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A HUMAN FACTORS METHODOLOGY FOR REAL-TIME SUPPORT APPLICATIONS

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INTRODUCTION

A human factors research and applications program is managed by the Mission and Data Operations Directorate (M & DOD) at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC). The M & DOD is responsibile for defining, designing, developing, and operating both data processing and real-time control systems in support of various NASA satellite missions. By virtue of this responsibility, M & DOD is concerned with incorporating the rapid and revolutionary advances in computer technology into system design cycles. Management at GSFC has also become aware that implementing the tools of new technology without due consideration of the user may result in lowered acceptance and less than optimal performance by the user. As a result, there has been an increased interest in the field of human factors (HF) which defines the limits and capabilities of the human as the dynamic component of systems operations.

The M & DOD has formed a Human Factors Group whose objectives are to provide research and development as well as applied human factors analysis for GSFC projects. This analysis includes recommendations for the application of human factors principles in the design of human-machine interfaces. Because the Human Factors Group was formed only recently, effective policy is still under development. One specific concern has been the formulation of a methodology to be used when human factors analysts interact with Goddard projects. This framework would facilitate an effective, informative pattern of interaction between the Human Factors Group and projects or facilities requesting assistance.

Recently, human factors analysis has been applied on an ad hoc basis to the Earth Radiation Budget Satellite (ERBS) mission operations room and the Mission Planning Terminal (MPT) software design project. The methodology proposed in this

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paper is based on insights resulting from experience with these two real-time support applications. Generally, these applications maintain the health and safety of spacecraft, provide computer and communications capabilities, and optimize data collection from scheduled spacecraft contacts as they occur.

The methodology is addressed to human factors analysts, project developers, and management. It is designed to assist in the process of coordinating the human factors analysis with the life cycle of system development, selecting areas for analysis, and selecting appropriate human factors tools. The document assumes some familiarity with human factors concepts. References are provided for further information on the details of specific theories and procedures.

BRIEF GUIDE TO METHODOLOGY

I. Establish a working relationship with the project:

   o Organize human factors analysis team:

      o HFG designates analyst(s) and analyst coordinator.

      o Project designates mission coordinator.

   o Develop a contractual aggreement:

      o Project states interest in receiving human factors support.

      o Human Factors Group (HFG) provides project with capabilities list.

      o Both project and HFG come to mutual agreement on goals and directions of human factors analysis.

      o Contract is drafted and signed.

   o Determine frequency of communications and required levels of feedback.

      o Meet at least twice monthly.

      o Place analysts on project mailing list.

      o Attend formal and informal design reviews.

      o Review progress periodically.

II. Orient human factors analysts to the project:

   o Observe existing system.

   o Review project documentation.

   o Develop and rank human factors criteria.

III. Identify the current stage of system development and conduct human factors analysis accordingly. Stages of system development identified below are based on DeGreene's (1970b) terminology. Human factors analysts will apply selected techniques at each stage, depending on the time and personnel allotted to the task.

   o Conceptual or planning stage:

      o Review documentation on existing or antecedent system.

o   Begin identifying behavioral and informational requirements.

o   Begin identifying design criteria, e.g., error tolerance.

o Definition stage:

    o   Refine design criteria. Conduct formal sessions to rank criteria or to evaluate rankings if they have been previously determined.

    o   Perform tradeoffs analyses to determine preliminary allocation of functions.

    o   Analyze tasks, functions, and jobs to evaluate preliminary allocation of functions and overall job design.

    o   Evaluate alternative subsystem components (e.g., interaction devices, display formats, command language, and workstation layout) for congruence with human requirements. Use empirical methods and other appropriate human factors tools.

    o   Conduct studies of staffing and training requirements.

    o   Evaluate external and internal documentation on the basis of criteria such as continuity, logic, and clarity.

    o   If time and staff qualifications allow, use simulation techniques or mathematical modelling to refine definitions of human requirements.

o Design and production stage:

    o   If human factors support begins at this point, identify human factors problems, areas of flexibility, and design constraints.

    o   Apply human factors tools, such as existing guidelines, expert judgment, and paper mockups, to area(s) for analysis. Perform task analysis to assess workload allocation.

    o   Assess alternatives on the basis of ranked criteria.

o Operational stage:

    o   Conduct field evaluations of operational system.

    o   Identify unanticipated design problems.

o   Evaluate user response to the system by means of surveys and interviews.

o   Evaluate efficiency and effectiveness of maintenance procedures.

o   Conduct error analysis on human performance.

o   Evaluate suggested changes for their potential impact on the human-machine inferface.

IV.   Document the analysis and make recommendations.

o   Maintain written records and chronology of analytical activities.

o   Prepare written reports including recommendations.

o   Make oral presentation using viewgraphs and handouts.

V.   Plan for regular evaluation of human factors considerations throughout the life of the system.

o   Schedule an annual review of human-machine-environmental compatibilities.

o   Present recommendations for enhancements to the system.

INITIATING AND PLANNING A HUMAN FACTORS ANALYSIS

OVERVIEW

Ground rules need to be determined to effect an orderly process of integrating the human factors analysis into the design schedule. The initial planning phase of a human factors analysis is of particular importance because human factors analysts are typically not included on the standard design team. Therefore, the Human Factors Group (HFG) and projects requesting human factors support should follow specific procedures to ensure the onset of prompt, effective actions. These procedures include a statement of project interest, a HFG response in the form of a list of areas human factors can impact, and finally, mutual consent to a contract for HF work to be undertaken.

ORGANIZING THE HUMAN FACTORS ANALYSIS TEAM

The Human Factors Group operates under the auspices of Code 500, Mission and Data Operations Directorate. Its membership includes NASA personnel, university faculty and graduate students, and other GSFC contractors. The human factors analysts are independent of specific projects at Goddard yet are responsive to the needs of the project to which they are assigned. Graduate student analysts are responsible to university faculty who, in turn, function as principle investigators, and are responsible to their NASA technical monitors. This organizational structure gives the human factors analyst some autonomy from the project. Historically, HF analysts have functioned as consultants. This role gives some distance from day to day problems and constraints and may yield a new and somewhat more objective perspective of the planned system. Because of his/her training, the HF analyst is often able to identify issues that may be causing human factors problems.

The requesting project should designate a mission coordinator to act as a liaison between the HFG and the project. This coordinator attends the monthly HFG meetings to report ongoing work and also maintains direct contact with the human factors analysts. If there are several HFG analysts, there is a need for coordination. It is strongly recommended that one HF person be given the responsibility to direct the process of developing human factors recommendations for the project (Peterson & Batterill, 1982). The aim is to develop an integrated team approach.

DOCUMENTING THE PROJECT'S HUMAN FACTORS REQUIREMENTS

A request for human factors support generally originates with a written or verbal statement of interest from the project to Code 502, Data Systems Technology Office, a branch of M & DOD. In return, the HFG should provide the project with a capabilities list, stating areas where human factors might be effective. This list defines the scope of human factors analysis in the GSFC environment where likely areas for analysis include the following:

- o   hardware selection and design

- o   software considerations such as dialogue
      types and display design

- o   documentation of operations and procedures

- o   workstation design

- o   command and control panel design

After evaluating the capabilities list and deciding on a subset of areas for analysis, the project should prepare a written statement of specific goals to be achieved through HF interaction. The HFG executive committee and the requesting project then determine the feasibility of a joint work relationship. When agreement is reached, human factors specialists are assigned to the project.

