpose of this chapter is to provide information on how to decide whether approved determinants are valid and how to revise and staff those that are outdated.

25.1.1. Improving Work Center Processes and Procedures. Team leads work with functional OPRs to improve existing work center processes and procedures. Additionally, incorporating process improvements from initiatives developed throughout the Air Force is an integral part of determinants maintenance.

25.1.2. Determinants may become outdated when the extrapolation limits are exceeded or when there are changes in one or more of the following: Mission, Organization, Processes or Procedures, and/or Equipment.

25.1.3. Revisions may require no measurement, partial measurement, or complete remeasurement of all activity responsibilities. Do not waste time measuring more than is necessary to update the functions total requirement.

25.2. Reviewing the Manpower Determinant for Currency.

25.2.1. Each manpower determinant is reviewed for currency at least once every two years. This consists of reviewing changes to functional OPR directives on the e-publishing website, reviewing organizational change proposals, reviewing command variances, performing trend analysis on WLF and/or WUC volumes, obtaining and reviewing functional OPR policy or procedural letters, and participating in functional OPR conferences.

25.2.2. Command manpower functions must establish controls to ensure approved command variances are reviewed and validated a minimum of once every two years**. (T-2)**

25.2.3. Request the functional OPR review the determinant and, as a minimum: review the POD/SWD, functional description, WLF, and/or WUC definition and source of count. If there are several work center determinants, review the entire function to identify specific determinants which are out-of-date. To find the currency of a determinant, use a checklist to answer questions, such as:

25.2.3.1. Have approved mission changes occurred that altered the work being done at the time the determinant was developed or updated?

25.2.3.2. Has policy and guidance changed causing procedures to change?

25.2.3.3. Is the activity still operating with the approved organizational structure that existed at the time of development or update? If not, have the realigned responsibilities or workload made the determinant invalid?

25.2.3.4. Are the PODs/SWDs or functional statements current? Do changes significantly increase or decrease process time? In some cases, minor changes can be made that do not affect process time or make the manpower determinant equation invalid.

25.2.3.5. Is the WLF and/or WUC definition still current and is the indicated workload source of count current? Has it proved reliable?

25.2.3.6. Has experience shown the models to be reliable in predicting required manpower? If not:

25.2.3.6.1. Are application points falling outside of extrapolation limits?

25.2.3.6.2. Has the determinant been used to allocate manpower?

25.3. Evaluating Currency Results.

25.3.1. Variances. MAJCOMs will submit approved variances for revision whenever circumstances warrant during the life of the determinant. (T-2) Requests for revision are sent to AFMAA for action.

25.3.2. Determinants. Some determinants may need complete revision due to of major changes in mission, organization, procedures, or when extrapolation limits are exceeded. AFMAA is the final decision authority for rescinding AFMDs. Once an AFMD has been rescinded as a result of a currency review, is added to the obsolete library and placed in the queue for future study.

25.3.2.1. Issues should be directed to AFMAA for review and detailed analysis by the appropriate requirements determination team. AFMAA forwards results to AF/A1M.

25.3.2.2. Functional OPR requests an AFMD currency review. Request is evaluated and the Functional OPR is notified of the decision.

25.4. Measuring Changed Work. For a partial measurement, measure only the changed work (processes and/or steps), where possible. In this case, a new manpower determinant equation should be derived using the adjusted man-hour determination. Table 25.1 provides one way to do this. It is not intended to preclude the use of other methods.

Table 25.1. Measuring Changed Work.

Step	Procedure
1	Measure the added and changed tasks and add the new tasks times for each location. Call the sum $Y_{1,i}$ where i = 1, 2, 3 ... n and represents each location. Thus $Y_{1,1}$ is the man-hour total of added or changed tasks for the 1st location, $Y_{1,2}$ is the total for the 2d location, etc.
2	Identify tasks which are no longer applicable plus the original times for added or changed tasks which are being re-measured. Adjust the process or activity times to the current WLF and/or WUC volume at each location and add their respective man-hours and call the sum $Y_{2,i}$ where i again represents a location. Thus, $Y_{2,i}$ is the sum at the i-th location, of man-hours for tasks which are no longer done plus tasks which are being re-measured.
3	Collect current workload data.
4	Compute man-hours allowed by the determinant for each location using the existing determinant man-hour equation. Call these man-hour totals $Y_{3,i}$ where i denotes a location.
5	Compute $Y_i = Y_{3,i} + (Y_{1,i} - Y_{2,i})$ for each value of i.
6	Recompute the manpower determinant equation using (X_i, Y_i) data pairs and determine its acceptability.

25.5. Updating Existing Determinants. The updated manpower determinant goes through the same approval process as the original determinant. Submit updated material to an original report, along with an explanation and justification for changes. For example, where updates consist of revised material that can be inserted directly or attached to the original determinant development report, the updated material, with appropriate justification and computations can be submitted as attachments to a letter of transmittal.

Chapter 26

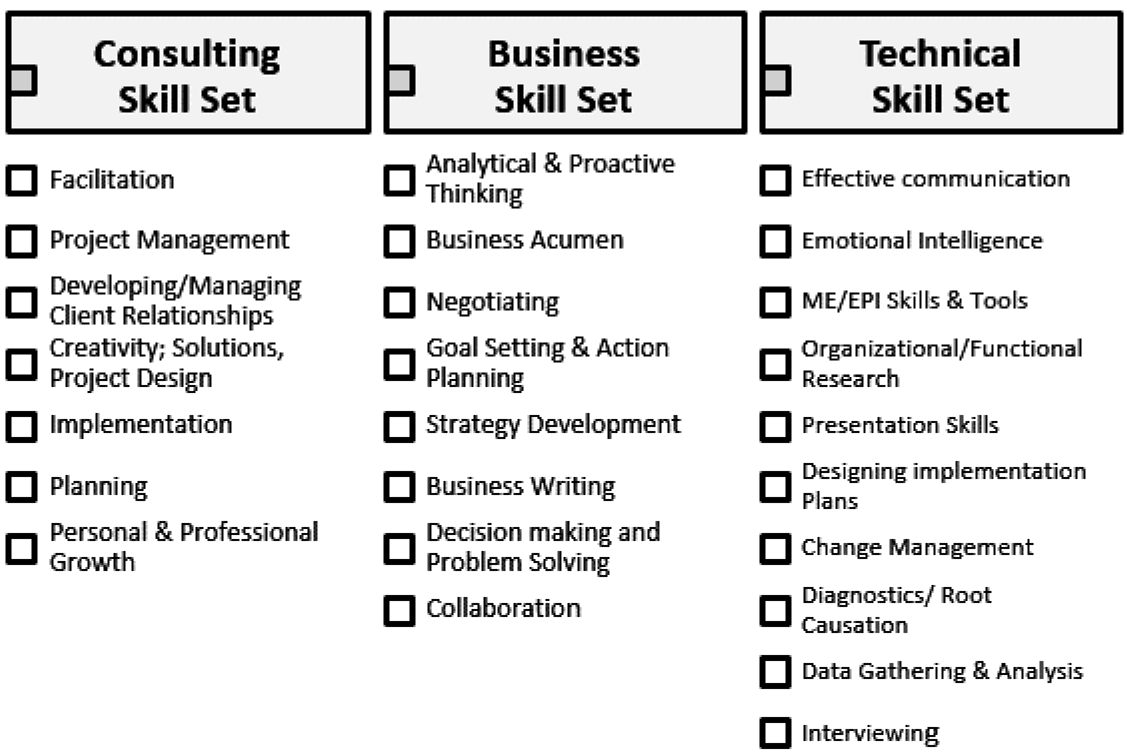
CONSULTANT SERVICES

26.1. Consultant Services.

26.1.1. Purpose of Consultant Services. A core capability within the manpower function is providing consultant services to unit commanders and functional managers at all organizational levels. Organizations may request manpower consultant services to facilitate problem solving or for general information and advice regarding manpower management or process related issues.

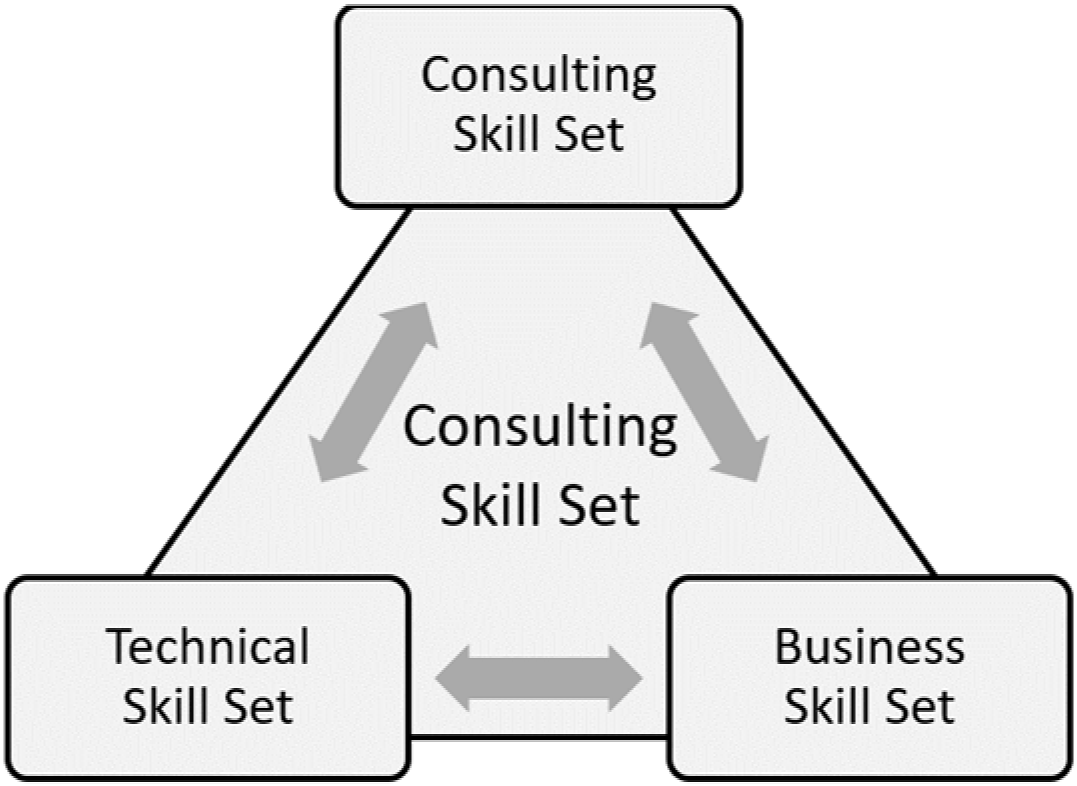
26.1.2. Definition of Consultant Services. Consultant services direct manpower and ME expertise toward problem resolution, effective resource usage, or mission performance improvements. These services may include brief consultation with management, or a more in-depth consultation requiring a study contract and report. Analysts should acquire broad based management skills, knowledge and behaviors to be successful consultants. Shown in Figure 26.1 are three categories of skill sets believed to be key to providing successful consultation services. Each category represents a vast set of desirable skills needed to provide consultant services.