The initial exchange establishes the capabilities of the HFG and determines the project's immediate priorities. However, before the analysis begins, the HFG analysts and the project managers should mutually agree on the goals and directions of human factors analysis and draft a contract to that effect. The contract should include the project's priorities for particular areas of analysis. For example, is workstation design, documentation, or hardware selection of prime importance? How much emphasis should be placed on the remaining areas for analysis? This written agreement defines the relationship between the project and the HFG and serves as a basis for periodic review of progress.

PLANNING COMMUNICATIONS AND FEEDBACK

Early in the formulation of a working relationship, both the project and the HFG should establish the desired frequency or regularity of meeting together. Previous experience has shown that a failure to establish a regular pattern of interaction leads to problems for the analyst. Problems include:

- o a slower start for the analysis

- o inadequate amount of information relayed by the project to the analyst

- o failure of HF analysts to keep abreast of changes made by the project

- o being unaware of working dynamics of the design team

- o an increased timing problem between generation of recommendations and the time when they can be incorporated into a design

To be effective, human factors analysis of a GSFC project requires frequent contact between the project and the HF analysts assigned to the project, attendance by HF personnel at any important project meetings, and guidelines for written communications between HF analysts and project personnel.

Frequency of Information Exchange

The HF analysts should meet regularly with the project design team, at least twice monthly. At these meetings they will have the opportunity to review progress, discuss any new issues, and resolve any problems encountered. These sessions should be part of the normal design process. Once the HF analysts have become oriented to the project, a regular meeting might be scheduled to rank the criteria used in human factors analysis. For example, in a workstation layout, is it more important for the commander to be protected, or to allow for ease of interaction among various control room personnel? In a software development design, is it more important to incorprate an on-line help feature or does the need and cost not justify its inclusion?

In addition to regular meetings, the analysts should be placed on the project's mailing list. Thus, they will be assured of receiving notice of upcoming meetings and copies of revised or newly released documentation.

Attendance at Design Reviews

Deadlines for design reviews are set by the development schedule of a system. Analysts should request a list of these scheduled dates. These design reviews range from informal, spontaneously arranged work sessions to formal design reviews planned months in advance. The evaluation of the ERBS workstation layout occurred over several informal working group meetings. In contrast, the software developers of the MPT project held a formal preliminary design review (PDR) followed by a formal critical design review (CDR) three months later. After each of these presentations, portions of the MPT development design were frozen and no longer amenable to further adjustment. For this reason, it is important for the human factors analysts to be aware of design reviews, both formal and informal.

Attendance at design reviews keeps the analysts abreast of information. Human factors analysts should always be notified of, and attend, the formal design

reviews and important informal working sessions. Selective attendance is recommended at other review sessions depending on their applicability.

Requirements for Written Communication

Often the HF analysts will need to provide responses to HF issues raised in a design review or in project documentation. Such responses should be in writing. If specific design recommendations are given, e.g., display screen configurations, they should be based on existing guidelines, established laws of behavior, or previous research which is cited in the report. This justification provides the project with empirical evidence to support implementation of such recommendations.

The entire span of written and verbal communication is obviously important. It forms the basis of an effective working relationship. Feedback from the project to the analysts and vice versa is also important. Periodically, HF analysts and the project coordinator should review the initial goals and objectives contained in the contract and determine whether they are being satisfactorily met. This periodic self-evaluation should include a brief written summary of human factors activity to date.

MANAGEMENT'S ROLE IN PROVIDING SUPPORT

Management support is vital for successful implementation of any program. Human factors, a new concept for most systems at GSFC, is in particular need of support during its introductory phase.

NASA Management

NASA management should provide ongoing support for human factors because the policies of senior management influence project managers, project staff, and supporting contractors. The support of project management for a specific human factors application is essential. To ensure this support, project management should

be included in the development of the HFG/project contract and be a signatory of the final document.

HFG Technical Monitors

Each contract has a monitor representing Goddard management. Because the HF analyst is typically not a Goddard employee, the role of the technical monitor includes the following functions:

o   acting as liaison between HF analyst and the project

o   coordinating the scheduling of meetings and onsite observations

o   identifying key personnel in projects

o   coordinating follow-up on action items

o   informing analysts of supplementary programs or talks presented at Goddard that would benefit analysts

o   being available to act on behalf of the HF analyst if there are policy problems with the project

o   following the progress of applied analysis to determine whether cooperation is effective

This support facilitates the smooth integration of human factors recommendations into the design process.

ORIENTING HUMAN FACTORS ANALYSTS TO THE PROJECT

OVERVIEW

Following the initial planning, human factors analysts need to gain a working knowledge of the project. Rather than attempting to master specific jobs, analysts must acquire a broad, conceptual understanding of the project as a system. Attention focuses on mission goals, general procedures, and expectations for human performance. Because these expectations may not be documented thoroughly, it is the analysts' responsibility to begin identifying the project's human requirements. Appropriate methods include onsite observation, informal discussions, and review of technical documentation. A formal discussion of design criteria is needed to develop the ranking of criteria which is used as the basis for analysis. Orientation aids analysts in identifying the stage of system development in effect as they begin the human factors analysis.

OBSERVING EXISTING SYSTEMS

If there is an existing system that is similar to the one being developed, observations and informal discussions with operational and supervisory personnel contribute enormously to the analysts' understanding of the project under consideration. If the project involves the development of an entirely new system, observation of any antecedent system will help analysts conceptualize the functions to be performed. In the case of MPT, human factors specialists observed CAIRS, an antecedent to the automated system being developed; in the case of the ERBS MOR workstation design, observations in the Data Operations Control (DOC) area and current MORs provided an understanding of real-time support procedures.

At the beginning of observational visits, the goals of the human factors analysis should be briefly explained to the operational staff in order to clarify the purposes of onsite observation. Once rapport is established with operators and their supervisors, it is invaluable to ask questions and raise potential human factors issues. After prolonged use of a particular system, operators are acutely aware of the extent to which human capabilities and limitations are provided for by that system, and they can be extremely helpful in formulating suggestions and recommendations for improvement. Their reactions to preliminary designs and their anecdotal accounts of past experiences with other systems are valuable contributions to the assessment of the project's human-machine interfaces and other human requirements.

The MPT and ERBS experiences suggest that observations in more than one command and control environment are essential to provide a generalized understanding of Goddard operations. Follow-up sessions with project developers also contribute immensely to an understanding of the relationships among components of the Goddard support network. A sense of interrelatedness is crucial to the development of an analytical framework.