Figure 26.1. Three Categories of Skill Sets.



26.1.3. It is important to recognize no skill set is greater than the other and a balance is needed to perform at the optimal level to provide maximum value to the clients. The management consultant framework at Figure 26.2 illustrates a continuous flow of various skill sets whereby usage is dependent on the scope and complexity of the provided consultant service.

Figure 26.2. Management Consultant Framework.



26.2. Consulting Skill Sets.

26.2.1. Facilitation. There are many different definitions and descriptions of what a facilitator does and what effective facilitation provides to the client. A facilitator's job is to lead and facilitate groups to a decision. The facilitator's primary role is making sure the group comes to a decision in an effective and efficient manner. The facilitator provides structure and keep things moving and on schedule. Effective facilitators focus on two main elements during a consultation: Content and Process.

26.2.1.1. Content. This element consists of defining the tasks to be accomplished and ensure the group stays focused of the tasks at hand.

26.2.1.2. Process. This involves the flow of the session(s) and the methods used to achieve the objectives. Process includes: methods; procedures; format and tools; group dynamics; norms; and cultural climate.

26.2.2. There are certain values that can be attributed to being an effective facilitator that have proven to be key for successful achievement of results. The following are the core values of facilitation:

26.2.2.1. Valid information. Effective facilitators share all relevant information with group members (e.g., strategy). Facilitators share the reasons for actions and statements and encourage others to disagree. Ultimately all issues are open to discussion.

26.2.2.2. Free and informed Choice. Effective facilitators understand while external controls generate compliance, internal controls generate commitment. Consequently, facilitators seek to increase the extent to which group members make their own choices about their work.

26.2.2.3. Internal commitment. This is a neutral result of valid information and free and informed choice.

26.2.2.4. Serving everyone's interests and thinking systematically. Effective facilitators help others to focus on the interests of all stakeholders when crafting solutions. Facilitators understand to remain effective, it is vital that groups maintain the ability to work together and meet members personal needs (as appropriate), as well as deliver quality services or products. Facilitators shift from focusing on placing blame to focusing on understanding how problems arise and how problems continue despite the sincere efforts of many people to solve them.

26.2.2.5. Increasing responsibility and ownership and reducing dependence. Effective facilitators seek to do for the group what it cannot yet do for itself. A facilitator should be able to recognize a systematic solution lies in helping the group address the root causes of its ineffective behavior, thereby increasing the group's ability to deal with similar problems in the future.

26.2.2.6. Creating conditions for learning. Learning is when members identify the core values and beliefs that guide behavior, understand how some values and beliefs undermine their effectiveness, and learn how to act consistently with a more effective set of values and beliefs. Effective facilitators share the core values, principles, and ground rules with others, discuss what meaning and ask for feedback. Facilitators model the values so others can make informed choices about whether to embrace these values.

26.2.3. Tools and Processes. A process or technique is the approach used by a facilitator to help participants achieve one or more goals of a workshop or meeting, such as the sharing of information, generating and organizing ideas, or making decisions. Several different processes are usually employed during the course of a workshop. Where models or methodologies provide a framework, processes and techniques are used to fill in that framework. To include: role playing; brainstorming or idea generation; scenario building; affinity diagramming; round robin or talking stick; process block diagram; criteria matrix; and ranking.

26.2.3.1. Project management. This is the application of knowledge, skills, tools, and techniques to meet the specified study deliverables. Project managers are tasked with overseeing all aspects of a study, ensuring that it is done well, on time, and within budget. Successful study managers demonstrate a blend of an analytical mindset and are at ease working with diverse groups of people. Professional study managers follow the study management process consisting of five major phases of a study: initiating; planning; executing; monitoring and controlling; and closing.

26.2.3.2. Managing client relationships. A consultant displays competency in this area when understanding the techniques required to develop, maintain, and manage business relationships with clients. This includes managing client's expectations during study delivery, establishing and maintaining relationships at all levels of the organization, and increasing loyalty throughout the course of an engagement and after study closure.

26.3. Consultative Skill Sets.

26.3.1. Analytical and proactive thinking. Consists of working systematically and logically to resolve problems, identifying root causation, and anticipating unexpected results. It's about managing issues by drawing on one's own experiences and knowledge and calls on other resources, as necessary. It involves a methodical step-by-step approach to thinking that allows consultants to break down complex problems into single and manageable components. Consultants who deploy analytical thinking use a process of gathering relevant information and identify key issues related to this information. This type of thinking also requires consultants to compare sets of data from different sources; identify possible cause and effect patterns, and draw appropriate conclusions from these datasets in order to arrive at appropriate solutions. Analytical thinking can be broken down into three main steps:

26.3.1.1. Gathering information. Here the consultant gathers all the necessary information required to solve the problems. It may be important to also recognize whether there is a need to obtain more or higher quality information in order to collect all the relevant data needed to arrive at an appropriate solution. Gathering information requires asking appropriate questions of yourself and of others in order to gain the necessary insights to make more effective decisions about the problems being answered. However, it's a good habit to consider the relevance of the sources and the means by which the information was gathered. Performance Data. Performance data takes statistical information to see how an organization is performing in key areas. By reviewing data, consultants can find the products/services, staff, and departments that are most efficient and/or determine areas of improvement.

26.3.1.2. Consultant acumen. This is a consultant's keenness and quickness in understanding in dealing with a situation, in a manner likely to produce a positive result. Business savvy and business sense are often used as synonyms, but each don't describe what people with a consultant acumen do differently than those who are lacking the skill. Individuals with a consultant acumen: have an acute perception of the dimensions of issues; can make sense out of complexity and uncertain future; are mindful of the implications of a choice for all the affected parties; are decisive; and are flexible if change is warranted in the future.

26.3.1.2.1. Developing a strong consultant acumen includes more thoughtful analysis, clearer logic underlying business decisions, closer attention to key dimensions of implementation and operations, and more disciplined performance management. Acumen is housed in the mind, and those with it are able to use it effectively without needing to rely on organizational support. Stronger consultant acumen among individuals across an organization encourages a shared understanding of the opportunities and threats facing the organization and enables a more logical and coordinated response. Consultants with this skill tend to display a superior understanding of the following four areas:

26.3.1.2.1.1. Understanding of thought processes. Consultant acumen provides a framework and direction to organizing one's thoughts and deciding how to allocate attention to the most important issues. Three dimensions of the consultant thought process are critical:

26.3.1.2.1.1.1. Mindful of the context, scope, and details of the situation at hand.

26.3.1.2.1.1.2. Prepared to make sense of the complexity and confusion surrounding most situations.

26.3.1.2.1.1.3. Ability to react, showing resilience and flexibility to create improvised responses to an unpredictable future.

26.3.1.3. Developing consultant knowledge. While knowledge relating to each element of a traditional organizational model is important, several of these elements are especially more critical than others:

26.3.1.3.1. Fully understand the cooperative and competing nature of stakeholder interests.

26.3.1.3.1.1. Have an appreciation for the need for a strategy that continues to allow the organization to be known as a leader within their domain.

26.3.1.3.1.2. Ensure that talent development required to sustain performance over time is critical to success and an essential skill for those with advanced consultant acumen.

26.3.2. Effective Use of Management Processes. Management processes are the tools, procedures and ideas that give structure to organizational thinking and communication about activities.

26.3.3. Management and Leadership Skills. The final aspect of consultant acumen is the ability to manage the various people relationships essential to the enterprise's success.

26.3.4. Negotiation. This is a method by which people settle differences. It is a process by which compromise or agreement is reached while avoiding argument and dispute. In any disagreement, individuals understandably aim to achieve the best possible outcome for a position or an organization. However, the principles of fairness, seeking mutual benefit and maintaining a relationship are the keys to a successful outcome. It's inevitable that, from time-to-time, conflicts and disagreements arise as the differing needs, wants, aims, and beliefs of people are brought together. Without negotiation, such conflicts may lead to argument and resentment resulting in one or all of the parties feeling dissatisfied. The point of negotiation is to try to reach agreements without causing future barriers to communications. In order to achieve a desirable outcome, consultants should follow a structured approach to negotiation. Consultants who are proficient in this skill follow this process of negotiation, to include the following stages:

26.3.5. Preparation. Before any negotiation takes place, a decision needs to be made regarding when and where a meeting is to take place to discuss the problem and who attends. This stage involves ensuring all the relevant facts of the situation are known in order to clarify your own position. Undertaking preparation before discussing the disagreement helps to avoid further conflict and unnecessarily wasting time during the meeting.

26.3.6. Discussion. During this stage, individuals or members of each side put forward the case as each see it, i.e., their understanding of the situation. Key skills during this stage include questioning, listening and clarifying. Sometimes it is helpful to take notes during the discussion stage to record all points put forward in case there is need for further clarification.

It is extremely important to listen. Each side should have an equal opportunity to present their case.

26.3.7. Clarification of goals. From the discussion, the goals, interests, and viewpoints of both sides of the disagreement need to be clarified. Clarification is an essential part of the negotiation process, without it misunderstandings are likely to occur which may cause problems and barriers to reaching a beneficial outcome.

26.3.7.1. Negotiate towards a win-win outcome. This stage focuses on what is termed a 'win-win' outcome where both sides feel each have gained something positive through the process of negotiation and both sides feel their point of view has been taken into consideration. A win-win outcome is usually the best result. Suggestions of alternative strategies and compromises need to be considered at this point. Compromises are often positive alternatives which can often achieve greater benefit for all concerned compared to holding to the original positions.

26.3.8. Agreement. This can be achieved once understanding of both sides viewpoints and interests have been considered. It is essential for everybody involved to keep an open mind in order to achieve an acceptable solution. Any agreement needs to be made perfectly clear, so that both sides know what has been decided.

26.3.9. Implementation of a course of action. From the agreement, a course of action has to be implemented to carry through the decision.