REVIEWING PROJECT DOCUMENTATION

Additional contributions to a conceptual understanding of the project come from a review of technical documentation. Because such documentation typically focuses on non-human system requirements, it is the analysts' task to identify the human requirements implied or suggested by technical specifications for hardware and software. The final report on ERBS MOR workstation design (Stewart, Murphy, & Mitchell, 1982) recommends that future project documentation include behavioral descriptions of required individual actions and person-to-person interactions. Implementation of this recommendation will ensure that the resulting documentation

provides valuable information for human factors analyses. Until such time as this suggestion is implemented, however, it is the responsibility of the human factors analysts to document these requirements. Descriptions of human requirements should be included in a preliminary report to the project and the technical monitor.

DEVELOPING AND RANKING HUMAN FACTORS ANALYSIS CRITERIA

Human factors analysts need a set of standards or criteria on which to base their analysis. To meet this requirement, appropriate human factors criteria should be identified in conjunction with the project. During this process, it is important to identify criteria which might have been left implicit or unstated by the project earlier in the orientation phase. Competing criteria should be identified and ranked before analysts attempt to assess the benefits and limitations of any one design. This procedure is recommended so that alternative designs can be evaluated against the same set of standards.

The development and ranking of human factors criteria proceeds within the context of NASA/GSFC policy and standard procedures. Explicit definition of project goals and candid discussion of the human role in the system are required to identify project-specific design criteria such as:

     o   reduction of human information processing requirements

     o   ease of maintaining equipment

     o   minimal distraction to the command operator

     o   useability of the system

     o   smooth traffic patterns

     o effective and efficient human performance

     o   reduction of staffing levels

Some of the emerging criteria will be related to each other, as minimal distraction to the command operator is related to effective and efficient performance. Additionally, some criteria will be stated in more general terms than others. Therefore, for purposes of clarity and organization, specific criteria should be listed under the appropriate general criteria. To avoid the need for major retrofitting of the analysis, the identification of design standards should be as exhaustive as possible. The general criteria should be ranked in importance, perhaps by the Delphi method of achieving consensus (Cascio, 1978; Huchingson, 1982). This ranking procedure can also be applied to the specific criteria listed under each general category. (Details on the Delphi method can be found in the later discussion of human factors tools, under Ratings by Experts.)

The absence of an explicit, prioritized set of criteria can result in the problem of shifting criteria described in Stewart et al. (1982). If the project's standards are ambiguous, it will not be possible to provide an effective human factors analysis of proposed alternatives. Identification of criteria can proceed in a series of informal and formal discussions attended by key decision makers. A formal meeting of all key personnel should be held to review and rank design criteria. This kind of formal review and documented ranking of criteria can eliminate the need to second-guess project managers on what it is they really want the system and its human component to achieve. Additionally, the list of priorities resulting from this discussion will later provide analysts with a basis for choosing appropriate outcome measures. Perhaps more important than any of these justifications is the sense of working together toward a common goal that will evolve from the group discussion of design criteria.

One caveat to human factors analysts: It is important to remain flexible about any ranking of design criteria, especially if the human factors analysis commences at an early stage in the system life cycle. Crucial criteria are likely to emerge at later

stages, requiring major retrofitting of the analysis. Therefore, a ranking of design standards should not be considered "frozen" at early stages in system development.

SUPPORT FROM PROJECT MANAGEMENT

Project management's responsibility during this orientation phase is to ensure that the following kinds of support are provided to the human factors analysis team:

- o assistance in scheduling and coordinating observation sessions and briefings

- o provision of staff time for briefings

- o delivery of all available documentation

- o identification of all key decision-makers

- o scheduling and coordination of formal discussion of criteria

With this support, human factors analysts can proceed quickly toward a conceptual understanding of the project and develop a sound basis for applied analysis.

CONDUCTING AN APPLIED HUMAN FACTORS ANALYSIS

OVERVIEW

In order to be as systematic as possible in determining human requirements and in formulating empirically-based recommendations, the human factors analysis proceeds; applied evaluation occurs within the identified stage of project development. Specific areas for analysis depend on the nature of the project. An appropriate combination of human factors tools is used to assess the human factors benefits of proposed designs. If the system will go through several iterations or releases prior to final implementation, cycles of human factors analysis and review continue until a final design is accepted.

SELECTING AREAS FOR ANALYSIS

In the sections that follow, major system components requiring human factors consideration are identified and discussed. Some of the considerations are based on the HFG experiences with MPT and ERBS. The MPT project focused primarily on software and documentation issues (Van Balen & Mitchell, 1983), while the ERBS MOR analysis was concerned with workstation design (Stewart et al., 1982). The other areas—job design, staffing, training, and systems evaluation—are included to suggest important areas where human factors analysis can improve system performance. Additional areas for analysis can be identified by consulting standard references (e.g., DeGreene, 1970a; McCormick & Sanders, 1982; Meister, 1971).

Hardware

Consideration of the human body, its structure and mechanical functions is central to hardware selection and design. This fit of the machine to the capabilities of the user increases operator performance, safety, and machine reliability (Van Cott

& Kinkade, 1972). The use of reliable anthropometric data (Diffrient, Tilley, & Bardagjy, 1981; Mitchell, Stewart, Bocast, & Murphy, 1982) permits the designer to include adjustable features or set the standards to accomodate the majority (95%) of human operators.

Another area of importance in hardware design is the selection of appropriate interaction techniques. There is a large volume of data on hardware components, e.g., visual display terminals (VDTs) and alphanumeric keyboards. Guidelines on these have become fairly standard. At greater variance are the findings on other interaction techniques, e.g., mouse, joystick, and light pen; the resulting guidelines are often task dependent. A survey of current recommendations is required to support an enlightened choice of hardware. Mitchell et al. (1982) synthesize current research findings and relate them to Goddard applications.

Because hardware procurement occurs early in system development at Goddard, it is crucial to have user-oriented guidelines for engineers to consult at this stage. In the case of the MPT and ERBS MOR human factors analyses, significant hardware was already purchased and thus imposed serious constraints.

Software

Issues concerning the human-computer interface are at the forefront of computer research. Technology is advancing faster than the human can adapt. Many activities in Goddard command and control rooms revolve around operator interaction with a computer. In order that computer systems be readily accepted and optimally implemented, software designers must consider the user. A partial listing of areas to be included for human factors analysis include the following (Engel & Granda, 1975; Foley & Van Dam, 1982; Mitchell et al., 1982; Ramsey & Atwood, 1979; Smith, 1981):

o   human-computer dialogue (dialogue types, coding, language syntax)

o   cognitive models of the operator (problem-solving techniques of users, operator analysis of information displays)

o   display screen density and configuration (information overload problems, formatting data)

o   fatigue, stress, low productivity, error rate

o   use of graphics, color

o   response time, terminal capabilities

Human factors analysts can provide recommendations that promote the development of an easily interpreted, friendly dialogue. For example, work on the MPT software system emphasized designing display frames that were uncluttered, consistent in format, and meaningful.

Documentation

Preparation of concise, easy to follow operator instructions is a necessity. It is through written manuals that design engineers guide the user to successful and optimal use of the system. Therefore, it is essential that operations and procedures be clearly presented. Inefficient system operation results from failure to provide adequate user support in manuals used for operations and maintenance (Damodoran, 1981; McCormick & Sanders, 1982; Rigney, 1970).

Human factors analysis provides data on the level of technical information needed by users to operate the system effectively. This data, along with knowledge of the minimal educational level of the user, guides the designer in selecting the appropriate level of vocabulary. For example, preliminary information on MPT operations indicated that several operators would be high school graduates. Correspondingly, the software engineers designed a user's manual free of

complicated technical jargon. The criteria used by human factors analysts in evaluating the manual include:

- o continuity
- o clarity of thought
- o avoidance of jargon or technical words
- o logical presentation of sequence of action
- o adequate number and type of illustrations, charts
- o adequate spacing, especially in procedures section
- o brevity, yet inclusiveness
- o concentration on hows rather than whys

On a related topic, Bailey (1982) suggests the use of performance aids, either devices or documents to aid the user. HF analysts suggested the use of small durable cards to remind the operator of the sequence of actions required for MPT. Attempts to facilitate the operator's understanding and mastery of the system through user-oriented manuals and performance aids will help reduce problems in the implementation phase.

Workstation Design

Inattention to anthropometric and psychological considerations in workstation design leads not only to user discomfort, but also to unsafe and unhealthy conditions, producing physical and psychological stress (Cakir, Hart, & Stewart, 1980). Human factors analysis of workstation design and implementation of the resulting recommendations can increase morale and motivation, while reducing stress and fatigue (Mitchell et al., 1982; Stewart et al., 1982). The ensuing benefits to performance and job satisfaction more than offset the costs of the analysis.

As detailed in Mitchell et al., (1982), command and control workstation design encompasses pre-design considerations, physical layout, equipment design,

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communication systems, command panel displays, command panel controls, and command panel layout. In the case of the ERBS MOR human factors analysis, however, the phrase "workstation design" referred to three areas designated by the project: physical layout, environmental issues, and component arrangement (Stewart et al., 1982). The point here is that the broad nature of workstation design requires that it be defined in specific project terms. In the case of MPT, with users located at distant sites, workstation design was not a major Goddard issue, but it was considered in collecting survey data that might be useful to system planners at Goddard (Van Balen & Mitchell, 1983). Whatever the project, it is crucial to define the areas for workstation analysis in terms that are mutually acceptable to the project and the human factors team. Recommendations that follow, on conducting analyses of physical layout, environmental issues, and component arrangement, are based on the ERBS MOR experience; guidelines on additional workstation design issues can be found in McCormick and Sanders (1982) and other standard references.

Physical layout. The configuration of equipment deserves close attention because of its heavy impact on users. Layout determines patterns of activity within the work place; it places constraints on what each seated operator can see, determining patterns of person-to-person interaction and patterns of human-machine interaction. Physical layout affects job satisfaction, either increasing morale and motivation or increasing frustration and annoyance.

A summary of existing guidelines on aspects of physical layout is provided by Mitchell et al. (1982). Areas requiring project-specific application of these guidelines, depending on staffing levels and equipment requirements, include physical accessibility, visual access, and circulation. Human factors principles used to guide an evaluation of alternative physical layouts include the following:

o   Person-to-person interaction should be facilitated.

o   Physical and visual access to all equipment, controls, and displays should be provided.

o   Equipment should be easily maintainable.

o   Traffic flow within and through the work environment should be smooth and safe.

These principles can be relied on as a basis for the development of human factors criteria, and they provide a context for conducting project-specific analysis. The purpose of such analysis is to achieve the optimal configuration of equipment within the constraints imposed by limited resources and requirements for maintenance. The ideal configuration is the one which best fulfills human factors criteria such as ease of human interaction, ease of human-machine interaction, ease of maintenance, and ease of traffic flow (Stewart et al., 1982).

Appropriate human factors tools are used in determining the optimal configuration. Because of severe time constraints, the human factors analysis of the ERBS MOR workstation design relied almost entirely upon published guidelines and observations at Goddard, including informal interviews and discussions. Time allowed only non-experimental manipulation of paper mockups, rather than any wider ranging simulation of alternative configurations.

If adequate time can be provided, simulations with different physical layouts should be conducted to assess the effect of layout on performance, motivation, levels of stress, and job satisfaction. The results of task analysis and link analysis provide a framework for the development of various simulated layouts. Computerized simulation of physical layouts, as described by Jones, Jonsen, and Van (1982) allows researchers to manipulate operating parameters and compare "many alternative designs...at minimal expense" (p. 40).

With the capabilities projected for the Goddard Human Engineering Laboratory, researchers will be able to employ such techniques. Complete specification of the

optimal physical layout can also benefit from formal operator surveys and non-experimental tradeoffs analysis. Converging results from all analyses can then be offered to support human factors recommendations on physical layout in Goddard settings and other user locations.

Environmental Issues. In addition to the physical layout of equipment, other aspects of the work environment directly or indirectly affect job satisfaction and performance. Physical environmental issues include lighting and glare, noise, temperature, air quality, furniture, and ambience. Although envrionmental issues will very from project to project and be of more concern to some than to others, the essential purpose of the human factors analysis in this broad area is to humanize the environment in order to improve working conditions and to enhance performance (Stewart et al., 1982). Additionally, consideration of the work environment is intended to support an organization's image, convey a sense of membership and importance to users, support normal environmental conditions, and assist users in learning about the workplace (Bailey, 1982; Mitchell et al., 1982).

A systematic approach to a study of project-specific environmental issues requires experimentation with specified levels of environmental variables. Although numerous combinations of variables are possible, it is probably most worthwhile to limit any one experiment to five or fewer experimental conditions in order to ensure interpretability of results. An empirical evaluation of noise effects, for example, might compare results at extremes and at levels recommended in the guidelines. Another empirical study might isolate a particular variable varying its levels, while holding other environmental variables constant.

Recommendations for ergonomically designed furniture can be made on the basis of existing guidelines. Attention to ambience or the atmosphere of the workplace should focus on providing coordinated, pleasant colors; visual relief from

controls and displays; a clean, odor-free environment; and necessary facilities as required by human needs and comfort (Mitchell et al., 1982). Direct experimentation on the effects of ambience and furniture on performance are not particularly necessary, since these effects are well known, but such experimentation might serve to document the role of these variables in Goddard settings.

Although the effects of some environmental variables are well known, their effects when combined are less well understood. It is known, however, that environmental load can be a source of stress to the operator and that, under stress, an operator is likely to overlook important information on system malfunctions (Landy & Trumbo, 1980).

Social-psychological environmental issues include the effects of shiftwork and group dynamics in multiperson work situations as well as the need for privacy and role definition (Mitchell et al., 1982). Systematic investigation of these issues requires both creative experimentation and applied analysis, including observation, formal attitude and satisfaction surveys, and interviews. Project-specific physical and social-psychological environmental issues should be considered in the interest of enhancing job satisfaction, morale, motivation, and performance.

System Component Arrangement. Research in Goddard settings is needed to formulate guidelines on the optimal arrangement of components such as KCRTs, monitors, and communications panels. The issue of rack-mounting versus adjustibility of terminals is of primary importance because rack-mounting imposes severe constraints on what can be done to meet human requirements (Stewart et al., 1982). If rack-mounting of components continues, empirical evaluation is needed to ascertain the relative benefits and limitations of fixed and adjustible components.