26.4. Tactical Skill Sets.

26.4.1. Effective Communication. Communication is about more than just exchanging information. It's about understanding the emotion and intentions behind the information being sent or received. It’s imperative to understand effective communication is a two-way street, a receiver and a sender. It’s not only how the message is conveyed, so that it’s received and understood by someone exactly in the way intended, but it’s also listening to gain the full meaning of what’s being said to make the other person feel heard and understood. More than just the words used, effective communication combines a set of skills, including nonverbal communication, engaged listening, managing stress in the moment, the ability to communicate assertively, and the capacity to recognize and understand our own emotions and those of the person the ME analysts is communicating with. Effective communication is the glue that helps deepen our connections to others and improve teamwork, decision making, and problem solving. It enables consultants to communicate both positive and negative messages without creating conflict or destroying trust. While effective communication is a learned skill, it is more effective when it’s spontaneous rather than formulated. It takes time and effort to develop these skills and become an effective communicator. The more effort and practice put in, the more instinctive and spontaneous the consultant’s communication skills become.

26.4.2. There are typically four key skills that translate to better and more effective communication. Consultants exhibiting these effective communication skills generally excel in the consulting environment: become an engaged listener; pay attention to nonverbal signals; keep stress in check; and are assertive.

26.4.3. Emotional Intelligence. This is the ability to recognize emotions, understand what’s being said, and realize how those emotions affect our peers. It also involves being able to identify a perception of others, understanding how each feel, which allows consultants to manage relationships more effectively. Consultants who display a high emotional intelligence are usually successful in most things. Why? Because consultants are the ones others want on their team. When people with high emotional intelligence send an email, it gets answered. When consultants need help, consultants get it. Because consultants make others feel good, consultants go through life much more easily than people who are easily angered or upset. Emotional intelligence is made up of four core skills that pair up under two primary competencies: personal competence and social competence.

26.4.4. Personal Competence. This is made up of self-awareness and self-management skills, focusing more on the individual than interactions with other people. Consultants who display personal competence have shown the ability to stay aware of their emotions and manage their behavior and tendencies. Self-awareness is the ability to accurately perceive emotions and stay aware of as each occurs. Self-management is the ability to use awareness of these emotions to stay flexible and positively direct your own behavior.

26.4.5. Social Competence. This is the ability to have social awareness and relationship management skills. Consultants with this competency have shown the ability to understand other people's moods, behavior, and motives in order to improve the quality of relationships. Social awareness is the ability to accurately pick up on emotions in other people and understand what is really going on. Relationship management is the ability to use awareness of those emotions and the emotions of others to manage interactions successfully.

26.4.6. ME/Continuous Process Improvement (CPI) skills and tools. As a manpower consultant, competence and skills in the ME methodology, tools, and techniques, and the CPI process is necessary in order to be successful. The purpose of the CPI engagement is to standardize, document, and improve the enterprise-wide processes of an Air Force function. The CPI process guides a process improvement team logically from problem definition to implementing solutions linked to root causes.

26.4.7. Practical Problem Solving Method (PPSM). This methodology provides a standardized approach to properly define a problem, its root cause, countermeasures, and countermeasure implementation. This approach is similar to plan, do, check, act, and define, measure, analyze, improve, and control. The activities of the PPSM are shown in Table 26.1.

Table 26.1. PPSM Activities.

Clarify & validate the problem
Break down the problem / identify performance gaps
Set improvement targets
Determine root cause
Develop countermeasures * implementation plan
See countermeasures through
Confirm results and process change
Standardize successful processes

26.4.8. Consistent application of the PPSM provides a concise and common format for presentation of data, problem solving facts, and information. This eases benchmarking and sharing of best practices when similar problems arise in other areas. The common structure provides a common language which easily translates into a common understanding. To attain a superior understanding of both the CPI process and the PPSM and ME methodologies requires the manpower consultant to possess the knowledge and practical application of a multitude of ME/CPI skills. Effective consultants are proficient and comfortable using the following tools found in Table 26.2.

Table 26.2. ME/CPI Tools.

Customer, Output, Process, Input, Supplier (COPIS)
SWOT
Five-Whys
Organizational Maturity Model
Project Plans
SWD
Value Stream Map
Process Flow Map
Lean
Six Sigma
Theory of Constraints
Pareto Chart
Control Chart
Fishbone-diagram
Gap Analysis

26.4.9. Do not agree to provide consultant services if the manpower consultant believes the sole purpose is to:

26.4.9.1. Justify predetermined manpower increases or decreases.

26.4.9.2. Expect the consultant to make a line management decision for the client.

26.4.10. Providing effective management consultant services requires the manpower consultant to continuously develop and improve a myriad of skills. The key to being a successful consultant is to strike an appropriate balance amongst the various skill sets that meets the needs of the Air Force community.

Chapter 27

MANAGEMENT ADVISORY STUDY

27.1. General Concepts. Air Force MEP personnel (here termed "consultants") or ME analyst provide in-house MASs at base, command, and Air Force-wide levels. Air Force commanders use this service to carry out the command mission efficiently.

27.1.1. It may be desirable to use a MAS when the client cannot devote time to the problem; a short-term analysis is needed to resolve an issue; the client has tried but cannot identify or solve the problem; specialized knowledge and skills are not available within the client's own resources; an ME analyst can introduce new concepts or innovative techniques and act as a catalyst for change; or an objective and/or impartial viewpoint is needed to give a fresh approach to a problem or to resolve conflicting views within the client's staff.

27.1.2. A MAS is not used to justify manpower changes, approve or lend scientific credence to a preconceived solution, discredit another organization or individual, or when the client expects the manpower to assume the decision-making role of line management. It is also not used as a method to quantify manpower or man-hours for the purpose of programming future requirements.

27.1.3. Guidelines Affecting MASs. Any Air Force commander, functional manager or supervisor (here termed client) may request MAS assistance. The base manpower function may perform MASs for any base unit or tenant. Study results are confidential and released only to official parties, with the permission of the client. The client has the final authority to reject or accept and implement proposed initiatives and/or manpower changes. MRSs can be used as sounding boards by the base-level manpower function during a local advisory study. However, these communications should not violate the client-consultant relationship.

27.1.4. Promoting MASs. Results and client satisfaction help promote MASs. Personal contact between Air Force MEP personnel and the client is an effective method of promoting a MAS. Articles and editorials in base or command news media also are excellent ways to promote this service. However, do not "over promote" the capability to do advisory studies. Active promotion may actually hurt the image of the Air Force MEP, if other scheduled workload does not permit a prompt reply to the client.

27.1.5. Conducting MASs. When conducting a MAS, the ME analyst uses a wide range of skills involving organizational analysis, investigation of management functions, work methods and procedures, and resource utilization. These skills are not acquired from formal training alone; these skills can also be attained through practical experience.

27.1.5.1. ME analysts are trained to analyze problems and facilitate process improvement. It is critical to gain the client's confidence, accurately define the problem, build a solution, and persuade the client to adopt the recommendations.

27.1.5.2. Effective communication and mutual understanding between the client and consultant is essential to the success of the study.

27.1.6. Need for the Improvement Process. In order to survive, every organization should constantly improve. In business, competition often forces inefficient firms from the marketplace. In the Air Force, programs compete for tax dollars and are under close scrutiny for each dollar spent. Improvement can be measured in dollars, time, and quality factors, and is eventually stated in terms of either lowering the cost of resources used to operate at the same level of effectiveness, or increasing operational effectiveness at the same or lower cost.

27.1.6.1. The improvement process should be managed if it is to have a significant and lasting effect. The changing military environment creates challenges each organization adapt to meet. However, under the pressure of day-to-day work, the manager does not always have the time to look for ways to improve operations. To meet this need, managers request a MAS in order to receive an objective full-time study, using the latest methods of analysis.

27.1.6.2. Improvement can be either sporadic or systematic. For effective management, improvement is better if done systematically

27.1.7. The Length, Approach, and Degree of Formality Depends on the Study. At times, the client and the consultant can decide informally on the preliminary research. More often, an expanded study is needed, especially if the client cannot define the problem clearly, or the problem is too complex or broad in scope.

27.1.8. Data Gathering. Although data gathering is done later in the advisory study, it starts at the time of problem recognition. Possible solutions may also be foreseen during Feasibility and Familiarization, but take caution not to have premature study bias. Do not concentrate on the solution until all pertinent data are collected and analyzed.

27.1.9. Initial Problem. The initial problem, as seen by a client, may be only a symptom of another problem. Regardless of whether a formal study is done, the first step is to identify and define the real problem(s). The problem statement serves as a starting point for initiating and directing the emphasis of the study.

27.1.9.1. Identifying and Defining the Problem.

27.1.9.1.1. Most MASs are problem-solving exercises. Problems themselves do not resist being solved; therefore, when a problem appears to resist solution, it is usually the problem-solver, or the action authorities who are resisting the use of correct problem solving techniques.

27.1.9.1.2. The problem statement points out symptoms and probable causes. If properly stated, it gives guidance for use during later analysis. Problem symptoms are often mistaken for problem causes; therefore, managers (and consultants) should probe for the root of the problem. The problem definition may show only the client's viewpoint (which is limited by perspective). However, the study may produce other views.

27.1.9.1.3. In the problem definition step, state the goals and limitations.

27.1.9.1.3.1. Goals are desired outcomes clearly identified during Feasibility to be covered in the problem solution. Some typical goals are: to decrease total processing time; to improve work procedures or workflow; to decrease space requirements; to improve the use of critical skills; to improve work quality; or to decrease resource expenditures (people, money, or material). Goals are stated in specific terms and ranked in priority. In final form, these goals spell out the study objectives.

27.1.9.1.3.2. Limitations or restrictions put barriers on study goals. Occasionally, certain specific limitations identified in Feasibility (e.g., regulatory requirements, local managerial preferences, etc.) may prove to be direct contributing causes to the problem. Attempt to mitigate these limitations.

27.1.9.1.3.3. At times, the client wants to study the cause and effect of directives that are controlled by an authority higher than the client. When this occurs, it is better to charter the study at the level that can change the directive. Although it is a limiting factor not to have a charter at that level, it is not a reason to not do the study. There are proper channels for staffing directive changes, either through the client's OPR or Air Force MEP channels.

27.1.9.1.3.4. On occasion, a good MAS solution to a problem is turned down by the client or by his or her superior. Do not treat this as a study limitation unless the client wants it to be listed accordingly.

27.1.10. Determining Feasibility of a MAS.

27.1.10.1. Environmental factors such as cost of the MAS, study timing, consultant's workload, client's workload, amount of time needed to build a solution, pressures for a solution, potential savings, and study priority impact the feasibility of the study.