Current human factors principles of arrangement are applicable when it is possible to determine task-activity parameters such as frequency, function, and sequence (McCormick & Sanders, 1982):

> Where there are common sequences, or at least frequent relationships, in the use of displays, controls, or other components, the layout usually should be such as to facilitate the sequential process—as in hand movements, eye movements, etc. Where there are no fixed or common sequences, the components should be grouped on the basis of function. (p. 351)

If an existing system is being studied for modification, a systematic approach to component arrangement entails the use of a variety of techniques such as filming, observation, recordings of eye movements, and interviews with operational personnel (McCormick & Sanders, 1982). If a new system is being developed, activity parameters must be inferred from technical documentation and verified to the extent possible in discussions with project planners.

In the case of the ERBS MOR project, it was not possible to conduct a task analysis or link analysis to document human interactions or interrelationships between operators and physical components. To develop a rationale for component arrangement, analysts relied on human factors principles, their own observations in command and control environments, briefings by project planners, and technical documentation. The proposed component arrangement was then evaluated on the basis of human factors criteria, resulting in four recommendations (Stewart et al., 1982):

o   The operator should be seated between a KCRT and a monitor to provide visual and physical access to job-related controls and displays.

o   The preferred movement sequence towards a communications panel is left-to-right, in agreement with population stereotypes.

o   To prevent accidental activation of keyboards, the operator should not reach across a keyboard to access a communications panel.

o   Monitors should be placed adjacent to communications
    panels in order to provide work space along the table top;
    if a monitor is placed between KCRTs, keyboards will
    occupy the work space.

Applied evaluation of alternative component arrangements is suggested to test
their effects in project-specific settings.

Job Design

With the increasing automation of real-time support systems, creative
approaches to job design are required to offset the problems noted by Mitchell
(1981): decreased operator ability to detect anomalous events as time spent in
monitoring increases; risk of ineffectiveness when response is required; and extensive
inactivity, resulting in operator boredom and degraded performance. In discussing
the implications of future technologies such as fully automated control systems,
Griffin (1982) foresees operator alienation, loss of identity, and loss of any sense of
responsibility or accomplishment. Given these negative implications of automation,
any organization should consider job redesign and enrichment before making
decisions on allocation of functions to people and other system components (Cascio,
1978; Landy & Trumbo, 1980).

Prior to planning for job enrichment, studies are needed to identify operative
motivational patterns. Low motivational levels are associated with costly levels of
turnover, absenteeism, and degraded performance (Bailey, 1982). However, users
who are motivated by internal values will usually perform well if their assigned work
affords them autonomy, responsibility, and adequate feedback (Bailey, 1982;
McCormick & Sanders, 1982). In operational situations where external motivators,
such as opportunities to socialize, have replaced internal motivators, job enrichment
to increase meaningfulness of work and sense of worth may be received less than
enthusiastically. Job enrichment may fail if internal motivating influences are not
designed into the system (Bailey, 1982; Griffin, 1982; Hackman & Oldham, 1980).

Effective job design and redesign involve the allocation of system tasks in such a way as to increase the probability of internal motivation. Individual differences in knowledge and skill, strength of the need for personal growth, and general job satisfaction moderate the success of the job enrichment approach (Hackman & Oldham, 1980). Although monotonous tasks can be allocated to machines and periodic rest breaks can be provided (Bailey, 1982), the human problems of boredom and fatigue in the supervisory control situation remain to be addressed. Mitchell (1981) suggests that task consolidation, use of simulation exercises, and creative construction of the human-machine interface are ways to increase interest and productivity while decreasing boredom and workload. Approaches to physical and mental workload assessment are discussed in detail by Kantowitz (1982) and Moray (1982).

Strategies of job design are based on diagnosis of the work system (Hackman & Oldham, 1980). Such strategies attempt to combine system tasks, other activities, rest periods, and interface designs to produce high levels of motivation, job satisfaction, and performance. Specific diagnostic techniques include observation, interviews, informal discussion, and questionnaires such as the Job Diagnostic Survey (Griffin, 1982; Hackman & Oldham, 1980). Approaches to job design are suggested by the job characteristics model (Hackman & Oldham, 1980), the Herzberg (1968) job enrichment model, the sociotechnical systems model (Davis & Trist, 1974), and the social information processing framework (Salancik & Pfeffer, 1978). A cognitive approach to an understanding of work motivation is represented by Vroom's (1964) valence/instrumentality/expectancy model. Empirical studies should be based on an integrated theoretical framework.

For work groups such as Goddard's multiperson crews, successful job design requires that consideration be given to social systems, group processes, and the total

organizational system; implementation and evaluation of changes in job design require careful planning to minimize resistance to change and other obstacles to success (Cascio, 1978; Griffin, 1982). Although job design was not designated for human factors analysis by the MPT or ERBS MOR projects, the human implications of automation suggest that this area should be given a high priority.

Staffing

A systematic approach to staffing requires qualitative and quantitative information about the people needed to operate and supervise a system. Sources of information include technical documentation and task analysis. A study of staffing requirements produces documents describing positions, manpower requirements, selections tests, and training requirements to be used in developing an integrated approach to personnel selection (Chapanis, 1970).

If attention is paid to evolving personnel requirements from the earliest stages of system planning, the information gained can contribute to a high level of human-machine compatibility. Operational procedures can also be designed in accordance with the required physical characteristics, educational levels, skills, and personality traits that have been identified in staffing studies. Such studies also make it possible to plan for the long-term use of human resources (Chapanis, 1970; Huchingson, 1981; Schneider, 1976).

One implication of the staffing literature is that faulty system design results if ongoing attention is not paid to human needs. Maximum system performance will not result if system design is incompatible with human capabilities and limitations. Staffing studies in Goddard settings could aid in achieving higher-than-present levels of compatiblity among system components and reduce the kind of ambiguity experienced in regard to staffing levels in the ERBS MOR (Stewart et al., 1982). A major goal of staffing at Goddard should be to avoid retrofitting of people to

equipment and procedures by planning new systems with a focus on the human component. Staffing studies could also contribute to the efficient use of personnel.

Training

Training has a direct relationship to staffing; the better the selection procedures, the more likely the person will be to possess the skills and knowledge necessary to perform a job. Therefore, less training is likely to be required. The goals of training programs are to have the employee acquire new skills, improve problem-solving and decision-making techniques, and develop the motivation for good performance (Wexley & Latham, 1981; Goldstein & Buxton, 1982).

Information obtained from a systematic task analysis forms the basis for the content of the training program. Wexley and Latham (1981) provide a detailed explanation of five different task analysis procedures for task identification: Stimulus-Response-Feedback, Time Sampling, Linear Sequencing, Critical Incident Technique, and Job Inventories. Specifically, all these procedures identify the overt behavior involved in performing the job. Use of this information ensures a training program that includes all system functions, subsequent user actions, and adequate evaluation of training effectiveness.

Martin (1973) further suggests the need for multi-media training techniques. In the case of MPT, software developers became aware of the advantage of videotaping the main training sessions. These tapes will be sent to the remote sites implementing MPT, to be used as training aids locally.

Analysis of training methods should begin immediately after the critical design review. Using the data from a task analysis, the HF analyst can determine whether the procedures followed in the training session allow the operator to develop the correct conceptual model of the system. Tests on the material to be mastered, questionnaires, and interviews are useful measures of training effectiveness.

Systems Evaluation

Within the context of system development, evaluation is necessary to verify that system components perform the functions for which they are designed (McCormick & Sanders, 1982). Using the continuing feedback from experimental testing of individual components, systems evaluation involves the "ongoing human assessment of systems performance...conducted in the context of operationally defined standards of systems performance in relation to available resources in a changing systems environment" (Sackman, 1970, p. 152). Planning for total systems evaluation should occur in the earliest stages of system development in order to ensure that the ultimate design allows for the occurrence of unexpected events, human error, environmental changes, and modifications to the system (Sackman, 1970). Personnel considerations play a central role within a framework of evaluation and management regulation.

Systems evaluation in Goddard settings needs to include personnel at all levels in order to provide accurate feedback as the system evolves. If total system performance is to be improved, test and evaluation of only hardware and software components will fall short of providing complete feedback. The NASA manned spaceflight program is an example of an integrated approach to human-machine test and evaluation, with data collection and analysis occurring at all stages of project development (Sackman, 1970).

Evaluation techniques available to the human factors analyst include the following (Huchingson, 1982):

    o   expert or user opinion surveys

    o   human engineering checklists

    o   observation in operational settings

    o   examination of reports on non-routine events

o   modelling and simulation techniques

o   experimental methods

Evaluative procedures often suffer from design flaws in three areas: subjects, criteria, and experimental procedures (McCormick & Sanders, 1982). However, the corrective feedback produced by well-designed human factors evaluations can result in a higher level of compatiblity among people, machines, environment, and procedures, creating conditions necessary for improved performance.

SELECTING HUMAN FACTORS TOOLS

Once an area has been identified for analysis, the next step is to select a technique or combination of techniques that will provide the necessary data. Problems of methodology and research design, beyond the scope of this document, are discussed in detail by such authorities as Cook and Campbell (1979), Kerlinger (1973), McCormick and Sanders (1982), Parsons (1972), and Plutchik (1983). Various human factors tools are described in the sections that follow, providing a sample of some commonly used human factors methods.

Literature Reviews

Existing guidelines in the human factors literature provide analysts with a foundation for conducting an analysis and making recommendations on specific Goddard projects. Current guidelines are summarized and synthesized by Mitchell et al. (1982). Additionally, analysts should consult any relevant sources in the literature for guidance in designing their own studies. A literature review will also reveal patterns of agreement or conflict in the results of empirical studies and assist efforts to identify human factors issues. An attempt to define human requirements will benefit from a review of the literature. When quantitative data is lacking, it

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may be necessary to extrapolate from research performed in a similar setting. A literature review will locate appropriate research findings for extrapolation.

Task Analysis

Most human factors analyses include a task analysis. Data derived from this exercise form the basis for determining system specifications, level and number of staff, design of training programs, possible design flaws, and the level of technical information required for successful operator performance (NUREG 0700, 1981). Because of its universal applicability, the task analysis should be performed as early as possible in system development. When entering a project, the HF analyst should ask whether a task analysis has been performed. If not, one should be conducted.

Basically, the procedure is to define system functions and then to analyze and describe progressively simpler tasks and subtasks (Meister, 1973). Task analysis establishes the behavioral aspects of the system including the sequence of actions. McCormick (1979), Anacapa Sciences, (1981), and Meister (1973) present detailed information on the steps to follow in a task analysis. Rappold (1982) and Stewart, Crowder, and Mitchell (1983) offer examples of task analyses related to the Goddard environment.

Link Analysis

Another technique used to determine optimal interaction of humans and machines is link analysis. It is primarily used to determine the optimal layout of people and machines in a system. Links are identified between human/machine, human/human, and machine/machine and rated on criteria such as importance or frequency. Steps to follow in conducting a link analysis are included in Anacapa Sciences (1981), Huchingson, (1981), and Mitchell et al. (1982). Analysts should incorporate a link analysis when their task includes workstation design, especially component arrangement.

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Ratings by Experts

In some cases, design decisions cannot be guided by published research results because no research has been conducted on the problem under consideration. Although it may be desirable to conduct empirical studies on the specific problem in question, lack of time may constrain the human factors analysis to non-empirical methods. On other occasions, a non-empirical approach is required by the nature of the problem, e.g., the need to rank design criteria, design for ease of maintenance, or determine staffing requirements. In these instances, decision making can be guided by the systematic application of expert judgment.

A popular method of soliciting and organizing collective opinion is the Delphi technique (Cascio, 1978; Huchingson, 1981). In this process, ratings are anonymously collected from individuals knowledgeable in their fields, summarized, and presented to these same experts for a second ranking. This procedure continues until a consensus appears in the rankings, assuring a more accurate decision than would be obtained from a single person or group face-to-face decision making.

At Goddard, such sessions should include system engineers, project managers, and human factors analysts. This participation in the rating process is likely to produce a high level of commitment to the final decision.

Non-Experimental Simulation

When time constraints do not permit empirical evaluation of different designs, physical simulation using mockups can help analysts visualize alternatives and assess tradeoffs. The fidelity of a simulation to a particular piece of equipment or real environment may range from the very abstract to the "real" thing. The degree of fidelity required is open to question but probably depends partly on the level of detail needed for decision making.

Non-experimental manipulation of paper mockups provided decision makers with a basis for selecting workable designs for the ERBS MOR and permitted a rapid assessment of each alternative's benefits and limitations (Stewart et al., 1982). In order to offset individual subjective judgments, this approach is best employed by analysts working together. It also lends itself well to use in project planning sessions as a means of achieving group consensus.

Surveys and Interviews

Data on user variables, such as attitude and job satisfaction, is collected by means of sample surveys and formal interviews (Kerlinger, 1973). Rigorous sampling, questionnaire construction, and validation are essential if results will be analyzed for statistical significance. Application of these techniques in Goddard settings is recommended, for example, to determine motivational patterns prior to designing jobs for supervisory controllers.

A good way to gather information about the intended user of a planned system is to conduct an informal survey of those currently in an antecedent operating system or those for whom the system is being specifically designed. This survey, in the form of a questionnaire, gathers information on the operating environment. For example, survey questions might cover the following areas: lighting, sound, component flexibility, ambience, personnel, supervisory style, task load, and operating procedures. A sample survey can be found in Van Balen and Mitchell (1983).

Surveys should be individually styled according to the intended audience and type of information sought. Information obtained from the questionnaires is helpful as a decision-making aid in the design process. References for help in conducting surveys include Babbie (1973), Kish (1965), and Stopher and Meyburg (1979).