27.1.10.2. The client should see the good that can come from an advisory study. To do this, the client and consultant jointly identify study goals (for example, to improve quality, reduce cost, or increase quantity). To guide the consultant, an agreement on the order of importance among goals needs to be reached with the client. If goals are prioritized during Feasibility, it is less likely to waste time and resources by going after goals not wanted by the client.

27.1.10.3. After the problem is defined and the study goals, scope, limitations and anticipated benefits identified, the consultant (perhaps jointly with the client) decides whether the study is to continue. If it is decided that the study does not warrant the cost of consultant resources, tactfully refuse or delay it.

Note: Make sure that both the client and consultant clearly understand and agree to the objectives and scope of the study. The client and consultant agreement identifies the study team composition (i.e., ME consultant, client staff, and representatives of other contributing organizations); states who uses the study findings and for what purpose; sets a tentative beginning date, which gives the client time to tell all subordinates about the study; forestalls misleading rumors and eases personnel fears; and sets a tentative completion date that gives the consultant time to develop recommendations. Table 27.1 provides the purpose and content for this agreement, the Memorandum of Understanding (MOU).

Table 27.1. Memorandum of Understanding.

Purpose: The main purpose of a MOU is to state the goals, the authority, and the responsibility of all parties. It is like a contract. The client wants certain results and the consultant agrees to give services needed to get those results. The memorandum is usually prepared by the consultant for the client and is signed by both. A formal MOU is not used for most advisory services, but can be a big benefit in complex or sensitive studies. **Content:** The MOU includes, but is not limited to: Title of Effort. A descriptive title of the subject. Problem. A clear statement that defines and describes the problem. Do enough research during Feasibility to ensure the problem, and not the symptoms, is defined. Objectives. A statement of the improvement objectives. This statement is definitive (for example, a 10% reduction in overtime, and a 15% decrease in the abort rate). Scope. Document what limits may affect the effort, such as anticipated program changes, known limits of funds and space, and operational constraints. Location. Provide the location of the installation, organization, and function. Recommendations. Explain the level of detail and format to be provided for recommendation(s). Authority To Approve and Implement, and Release Recommendations. State the agreed upon client's organizational level that has authority to approve and implement improvements, and release recommendations and results. Information to include the report and abstract is not to be released without approval of the client. Designating the Consultant. List all personnel who are to be involved in the effort, their security clearances, and the access they need to classified material. Access Authority of Team. A statement that provides consultant personnel access to existing reports and data, work areas, and personnel needed to get information to conduct the effort. Responsibility of Other Elements. A statement that documents the involvement of other units and personnel to support and help the consulting team. This may need prior coordination with supporting units. Reports. Describe the type and frequency of status reports to be provided to the client. Signatures. Signature blocks are provided for the consultant and client. This document is to be signed before any significant work is accomplished.

27.1.11. Study Design. A great deal of Study Design (and possible scheduling as well) is done during preliminary research. Study Design is actually an extension of the initial study definition, as specified in the MOU. Design efforts complement and support Feasibility.

27.1.11.1. Study Design determines the how of the study to include: Study approach (e.g., measurement techniques, a synopsis of the nature of the work); strategies for study completion (e.g., data collection methods, involvement of installation manpower offices) and any other pertinent information study team needs to facilitate study completion.

27.1.11.2. During Study Design, the consultant formalizes plans for doing the rest of the study. A systematic and detailed plan is important for several reasons. Guard against unnecessary action by deciding, ahead of time, what steps are needed to do the study and the sequence of these steps. Careful planning lays the groundwork for efficient use of consultant personnel and helps save the time of client personnel. A plan serves to focus effort on common objectives and maintains consistency of action by both the consultant and client.

27.1.11.3. Available time and talent, knowledge gained during Familiarization, the client-consultant agreement, and the complexity of the problem under study are four main concerns in developing the details of study plans and schedules. The study design clearly spells out the approach, techniques to be used, sequential steps, types and required quantities of factual data and time phasing. Consider the following planning factors:

27.1.11.3.1. Develop a working plan for fact-finding and to determine the type data to acquire; the sources of data; the techniques to collect the data; and the reporting format.

27.1.11.3.2. Define study team personnel requirements and qualifications and possible sources of expertise (e.g., consultants, client operating personnel, and other outside offices and/or agencies).

27.1.11.3.3. Identify each individual study team member's roles and responsibilities.

27.1.11.3.4. State how findings are to be coordinated and exchanged (such as interim briefings, reports, and interim decisions).

27.1.11.3.5. Identify the required study actions and/or milestones. Identify when vector checks are to be conducted to check on study progress and/or for updating the study plan.

27.1.11.3.6. Indicate how administrative support arrangements are to be handled, such as security, working space, administrative and/or computer support, travel funds and authorization, and supplies.

27.1.11.3.7. Identify a test period for new procedures, layout, or organization, as needed. Advise who is responsible, and when, for procedural development, briefings, orientation of personnel taking part in the test, conducting the test, and evaluating the results.

27.1.11.3.8. Determine the format to be used for reports, report preparation responsibilities, and milestones for report accomplishment.

27.1.11.4. The need for careful study planning cannot be stressed enough. Do not let the study head out in all directions because this often reveals new problems and opportunities for improvement. Do not be tempted to increase the scope to the point the study becomes unmanageable. When this happens, the original objectives are lost in confusion. To avoid this, the objectives, scope, and schedule is logically and carefully planned early in the study. Develop the plan so it serves as a guide for judging study progress and keep study efforts aimed toward solving the problem.

27.1.11.5. Consider cost in the design process so that the benefit outweighs the cost. Obviously, there is a point of diminishing returns in the amount of time that can justifiably be spent improving a management practice.

27.1.11.5.1. Some preliminary analysis and planning is needed to study the probable cost and potential savings of a study. Many advisory study costs are not identifiable in terms of tangible dollars. Study benefits can take on intangible forms, such as improved morale, increased service, or better managerial control.

27.1.11.5.2. Finding out just how beneficial a study may be, is often a highly subjective process. Nevertheless, plan to give an overall advisory service that is truly worth its cost.

27.1.12. Data Gathering. Data gathering forms the basis for later analysis and recommendations for improvement. Clearly define what is being accomplished and how effectively it is being done. The data gathered should be accurate, unbiased, and comprehensive. Failure to collect and document pertinent and accurate facts can have serious consequences, especially when the time comes to present and obtain agreement with the study findings and recommendations.

27.1.12.1. Three Objectives for Data Gathering:

27.1.12.1.1. Objective #1 - Collecting Facts. Usually, three versions of "the facts" are discovered; what the directives state, what operating officials think is being done (or should be done), and what is actually being done. For this reason, direct the examination at the regulatory, managerial, and performance levels.

27.1.12.1.2. Objective #2 - Collecting Opinions and Suggestions. Encourage client personnel to voice opinions. Opinions are personal judgments not specific events or facts. Suggestions for changing or improving operations are also recorded and later given careful consideration during the Analysis phase. Many good ideas come from client personnel and may lead to effective solutions.

27.1.12.1.3. Objective #3 - Promoting Acceptance of Improvements. The technical aspects of a study are often relatively easy if the proper study technique is selected. In fact, the hardest task may be to convince operating personnel and the client to accept needed improvements. Actively seek consultant acceptance from the client and operating personnel by honestly and objectively looking at all recommendations. Remember, the consultant is there to assist the client and should be interested in their involvement in the solution process. If this is kept in mind, resistance to change is lessened and operating personnel supports and assists in implementing ideas.

27.1.12.2. Basic Principles for Data Gathering:

27.1.12.2.1. Stay within the scope, schedule, and objectives stated in the plan.

27.1.12.2.2. Follow these guidelines to determine the breadth and depth needed for fact gathering.

27.1.12.2.2.1. In making initial contacts, start at the top and work down. This approach gains proper perspective and support from each level of supervision.

27.1.12.2.2.2. Usually one to several aspects of the overall problem tends to dominate all others. Concentrate study efforts on accurately identifying, defining, and solving these issues. Unless the causes and workable solutions are found for these issues, the study may have little or no value. But, when solved, the issues create a chain reaction for resolution of lesser concerns.

27.1.12.2.2.3. How much data are enough? Irrelevant data or data defined as only "nice to know" are a waste of consultant time. But, it is better to have too much data than too little. A conclusion, either incorrect or weakly supported due to lack of essential data, is worse than the cost of collecting too much data that leads to a clear and firm conclusion. Remain flexible when deciding how, when, where, and what data to collect. In the end, the experienced judgment of the consultant is essential for these decisions.

27.1.12.2.2.4. To ensure information is accurate, record data in a planned, orderly fashion so that valuable facts are not lost later in the study. Clearly identify each item so that an audit trail is left which shows when, where, and from whom data was obtained.

27.1.12.3. Information requirements and data gathering methods. Consultants are asked to solve problems that reside in complex environments which require careful fact-finding and investigation to reveal pertinent background information.

27.1.12.3.1. Personnel and documentation are two main sources of information in data gathering. These sources complement each other and are to be used in every possible case. Obtain information from these sources by one or more of the following methods: documentation review; interviews; observation; and questionnaires.

27.1.12.3.2. Selecting the methods to use depends on the nature of the problem. One is the amount of time the consultant has available, versus the time that is needed. The second is to consider the basic limitations and advantages of each technique.

27.1.12.3.3. Validating data. Errors, omissions, or misunderstandings in data can lead to unsound recommendations and result in confusion, excessive expense, and personal embarrassment. Make sure that analyses and recommendations are based on facts, not on unfounded rumors or misunderstandings. Verify all important information against basic documents or factual data.

27.1.12.3.3.1. When questionable information is received, record the source of information and verify the initial discovery with the source to clear up any areas of doubt. When required, validate information with the supervisor. Take care not to reveal information given in confidence or information which might create friction within the activity.

27.1.12.3.3.2. Verification with supervisors provides corrections to data and may yield additional dividends. For example, a supervisor who is unaware of what subordinates are doing, or disagrees with what subordinates have reported maybe a signal to evaluate supervisor and subordinate relationships, or operating policies and procedures.

27.1.12.3.3.3. As a rule, verify the information as much as is necessary to confirm or disprove it. Use judgment to determine the need and practicality for the extent of data verification.

27.1.12.3.3.4. In larger studies using several consultants, schedule intra-group meetings to keep all participants up-to-date on the study's progress and to verify findings. These meetings also help to reemphasize the overall study objectives, and help consultants see the most recent findings as a part of the whole picture.

27.1.12.3.3.5. The evaluation process, performed while obtaining data, is really the first stage of the analysis process. Data reviewed during the collection process may show a need for additional information or that redirection is needed.

27.1.12.3.3.6. If the data does not support productive results, do not continue to collect data that only adds confusion to the effort. Instead, perform a thorough analysis of the collected data, and seek a fresh view from other ME analysts. Since these analysts are not deeply involved in the study, these analysts may provide valuable insight or ideas. A fresh viewpoint may define the need, and indicate that additional data collection is warranted.

27.1.12.4. Data gathering often marks the start of active contacts with client personnel. The manner in which these contacts are initiated can critically affect the success of the study.

27.1.12.4.1. Coordinating the study request and MOU with the client, and possibly with other key staff members, establishes rapport between these officials and the consultants. However, there may not have been much contact with the people in the function(s) being studied. Devote particular attention to telling the workers about the study, the methods to be used, and how and why specific data are collected.

27.1.12.4.2. Ideally, the client should designate a person (or persons) to act as liaison and to be an active study team member(s). The liaison can then arrange for office space or other support and introduce other team members to client personnel. In so doing, this person often conveys the client's endorsement of the study to other functional personnel. Finally, the liaison can assist by coordinating the organization's efforts to compile data supplementing that collected directly by the consultants.

27.1.12.4.3. As the time for collecting information nears, recall the study approach, the time planned for interviewing workers, and the identification of essential elements of the study problem(s). In actual discussions with workers, there may be a tendency to depart from the original approach. To avoid this, meet often with study personnel, to make sure that the objectives of the study are still being met.

27.1.13. Data Analysis.

27.1.13.1. Techniques for Analysis. A thorough analysis is needed to learn the total situation. Do the analysis scientifically and without bias from preconceived ideas or opinions.

27.1.13.1.1. Use proper techniques to display data to find relationships, verify facts, and ensure that all required facts or information is known. Since MAS information requirements vary greatly from study to study, make no attempt to standardize data arrays.

27.1.13.1.2. Pick the type, detail, and arrangement that best allows answering the questions of why it is necessary, what is actually done, where it is done, when it is done, who does it, and how it is done. The most creative part of the improvement process is developing new methods or procedures.

27.1.13.1.3. Improvement recommendations are often obvious. At other times, a systematic study of operations, processes, relationships, or procedures are needed to find good solutions. Several techniques are available for this purpose as shown in Table 27.2.

Table 27.2. MEP Techniques.

Process Flowcharting (refer to Section 3.1.)
Layout analysis (refer to Section 3.2.)
Man-hour and shift profile analysis (refer to 17.4.5.)
Work distribution analysis (refer to Section 3.11)

27.1.14. Developing Recommendations. Strive to develop recommendations that are practical, realistic in terms of resources, and in terms that the client is most willing to accept. Remember the normal resistance-to-change, so take every opportunity to discuss new proposals with everyone involved.

27.1.14.1. Make every effort to get client personnel involved with the improvement process. The more personnel are involved in developing improvements, the more readily the changes are accepted.

27.1.14.2. Periodic discussions that are centered on tentative recommendations help the client and consultant focus on developing sound and practical solutions.

27.1.15. Briefing the Results.

27.1.16. When analysis is complete, brief the results to the client.

27.1.16.1. Address all the main facts surrounding the data gathering process, the conclusions reached, the recommended improvements, and the detailed implementation plan. State all facts, conclusions, and recommendations in positive terms.

27.1.16.2. Discuss major ideas of the study in the order of the anticipated acceptability, leading off with less controversial ideas and following with those likely to involve client hesitancy.

27.1.16.3. Be prepared to discuss major ideas with alternatives in mind. Many times, an alternative is preferred by a client and results in the improvement being implemented.

27.1.16.4. Ensure that any recommendations that involve other functions are properly coordinated and documented. Ensure there are no surprises and the briefing summarizes all previous discussions and interim reports.

27.1.16.5. Ensure the MAS report reflects any changes discussed during the out brief.

27.1.17. Implementing Study Findings. Implement study findings after the recommendations and implementation plan are accepted. The following actions are performed:

27.1.17.1. Ensure the people affected by the study are briefed on the plan, its results, and their responsibilities in the process.

27.1.17.2. If necessary, set up a trial period to test new procedures.

27.1.17.3. Ensure the improvement is implemented as designed. Also, answer the client's questions and render help to the function.

27.1.17.4. Allow time for changes to be placed into action. Avoid the tendency to change recommendations when there are implementation difficulties because rash changes lead to confusion.

27.1.18. Perform Follow-up Visits After a Trial Period.

27.1.18.1. Ensure the recommendations are working and make any needed adjustments.

27.1.18.2. Obtain the necessary information to determine savings and develop the MAS abstract.

27.1.18.3. Perform periodic visits, based on the study initiatives, but typically accomplished at 1, 3, and 6 month intervals after initial implementation. This helps to ensure improvements are working and provides feedback on the value of the recommendations. Fol1ow-up visits may open discussion for additional ideas to improve the work center.

27.1.19. Ending the Study. The client may want a final briefing to end the study after improvements are implemented and the follow-up visits are conducted.

27.1.19.1. This is a good opportunity to discuss initial improvements the client chose not to implement or new ideas that resulted from implementation of recommendations.

27.1.19.2. Be careful to avoid being involved in a never-ending study of a single organization. Stay within the boundaries of the scope established in the MOU.

27.2. MAS Documentation. The MAS report provides the client enough information to make valid decisions and carry out the recommendations. It serves several purposes.

27.2.1. MAS Report. The report meets the client's needs by providing solid justification for all recommended actions. Second, if approved for release, it provides findings and recommendations for other potential users and documents the efforts of the consultant.

27.2.2. Report Format. The format is based on the scope of the study and how the report is to be used. The report may range from a memorandum of record to a paper similar to an AFMD development report. The report is generally divided into three sections. An example format is provided in Table 27.3.

27.2.2.1. In the first section, provide an overview of the study conclusions, recommendations, and benefits to be gained from implementing the improvement(s).

27.2.2.2. In the second section, state the study objectives; identify the problem, facts and assumptions; discuss the findings and alternatives and reasons for retaining or discarding them; describe the recommended improvements and the expected benefits or results of the improvements; and provide a detailed implementation plan.

27.2.2.3. The third section includes the necessary backup information, data arrays used during analysis, and any other documentation needed to give solid rationale upon which to base required decisions. Arrange this section so that the reader has information to support the conclusions reached in the 1st and 2nd sections.

Table 27.3. Example of a MAS Report.

Title of Study – Management Advisory Study Report
Preface. Summary of information that is in the MOU (e.g., improvement objectives and scope of study). Table of Contents.
Section I – Summary of Conclusions, Recommendations and Benefits:
Conclusions (these form the basis for recommendations). Recommendations (brief summary of major recommendations). Benefits (summary of benefits for all study recommendations to be implemented).
Section II – Management Advisory Study Details:
Detailed description of study objectives and scope of the study. Discussion (identify the problems, facts, and assumptions, and describe any problems associated with the present process or procedure, including the impact on the overall effectiveness of the work center). Conclusions (detailed description). Recommendations (detailed description). Benefits (detailed list of benefits expected as a result of implementing the recommendation(s), including such items as statements of increased operational effectiveness, estimated savings, and significant intangible benefits). This section clearly demonstrates to the client the benefits of implementing the recommendation(s). Proposed Implementation Plan (provide a plan the OPR can follow to implement the recommendations and state specifically who should do what and when).
Section III – Documentation. This includes work counts, shift profile charts, layout charts, and other items needed to support recommendation(s) and allow the client to objectively analyze alternative proposals.

27.2.3. MAS Abstract.

27.2.4. An abstract of the study may be provided (with client approval) to Air Force MEP administrators, functional officials, and other interested Air Force organizations. It can also be used to weigh the cost benefits of the program and provide good publicity for the Air Force MEP.

27.2.4.1. The abstract is developed at the end of implementation and follow-up, and the amount of detail varies by the complexity of the study.

27.2.4.2. The format and information requirements for all abstracts is provided in Table 27.4.

Table 27.4. MAS Abstract.

Study Identification:
Command:
Study Title:
Client: Identify office and title only of the individual who requested the study; do not use surnames.
Functions Involved: Use work center title and function code specified on the manpower document.
Consultant: Identify who led the study, mailing address and DSN number
Study Location: Base, state
Date Results Presented to Client: Month, Year
Improvement Objectives: Briefly describe the study goal. If the goal identified during Feasibility was modified during the course of the study, merely present the end goal. It is not necessary to explain if; why; or how the study objective(s) changes. In presenting an objective, two approaches are acceptable. If there is but one objective, or if a number are closely interrelated, a single narrative paragraph is appropriate. However, if multiple, nonrelated objectives are identified, introduce them with general introductory comments and list the individual objectives as subparagraphs.
Recommendations Implemented: Use either a single paragraph or multiple subparagraphs, whichever is most suitable. The important thing is that the recommendations accomplish the stated objectives.
Applicability of Improvements: Provide a determination if improvements apply to other locations within the command or the Air Force and a statement why each would. Studies involving physical layouts and relationships, space utilization, or labor availability and grade peculiarities are local in nature.
Analysis Techniques: A description of the analysis tools used.
Study Impact:
Documented Savings: Total dollar savings, minus any costs that go with implementation (provide both figures, and net savings). Provide the annual savings, multiplied by 2 years, plus the savings for the rest of the implementation fiscal year, e.g., January implementation produces a 9-month savings. If there are no dollar savings, indicate NA.

First Year Savings	$ XXXX.XX
Implementation Cost (If in 1st year)	- XX.XX
Net Savings – Current Year (1st year)	XXXX.XX
Savings for FY 20XX + 20XX	+ XXXX.XX
TOTAL SAVINGS	$ XXXX.XX

Intangible Benefits:

Signature Block
Consultant

I concur with this study abstract and authorize its release.

Signature Block
Client

27.2.5. Client Approval and Reporting Criteria. To protect the client-consultant relationship, be sure the client concurs with the release of the abstract and/or MAS report (i.e., have the client sign an acknowledgement for release). If the client has agreed to release, then forward a copy of the abstract to AFMAA for cross-feed purposes. If the client does not concur, note this in the report and abstract and file it along with the other study documents. Do not forward MAS documents that have not been released by the client.