Empirical Evaluation

The emphasis in human-machine system experiments is on the controlled manipulation of specified variables to test one or more hypotheses (Parsons, 1972). If levels of variables are not directly controlled, fallacious interpretations of results are likely (Kerlinger, 1973). One function of the proposed Goddard Human Engineering Laboratory is the performance of human-machine experiments.

Simulation. Empirical, simulation-based evaluation of alternative workstation designs, for example, requires at least two possible configurations and data collection on such measures as performance, stress, fatigue, and job satisfaction from experimental and control subjects. Issues in simulation research, including levels of fidelity and methods of measuring human performance, must be addressed and solutions applied consistently to ensure generalizability of results from study to study and setting to setting. Guidelines on the construction and experimental use of mockups are provided by Mitchell et al. (1982).

Studies of Group Processes. Empirical evaluation can occur in field experiments conducted in operational settings. This approach is particularly suited to the study of small group dynamics but requires the experimenter to control sometimes uncontrollable variables (Cook & Campbell, 1979; Kerlinger, 1973). The random assignment of subjects would, in itself, present a challenge to researchers in Goddard settings. If the difficulties of field experimentation can be overcome, valuable data can be collected on optimal work-rest cycles, social systems, and job design (Kahn, 1974; Parsons, 1972; Shaw, 1976).

Modelling

As a diagnostic tool, modelling overlaps with simulation techniques yet is distinctive in its mathematical approach. Modelling, a quantitative design method of representing the human-machine interface, allows engineers to predict design

choices. A preliminary task analysis aids in defining the parameters of the model. The Mitchell et al. (1982) guidelines provide a synopsis of possible modelling techniques to incorporate in system design at Goddard. Pew and Baron (1982) offer an interesting comparison of psychologically based models, such as network and information processing models, and several control theoretic approaches to modelling human behavior. In order to use modelling techniques effectively, one must have a strong background in mathematics and experience in developing models.

Tradeoffs Analysis

A systematic assessment of the benefits and limitations of alternative designs can occur only within the context of a well-defined set of design criteria. Without explicit, ranked criteria, such an assessment will be haphazard and invalid. If adequate time is not provided for application of the appropriate human factors tools to the designated areas for analysis, tradeoffs associated with alternatives must be assessed entirely on the basis of recommended guidelines and human factors expertise. Working down through the ranked criteria, analysts must judge the degree to which each design fulfills each criterion. This can be a time-consuming process, but it provides a rational basis for making recommendations to the project (Stewart et al., 1982).

When sufficient time has been permitted for data collection and analysis, benefits and limitations of particular designs can be assessed and recommendations justified with quantitative support. It may, for example, be possible to compare the relative costs of different configurations in terms of error rates, stress levels, and effects on motivation. A systematic appraisal of design benefits might also be supported by appropriately weighted performance and job satisfaction data. A complete tradeoffs analysis, providing a balanced assessment of benefits and limitations, is a necessary step if the project is considering alternative designs.

DOCUMENTING THE ANALYSIS

Once the human factors analysts have become oriented to the project and have examined the design from a user's perspective, they are ready to formulate guidelines to present to the project for consideration.

Record Keeping

In the early stages of development, analysts may be given specific tasks such as recommending the best selection of color combinations to use on CRT displays. A written record of all such tasks and recommendations should be kept. A chronology of human factors activities is especially useful as a reference.

Reports

A written report is needed where analysis covers a large area. For example, response to a design review or the presentation of specific recommendations for design issues under consideration require a concise written report. These interim reports are valuable sources of communication with the project; they state the human factors recommendations based on documented research or expert opinion and prompt a response from the project concerning these recommendations. In the case of MPT, a written report plus red-inked suggestions written in a user's manual were used to document needed changes in the manual. A report that generates appropriate questions concerning design issues raised during a design review also initiates further interaction with the project. For example, the human factors analysts can assist the design team in responding to Review Item Dispositions (RIDS) raised during a formal design review. Immediate follow-up or response to all reports is recommended. At the conclusion of a contract, a final report is prepared documenting all human factors analyses and recommendations. It is distributed to the project and members of the Human Factors Group.

Presentations

Upon completion of the human factors analysis, it is possible that the analyst will be asked to give a presentation. Ideally, this presentation should not last more than 40 minutes, depending on the scope of the topic. Viewgraphs should be prepared and a corresponding handout distributed to those attending the presentation. This procedure was used sucessfully in summarizing the process of design evolution and presenting major recommendations of the ERBS MOR workstation design analysis.

MANAGEMENT SUPPORT

During the performance of a human factors analysis, there is a continuing need for management support in the following areas:

- o provision of adequate facilities and equipment as required by analytical procedures

- o scheduling of personnel to meet the requirements of experiments and field studies

- o liaison between the human factors team and the project

- o execution of verbal assurances concerning delivery of required information and documentation

This support assures the timely completion of the analysis which, in most cases, requires extensive coordination and cooperation among all those concerned. Management's positive attitude, conveyed through its facilitation of the analysis, contributes to the conditions necessary for the general acceptance and implementation of ensuing human factors recommendations.

COORDINATING THE ANALYSIS:

MAJOR STAGES OF SYSTEMS DEVELOPMENT

OVERVIEW

To ensure maximum compatibility of physical components and human operators, human factors analysis is required during the major stages of systems development (Meister, 1982). However, human factors support is not always requested or incorporated in the early phases of system concept generation. Human factors support is often requested only at an advanced design stage. For this reason, analysts need to determine what engineering stage is in progress when they are introduced to a project, become familiar with the project's background and operations, and proceed to conduct an appropriate analysis. The point at which a human factors analysis is introduced determines, in part, the extent to which human factors recommendations can be effectively incorporated to produce high levels of compatibility among system components, e.g., hardware, software, personnel, and environment.

SYSTEMS DEVELOPMENT

An overview of the engineering stages of system development is given by DeGreene (1970a). As illustrated by Figure 1, the engineering stages in systems development establish a framework for human factors analysis. Beginning in the conceptual stage, refinement of system requirements moves from the general to the specific. From the conceptual or planning stage, systems development proceeds through definition, design and production, and operational stages (DeGreene, 1970a). The concluding phase of the definition stage overlaps with the beginning of the design and production stage, as indicated by the parallel section of the diagram in Figure 1. This overlap occurs because the iterative design process contributes to

Conceptual or Planning Stage

Preliminary statement of behavioral and informational requirements for the human component

Human Factors Analysis: Applied Techniques

Evaluation of human performance and recommendations for system enhancements

Recommendations on allocation of functions, job design, staffing, training, and documentation