Shon J. Manasco
Assistant Secretary of the Air Force
Manpower and Reserve Affairs

Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

References

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AFI 38-401, *Continuous Process Improvement,* April 15, 2016

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AFI 36-802, *Pay Setting*. September 01, 1998

AFI 65-503, *United States Air Force Cost and Planning Factors*, July 13, 2018

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AF Form 847, *Recommendation for Change of Publication*

Abbreviations and Acronyms

AF—Air Force

AFI—Air Force Instruction

AFMAA—Air Force Manpower Analysis Agency

AFMAN—Air Force Manual

AFMD—Air Force Manpower Determinant

AFS—Air Force Specialty

AFSC—Air Force Specialty Code

AoA—Analysis of Alternatives

AOR—Area of Responsibility

API—Aircrew Position Identifier

AVG—Average

CANN—Crediting Cannibalization

C&R—Correlation and Regression

CFTE—Contract Full-Time Equivalents

CHIDIST—Chi-Squared Distribution

COPIS—Customer, Output, Process, Input, Supplier

CPI—Continuous Process Improvement

DoD—Department of Defense

EOR—End Of Runway

FAC—Functional Account Code

FEE—Functional Estimating Equation

FP—Flow Procedures

FREQ—Frequency

FTEs—Full-Time Equivalents

FYDP—Future Years Defense Program

H0—Hypothesis

Ha—Alternative Hypothesis

HQ—Headquarters

IAF—Indirect Allowance Factor

LCL—Lower Control Limit

LCOM—Logistics Composite Model

Lq—Queue Length

M&O—Manpower & Organization

MAF—Man-Hour Availability Factor

MAJCOM—Major Command

MANTAB—Manpower Table

MAS—Management Advisory Study

MDS—Mission Design Series

ME—Management Engineering

MEP—Management Engineering Program

MFP—Major Force Program

MIN—Minutes

MMF—Minimum Manpower Factor

MOU—Memorandum Of Understanding

myPERS—My Personnel System

NCO—Noncommissioned Officer

NT—Normal Time

OA—Operational Audit

OJT—On-The-Job Training

OMP—Optimistic, Most Likely, Pessimistic

OPR—Office of Primary Responsibility

PAI—Primary Aircraft Inventory

PCS—Permanent Change of Station

PEC—Program Element Code

PEF—Program Estimating Factor

PF&D—Personal, Fatigue, and Delay

PM—Performance Measure

PMO—Program Management Office

PPE—Personal Protective Equipment

PPSM—Practical Problem Solving Method

PQT—Position Qualification Time

PRT—Post Related Time

R2—Coefficient of Determination

RPA—Request for Personnel Action

SAT—Standard Activity Time

SCPD—Standard Core Personnel Document

SME—Subject Matter Expert

SSE—Sum of Squares Unexplained by Regression

SSR—Sum of Squares Explained by Regression

ST—Standard Time

STS—Specialty Training Standards

SWD—Standard Work Document

SWOT—Strength-Weaknesses-Opportunities-Threats

Sy—Syntax

TCTO—Technical Compliance Technical Order

TDY—Temporary Duty

TSS—Total Sum of Squares

U—Unscheduled

UCL—Upper Control Limit

UMD—Unit Manpower Document

USAF—United States Air Force

USDH—United States Direct Hire

WIP—Work-In-Progress

WLF—Workload Factor

Wq—Mean Customer Time In Queue (Waiting Only)

WS—Work Sampling

WU—Work Unit

WUC—Work Unit Count

Ym—Measured and/or Calculated Man-Hours

Terms

Accountable Time—Total man-hours the work center supervisor is held accountable in determining productivity or operational efficiency. Accountable time equates to assigned time plus borrowed time plus overtime minus nonavailable time minus loaned time.

Adjustment Factor—A specific computed value used to adjust an individual process time or associated work unit count.

Aggregation—The procedure of summing fractional work center manpower requirements (generated by application of manpower determinants) before applying rounding procedures. This definition is applicable only when the term is associated with fractional manpower.

Air Force Manpower Determinant (AFMD)—A means of quantifying manpower requirements. Determinants may cover a wide variety of products including but not limited to; manpower determinants, assessments, models, and guides.

Allowance—A time increment included in the standard time for an operation to compensate the worker for production lost due to fatigue and normally expected interruptions, such as for personal, rest, and unavoidable delays. It is usually applied as a percentage of the normal or leveled time to determine standard time.

Allowance Factor—A coefficient, based on authorized allowances, that is applied to productive time (leveled time, if appropriate), and results in the productive allowed time.

Allowed Time—The leveled time plus allowances for rest and delays. If leveling is neither required nor feasible, the allowed time is the actual productive time plus necessary allowances for personal, rest, and unavoidable delays as appropriate.

Ancillary Training—Training that contributes either directly or indirectly to mission accomplishment, but is separate from requirements in an individual's primary Air Force specialty. Included are training subjects not identified in specific Air Force Specialties contained in Air Force Officer Classification Directory or Air Force Enlisted Classification Directory or appropriate civilian job qualifications and classification standards. Examples include standards of conduct, disaster preparedness, and drug and alcohol education. Also included are all non-Air Force Specialty-related training conducted in conjunction with formal technical programs such as student leader training and study habits.

Ancillary Work—Direct work performed by a work center but is not associated with an output.

Assigned Strength—Computed monthly average number of military and civilian personnel assigned to a work center during the data collection period (e.g., the personnel actually in-place to accomplish the collected workload). Includes full-time and/or part-time over hires, contract full-time equivalents accomplishing work center responsibilities, borrowed personnel from other functions to include Air Reserve Component augmentation (e.g., man-days), and documented uncompensated overtime. Excludes personnel deployed or loaned out to other functions.

Assigned Time—The normal duty hours prescribed for an individual assigned to a military unit. Total assigned hours are computed by multiplying daily normal duty hours by the net assigned duty days (gain report not later than date to loss report not later than date). Net assigned duty days exclude relief days (for example, weekends and holidays). Note: For purposes of this computation, borrowed personnel are not classified as assigned.

Assumed Work—Work being done that is not necessary to work center productivity. Assumed workloads are not compensated for in the determinant.

Available Time—Man-hours dedicated to performance of primary duties.

Avoidable Delay—Any unnecessary delay, regardless of source, that causes work stoppage. Time lost to avoidable delay is not included in the determinant.

Balk—A situation in queueing analysis where a member of the input population (a customer) arrives for service, but elects not to enter the queue (perhaps it was too full). This behavior alters the arrival pattern.

Base Population (assigned)—The summation of all categories of assigned personnel at an Air Force installation. This definition may be expanded to include assigned personnel not located on, but supported by, the installation. Base population may also be modified to exclude certain categories of assigned personnel.

Base Time—The time required for completion of a task under the circumstances defined as standard, except it does not include any time for the operators' personal needs and time lost due to other miscellaneous causes.

Benchmark Time—Reasonably expected value for frequency, per accomplishment time, or workload values to be used as guides during work measurement.

Bivariate Equation—An equation that contains only two variables, such as X and Y.

Borrowed Time—Time on loan from another work center.

C-Bar—The c symbol (c-bar) represents the mean number of defects.

Chi square—The measurement of how expectations compare to results. The data used in calculating a chi square statistic must be random, raw, mutually exclusive, drawn from independent variables, and drawn from a large enough sample.

Common Cause—A cause of variation in a process that is random and uncontrollable.

Constraining—A process that an analyst incrementally changes the availability of resources used during simulation in order to determine mission requirements. Non-manpower resources are constrained on a unit basis and manpower resources are constrained by specific shift authorizations.

Continuous Process Improvement—Using the combined knowledge of all workers associated with a process to identify small or large changes will improve the product or service that results.

Contract Full-Time Equivalent (CFTE)—The amount of manpower required if the contract workload were done in-house at the same workload and level of performance as the contractor. Contract full-time equivalents are in terms of civilian manpower requirements. During the application process, manpower determinants are computed. Contract full-time equivalents values (representing workload included in the determinant) are subtracted from the computed requirement to yield the in-service portion of the work center requirements.

Control Chart—A chart showing time-related performance of a process. It's used to determine when the process is operating in or out of statistical control, using control limits defined on the chart.

Control Limits—A statistically derived limit for a process that indicates the spread of variation attributable to chance variation in the process. Control limits are based on averages.

Customer, Output, Process, Input, and Supplier (COPIS)—A visual tool for high-level documentation of an organization's process from beginning to end. COPISs are very useful to define a study scope, clarify the mission and to give everyone the same understanding of the process.

Define Measure Analyze Improve Control—Refers to a data-driven improvement cycle used for improving, optimizing, and stabilizing processes and designs. The defining, measure, analyze, improve, control improvement cycle is the core methodology used to drive AFMAA Continuous Process Improvement studies: 1. Clarify & Validate the Problem; 2. Break down the Problem and Identify Performance Gaps; 3. Set Improvement Target(s); 4. Determine Root Cause; 5. Develop Countermeasures and Implementation Plan; 6. See Countermeasures through; 7. Confirm Results and Process Change; 8. Standardize Successful Processes.

Delay Allowance—A time increment in a time standard used to compensate for unavoidable delay.

Determinants Application—A systematic determination of required or allowed manpower authorizations for Air Force activities using manpower determinants. The process consists of relating prescribed workload factor volumes to manpower models or tables resulting in a numerical identification of whole authorizations normally by Air Force specialty, skill level, and grade. Often referred to as "pricing out a determinant."

Determinants Development—A study phase that designs, measures, analyzes, and determines a work center or function's manpower requirements.

Direct Time—Productive time expenditure that can be identified with and assessed against a particular end product (work unit, workload factor, etc.) or group of products accurately and without undue effort and expense.

Directed Requirement Technique—An OA technique that recognizes many activities and some positions as directed requirements. These requirements may apply to whole-man positions; to directed frequencies, such as monthly inspections; or to directed time values, such as the periodic run up of a standby electrical power generator.

Element—A subdivision of the work cycle made up of a sequence of one or more fundamental motions and machine or process activities, that is distinct, describable, and measurable.

Equivalent Workload Factor—A single, constructed workload factor value derived by a weighting of multiple work units. The weighting process is done by selecting one unit as the prime work generator, assigning a value of 1.00 to it, and giving all other applicable work units a weighted value in relation to that prime factor.

Extrapolation—Extension of the regression line beyond the range of the input data to increase the determinant's utility, to expand the manpower determinant's applicability, and to prevent rapid obsolescence due to workload changes.

Fi—Is the activity frequency converted to monthly.

F Test—Any statistical test in which the test statistic has an F-distribution under the null hypothesis. It is most often used when comparing statistical models that have been fitted to a data set, in order to identify the model that best fits the population from which the data were sampled.

Facilitator—A person who functions as the coach/consultant to a group, team, or organization. The facilitator focuses on the techniques to generate ideas from the participants of the workshop or improvement team.

Familiarization—Gaining knowledge and better understanding of the function(s) under study.

Family of Determinants—A group of manpower determinants, concurrently or separately developed, related by the characteristic that the entire group is common to the same functions or work centers.

Fatigue—An allowance made in a manpower determinant to account for mental or physical weariness caused by job difficulty and environmental conditions.

Flow Diagram—A representation of the location of activities or operations and the flow of materials between activities on a pictorial layout of a process. Usually used with a process flowchart.

Fractional Manpower—Manpower requirements to do a specific workload, expressed in fractional parts of whole persons.

Frequency—The number of times a specific value occurs within a sample of several measurements of the same dimension or characteristics on several similar terms. In work measurement, the number of times an element occurs during an operation cycle.

Function—A group of personnel that use similar machines, processes, methods, and operations to do homogeneous work usually located in a centralized area.

Functional Estimating Equation (FEE)—An estimating equation that is used to predict manpower requirements for a functional group. Each functional estimating equation has two parts: a mathematical equation and a series of percentage factors by program element code.

Functional Measures—Indicators of performance documented for feedback to all levels of management on productivity; a monitoring tool that is reactive to the needs of management in terms of input, output, efficiency, effectiveness, and unit labor cost indicators.

Functional Model—A mathematical representation of the relationship between the manpower in a specific function and relevant policy, program, or workload variable.

Good Operator Timing Technique—An OA technique that establishes time values by measuring the time a qualified individual spends on a given activity.

Grade Structure—Distribution of grades within an organizational entity.

Groupthink—a pattern of thought characterized by self-deception, forced manufacture of consent, and conformity to group values and ethics.

Historical Records—Documented past work performances of the work center. Includes mistakes or inefficiencies of past operations. Syn: Historical Data.

Idle Time—Any time expended by the worker either in an avoidable delay status or in doing unnecessary work when work is available. It does not include time for personal, rest, and unavoidable delays. Idle time is not included in a manpower determinant. An individual who goes to the base exchange, commissary, barber shop, etc., and meets the above conditions, is classified as being on idle time.

Impact Application—The result of a newly-developed manpower determinant that is applied to either the total or partial number of bases in the work center population to show the effect that the determinant has on a work center's current manpower requirements.

Indirect Allowance Factor (IAFs)—The indirect allowance factor is the monthly man-hours allowed to perform indirect duties. It is applied as a percentage of total monthly direct man-hours to determine the total monthly allowed man-hours required by the work center.

Indirect Time—Time that does not add to the value of a product, but must be done to support the manufacture of the product. It may not be readily identifiable with a specific product or service.

Inferred Workload—Workload that is defined as the responsibility of another work center. It can be treated by transferring either the workload, prior to measurement, or the time expended on that workload (loaned time) to the appropriate work center, after measurement.

Input—Products and/or services received from suppliers in order to perform a process.

Internal Work—Manual work done by an operator while a machine or process is operating automatically.

Layout—The physical arrangement, either existing or on plans, of facilities or items necessary to do a work task.

Layout Analysis—Studies used to improve production, ease physical exertion, and shorten travel for material and personnel.

Leveled Time—Actual productive time adjusted to account for differences in pace of observed workers.

Leveling—Process whereby an analyst evaluates observed operator performance in terms of a concept of normal performance. Syn: Performance or Pace Rating.

Loaned Time—Time loaned to other work centers. This time is not accountable to the work center providing the loaned time.

Management Advisory Study—A consultant service requested by a base-level work center supervisor or manager and generally applicable only to that base. Specific results are released with permission of the requesting office of primary responsibility.

Management Work Center—Set up to manage two or more subordinate work centers. Syn: Overhead Work Center.

Man-hour—A unit of measuring work. It is equivalent to one person working at a normal pace for 60 min, two people working at a normal pace for 30 min, or a similar combination of people working at a normal pace for a period of time equal to 60 min.

Man-hour Availability Factor (MAF)—This factor is the average number of man-hours per month an assigned individual is available to do primary duties. Required man-hours are divided by the man-hour availability factor times the overload factor to determine the manpower requirements.

Man—hour Population—The total set of man-hours that a sample is drawn from reflecting the required man-hours for a work center. This set includes: man-hours for all personnel assigned, borrowed time, and overtime. It does not include loaned time.

Manpower Authorization—A funded manpower requirement.

Manpower Determinant—The basic tool used to determine the minimum level of manpower required to support a function. It is a quantitative expression that represents a work center's man-hour requirements in response to varying levels of workload.

Manpower Determinants Project Plan—Document prepared addressing WHAT is to be measured and HOW it is to be measured.

Manpower Determinants Study Final Report—Historical documentation consisting of the manpower determinant, supporting comments and documents, and computational data.

Manpower Model—Mathematical equation that describes the relationship between independent variables (workload values) and manpower or man-hours.

Manpower Requirements—Human resources needed to accomplish specified workloads of organizations. There are two types of manpower requirements: funded and unfunded. Funded manpower requirements are those that have been validated and allocated. Unfunded requirements are validated manpower needs that have been deferred because of budgetary constraints.

Manpower Resources—Human resources available to the Air Force that can be applied against manpower requirements.

Methods Improvement—A systematic way of finding easier, faster, or more economical methods of doing work.

Minimum Manpower—A method of developing a determinant that couples a functional OPR-approved requirement with a predetermined manpower factor.

Minimum Manpower Factor (MMF)—A fractional manpower computation that shows the manpower required to man a position. This factor is dictated by the need for one or more individuals to be on duty, although these individuals may not be continuously productive.

Mission Directive—Description of work that explains a work center's responsibility.

Mix—The combination of military, civilian, and contract resources used for mission accomplishment.

Model—A mathematical equation or process flowchart used to represent a selected process or system in order to evaluate, improve, or predict system performance e.g., predicting required manpower.

Modeling—The building of a process flowchart used to represent a selected process or system in order to evaluate, improve, or predict system performance e.g., predicting required manpower.

Modular Equations—A series of equations that represent one work center or family of determinants. These equations are appropriate when all required man-hours for a work center or family of determinants can be subdivided into separate independent modules.

Multicollinearity—Sometimes during multivariate correlation and regression analysis, two or more of the independent variables may be highly correlated with each other. This situation is called multicollinearity, and it is an undesirable condition. This means there are correlated independent X-variables adding similar (thus, little additional) information to the model. Note: In some instances, there is not always a clear distinction between variables as to which the dependent is and which the independent variable is.

Multi-location Determinants—Determinants that apply to more than one location that are developed from the data collected at two or more Air Force installations.

Multivariate Equation—An equation containing two or more independent variables.

Nominal Group Technique—A consensus planning tool that helps prioritize issues. In the nominal group technique, participants are brought together for a discussion session led by a moderator. After the topic has been presented to session participants and each have had an opportunity to ask questions or briefly discuss the scope of the topic, the participants are asked to take a few min to think about and write down their responses. The session moderator will then ask each participant to read, and elaborate on, one of their responses. These are noted on a flipchart. Once everyone has given a response, participants will be asked for a second or third response, until all of their answers have been noted on flipcharts sheets posted around the room Once duplications are eliminated, each response is assigned a letter or number. Session participants are then asked to choose up to 10 responses each feel are the most important and rank them according to their relative importance. These rankings are collected from all participants, and aggregated.

Nonavailable Time—Assigned man-hours allowed for participation in those activities directed, recognized, and approved by the Air Force, that render the individual unavailable for assigned primary duties. For example:

1. Leave. Permission to be absent from work or duty in official status for a specified period of time to include passes and rest and recuperation.
2. Permanent Change of Station Related. The time workers are absent from duty for accomplishing tasks generated by a permanent change of duty station. This includes in and out processing, family settlement, and authorized shipment of privately owned vehicle.
3. Medical. Official permission to be absent from primary duty for medical reasons such as pregnancy, inpatient and quarters cases, outpatient visits, physicals, and dental visits.

4. Organizational Duties. Official release from primary duty to do aerobics, counseling, reviews boards and councils, Sponsor/Individualized Newcomer Treatments and Orientation Program, and additional duties.
5. Education and Training. Official release from duty to attend ancillary training, squadron officer school, NCO Academy, TDY, and technical training. Also includes taking tests such as Promotion Fitness Exam, Skills, Knowledge, and Tools, Air Force Supervisory Exam, and College Level Examination Program.

Non-measurement Approach—Measurement techniques that are used to validate the existing manpower requirements without actually doing a statistically controlled work measurement. The non-measurement approaches are staffing pattern, directed requirements, position manning and simulation.

Non-measurement Methods—Measurement techniques that are used to validate the existing manpower requirements without actually doing a statistically controlled work measurement. The non-measurement approaches are staffing pattern, directed requirements, position manning and simulation.

Non-productive Time—Accountable time expended in either personal, fatigue, and delay, standby, on call, or idle (avoidable delay) status.

Non-programmable Workload Factor—If the selected workload factor is not in programming documents or if the transition of a potential workload factor to a programming variable cannot be made due to differences in definitions, then the workload factor is nonprogrammable.

Non-transferable Work—Work essential to the work center that must be done at a specific time or period. It can be direct or indirect type work.

Observation—In WS, the act of noting what the people in a work center, or in a specified portion of a work center, are doing at a specific instant. Such an observation yields a number of samples equal to the number of people observed. See Sample.

On Call Time—A nonproductive category of time when an off-duty worker can be contacted by telephone or other means at a prearranged location other than the work station. Only the productive time spent by the worker in the work center or at the work location, including necessary associated travel, is to be credited to the work center. Examples are: a photographer needed to periodically take photos after duty hours or a maintenance specialist who is needed infrequently to repair or replace a critical item of equipment.

Operational Audit (OA)—A MEP work measurement method consisting of one or a combination of the following techniques: good operator timing, historical records, technical estimate, standard time, and directed requirement.

Outliers—A term used to describe those data points that do not conform to the general pattern or trend described by a data array or scatter gram, (for example, data points that are beyond established control limits or that are significantly divergent from an otherwise apparent trend).

Overspecialization—Work centers that have become too specific in work description, thereby causing many small work centers to be established.

Overtime—Time expended in excess of regularly scheduled working hours.

Performance or Pace Rating—The act of comparing an actual performance by a worker against a defined concept of a normal performance. Various methods of performance rating are in use. These methods differ primarily as to the basis on which the comparisons are made. Pace rating is the method of performance rating prescribed for use in the MEP. See Leveling.

Personal Allowance—Time included in a determinant to permit a worker to attend to personal necessities, such as obtaining drinks of water or making trips to the restroom (usually applied as a percentage of the leveled, normal or adjusted time).

Poisson Distribution—Independence of an occurrence in an interval and the proportionality of an occurrence to the size of the interval.

Position Manning—Position manning is used to compute total requirements needed to fill mission critical positions that demand constant vigilance to the job while manning the position. In addition to the minimum manpower computation, allowances are provided to account for duties and responsibilities that cannot be accomplished while working in the position, such as recurring qualification training. See Position Qualification Time and Position Related Time.

Position Qualification Time (PQT)—A constant man-hour requirement directed by higher headquarters policy. It is used to determine the minimum-manpower factor.

Post Related Time—Applies only to Security Forces post requirements. It consists of the average monthly man-hours needed for processed which must be done either before or after position coverage starts.

Practical Problem Solving Method (PPSM)—An eight step approach to problem solving which includes: 1. Clarify the Problem; 2. Breakdown the Problem; 3. Set the Target; 4. Analyze the Root Cause; 5. Develop Countermeasures; 6. Implement Countermeasures; 7. Monitor Results and Process; 8. Standardize and Share Success.

Predictability—A significant attribute that allows reliable predictions for future time periods to make a determinant useful for programming future requirements.

Primary Aerospace Vehicle Authorized (PAA)—Aircraft authorized for performance of the unit's mission (e.g., Combat, Combat Support, Training, Test and Evaluation, etc.). The primary aerospace vehicle authorized forms the basis for the allocation of operating resources to include manpower, support equipment, and flying hour funds. The operating command determines the primary aerospace vehicle authorized required to meet their assigned missions.

Primary Aerospace Vehicle Inventory (PAI)—Aircraft assigned to meet the primary aerospace vehicle authorized.

Procedure—A sequence of written operations established to get uniform processing by telling what actions are to be taken, who takes them, the sequence to be followed, and the tools to be used.

Procedure Chart—A graphical display showing the flow of material or information in an organization. It reflects the flow of information between work stations and between work centers, shows decisions made, and actions taken by individuals.

Process—A sequence of work activities needed to accomplish an output.

Process Flowchart—A graphic, symbolic representation of the work done or to be done to produce a product or service as it passes through some or all of the stages of a process.

Productive Time—Time spent doing work that is useful and essential to the mission of the work center. See Direct Time and Indirect Time.

Program Change—An approach used to determine programmed requirements. This could cause manpower changes.

Program Element Code (PEC)—An alphanumeric code assigned to each program element that is used to identify a Major Force Program.

Programmability—A resource identified in a programming document.

Programmable Workload Factor—A workload factor and definition that matches a program variable found in programming documents that allow the workload factor to be programmable (e.g. PAA, PAI, base population, square footage).

Programming Document—An official programming document published by the Office of the Secretary of Defense or the Department of the Air Force. This document exhibits a program identifying the resources required, by time period, to provide defense capabilities necessary to support the national strategy, for example, the United States Air Force program bases, units, and priorities.

Projected Workload—An amount of work proposed or anticipated to meet the requirements of a program over a specified period.

$\bar{R}$—The average range.

Rater Proficiency—Skill of a technician to gain a mental image of normal and to rate in a consistent manner.

Ratio Unit Time—A computational method using a ratio of man-hours required to workload accomplished to develop a determinant. This method is generally used for single location determinants.

Regression Analysis—A mathematical examination of relationships between two or more variables showing how useful these variables can be for prediction purposes.

Relatability—A characteristic relating to manpower requirements. A change in the value of the workload factor produces a corresponding change in the man-hours needed to do the task.

Relative Accuracy—Size of error allowed in the sample when accuracy is stated relative to the value of the mean. Relative accuracy is used primarily in time study.

Required Grade—The grade reflected in the required grade column (Data Element-RGR) of the unit manpower document. The grades in this data element represent unconstrained requirements needed to do the job and are, when applicable, determined by the management engineering process.

Resource Utilization—The application of resources (personnel, materials, and services) to accomplish missions, functions, and responsibilities.

Rest—An allowance made in a manpower determinant to account for mental or physical weariness caused by job difficulty and environmental conditions.

Rounding—A process that terminates an endless string of decimal places.

Sample—A single recorded status of one person during an observation of a work center. Usually, more than one sample comes from one observation. The number of samples needed affects the number of observations required for each work center.

Sample Size—The number of samples taken usually for a desired level of accuracy.

Sampled Time—Computed man-hours from a WS study which are based on total available samples.

Scatter Diagrams—A two-dimensional chart on which known values of two variables are plotted. Examination of the chart shows the form of relationship which exists between the variables - for example, straight line or curvilinear.

Simulation—A non-measurement method used to determine total work center manpower requirements. The most common technique is queueing.

Snapback—A method of reading a watch when doing a time study.

Staffing Patterns—Man-hours allowed, usually on a one-for-one basis, in work centers that are not governed by rate of production, but are established for management functions.

Standard—An exact value, physical entity, or abstract concept established and defined by authority, custom, or common consent to serve as a reference, model, or rule in measuring quantities or qualities, establishing practices or procedures, or evaluating results. A fixed quantity or quality.

Standard Time—
1. The time that is considered necessary for a qualified worker, working at a normal pace under capable supervision and experiencing normal rest and delays, to do a definite amount of work of specified quality when the prescribed method is followed.
2. Time measured by use of rigid statistical methods; for example, time study.
3. The normal or leveled time plus allowances for rest and unavoidable delays.

Standard Work Document (SWD)—A format that shows work center responsibilities structured for easy measurement of process and steps.

Standby Time—When the worker is required to be present to do time-sensitive work, and is in a ready status to do this work, but is prevented from doing it because none is available. Time can be classified as standby only when it is essential to mission accomplishment and when no work can be done or made available during that period. Examples of standby time are: an emergency room medical technician awaiting patients; a commissary ID checker awaiting customers to enter the checkout line; a taxi driver awaiting passengers at a dispatch office; and a passenger processing specialist awaiting aircraft arrival.

Stratified Random Times—Random times selected to provide equal number of observations for each specified time period, such as four random times per hour.

Strengths, Weaknesses, Opportunities, and Threats (SWOT)—A framework that assesses what an organization can and cannot do, for factors both internal (Strengths and Weaknesses) as well as external (Potential Opportunities and Threats) that have an impact on the viability of a product, study, business-line, or service.

Study Sponsor—The study sponsor is the HAF functional representative for Air Force studies, MAJCOM functional representative for MAJCOM studies, or wing-level functional representatives for single point studies.

Study Representative—The subject matter expert appointed by the study sponsor that works closely with the study lead to ensure completion of a study.
Systems Analysis—Investigating a system of operation in an organization from supplier to customer. Then developing a new system incorporating the viable ideas of all workers in the system with the intent of improving service to the customer.
T—Total monthly man-hours.
Ti—Standard activity time.
Task List—A clear and complete description of the actions or duties of an individual.
Technical Estimate—A determination of the standard hours required for a given task, based on an estimate by individuals who are technically and professionally competent to judge the time required.
Time Study—A work measurement method consisting of careful time measurement of the task with a time measuring instrument. The study is adjusted for any observed variation from normal effort to pace. It allows adequate time for unavoidable or machine delays, rest to overcome fatigue, and personal needs. Learning or progress effects may also be considered. If the task is long, it is normally broken down into short, relatively homogeneous work elements, each of which is treated separately by, and in combination with, the rest.
Transferable Work—Work that is essential to the work center, but may be done at any time or during any period. It may be direct or indirect type of work.
Unavoidable Delay—An occurrence that is essential and outside the worker's control or responsibility that prevents the accomplishment of productive work.
Unavoidable Delay Allowance—See Delay Allowance.
Unit Manpower Document (UMD)—A detailed manpower listing reflecting the distribution of manpower allocations into a finite structure of authorizations (by work center).
Variance—A condition that exists that either adds to or subtracts from the core workload, or impacts the way the work is performed. A variance can be the result of environmental, mission or technological differences, and can be either negative or positive.
1. Environmental Variance. Accounts for different operating conditions from those used to develop the core manpower determinant (e.g., snow, geographical separation, etc.). It can either increase (positive) or decrease (negative) requirements.
2. Mission Variance. Accounts for different operating processes from those used to develop the core manpower requirements. It can either increase (positive) or decrease (negative) requirements.
3. Technological Variance. Accounts for different operating equipment from those used to develop the core manpower requirements. It can either increase (positive) or decrease (negative) requirements.
Variation—A measure of the dispersion or scattering of values about the mean of a distribution.
Work Center—A group of personnel that use similar machines, processes, methods, and operations to do homogeneous work usually located in a centralized area. The term is used to identify a relatively small activity within a broad functional segment. Personnel within a work center do work that basically contributes to the same end product or result (duties are similar or closely related).
Work Cycle—
1. A pattern or sequence of tasks, operations, or processes with a distinct beginning and ending point.

2. A pattern of manual motions, elements, activities, or operations that are repeated without significant variation each time a unit of work is completed.
Work Distribution Analysis—A technique to improve production that helps find out what work is being done, how much time is spent on it, and who is doing it.
Work Flow—The flow or movement of things being processed from one operation to another.
Work Measurement—Process to obtain data necessary to compute accurate manpower requirements. Techniques include WS, time study, and good operator timing and technical estimate. Usually results in a manpower determinant or guide.
Work Sampling—The application of statistical sampling theory and techniques to the study of work systems. The characteristics of the sampled (observed) work done are used to produce estimates of the amounts of work and types of activity done. Work sampling data can be used in conjunction with associated work counts to compute determinants.
Work Unit—The basic identification of work accomplished or services performed. Work units should be easy to identify; convenient for obtaining productive count; and usable for scheduling, planning, and costing. Syn: Workload Factor.
Work Unit Count—The number of work units done during a specified time period.
Workload—An expression of the amount of work, identified by the number of work units or volume of a workload factor, that a work center has on hand at any given time or is responsible for doing during a specified period of time.
Workload Factor (WLF)—
1. An index or unit of measure that is consistently expressive of, or relatable to, the manpower required to accomplish the quantitatively and qualitatively defined responsibilities of a work center.
2. An end product (or a combination of products) that represents the work done in the work center. It may be either something physically produced in the work center (referred to as a production-type workload factor) or something that is external to, but served by, the work center (referred to as a work generator-type workload factor).
$\bar{X}$—The bar above the X indicates an average is used and the chart is call an $\bar{X}$ chart.