Human factors implications of alternative designs

Operational Stage

Definition Stage

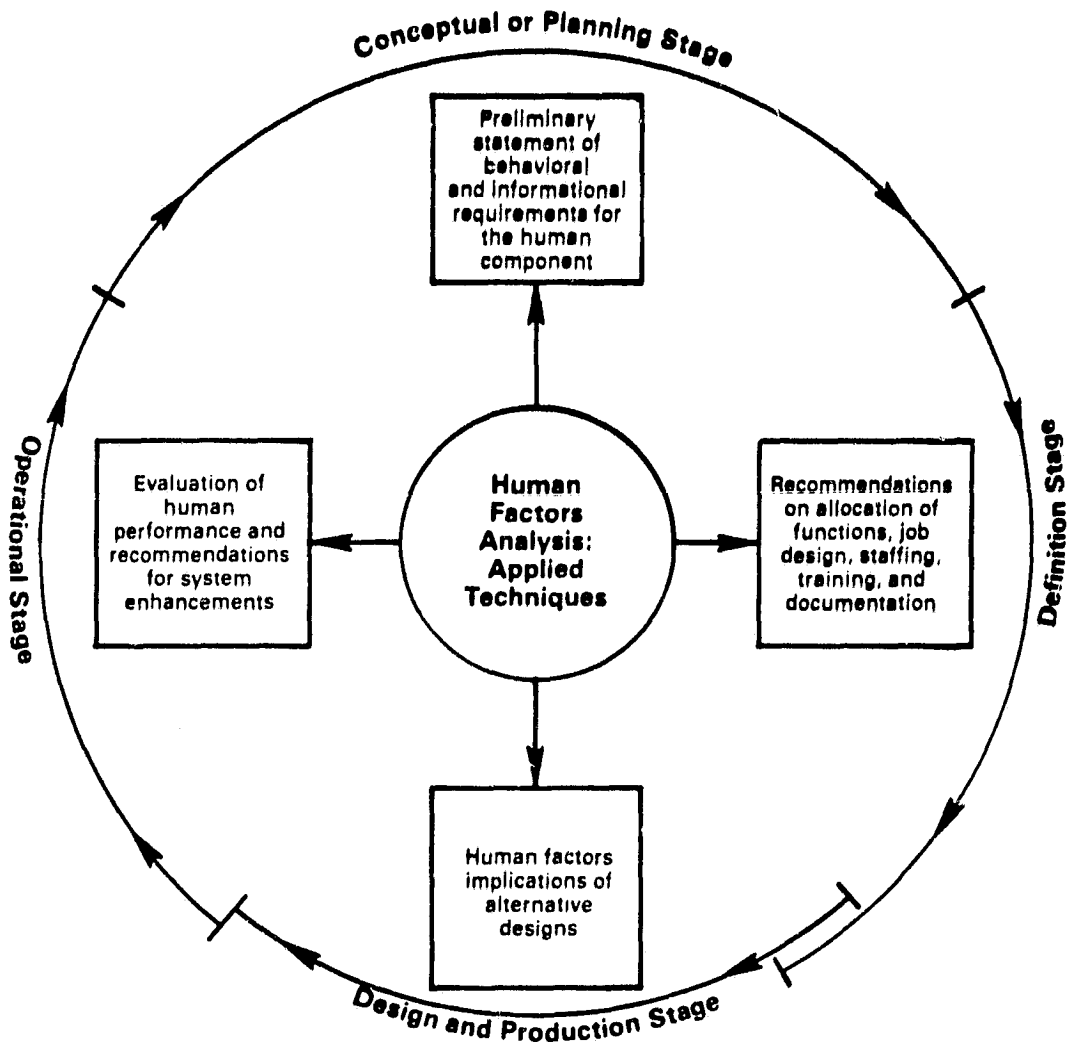**Design and Production Stage**

**Figure 1: Human Factors Impact on System Life Cycle
(adapted from De Greene, 1970)**

refinement of system requirements and because further definition necessitates design readjustments. Evaluations conducted during the operational stage contribute to the development of enhancements to the current system. Systems development proceeds in life-cycles, with concepts for a second generation system evolving from experience with the operational system, as indicated by Figure 1.
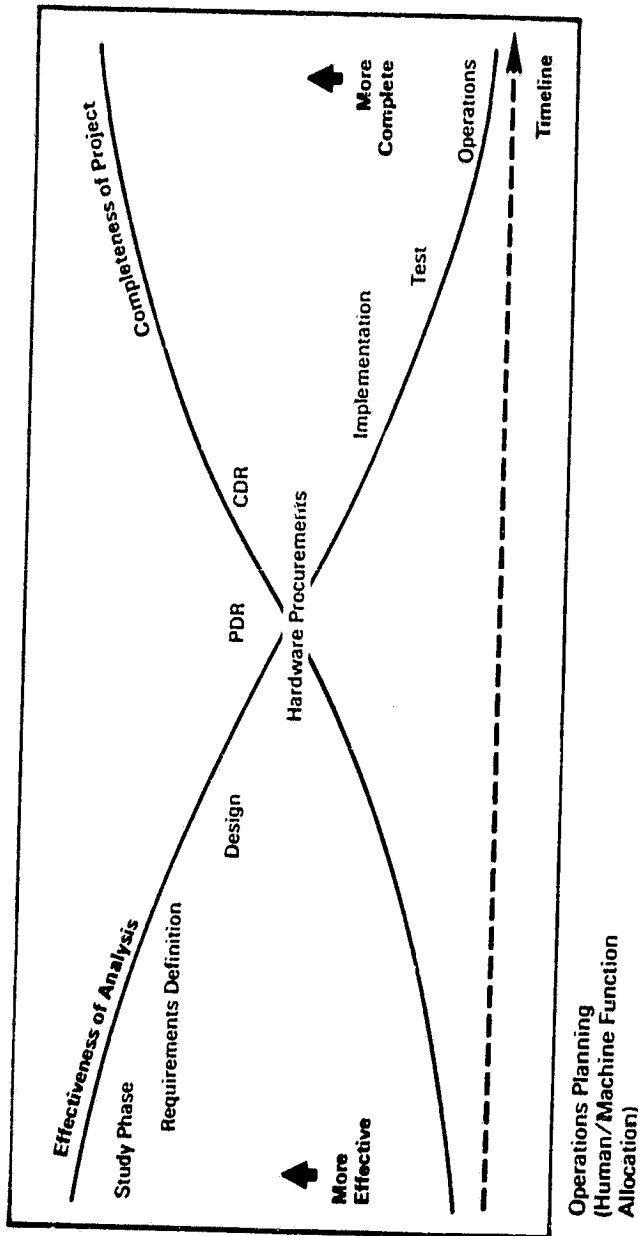
In the Goddard environment, engineering stages are described by the phrases incorporated into Figure 2: Study Phase; Requirements Definition; Design, including Preliminary Design Review (PDR) and Critical Design Review (CDR); Hardware Requirements; Implementation; Test; and Operations. This breakdown of stages in systems development can be considered as an alternative to and further elaboration on DeGreene's terminology:

    o   Conceptual or Planning Stage = Study Phase

    o   Definition Stage = Requirements Definition

    o   Design and Production Stage = Design (PDR and CDR) +
                Hardware Requirements + Implementation + Test

    o   Operational Stage = Operations

The crucial point made by Figure 2 is that an early introduction of human factors analysis is necessary to ensure the effective incorporation of recommendations emerging from the analysis. The more complete the project is when human factors analysis begins, the less likely it is that effective use can be made of input from the analysis (Moe, 1982).

The following sections, based on DeGreene's (1970a) framework, provide a guide to the application of appropriate human factors techniques at each stage of systems development. These sections suggest ways to coordinate the human factors analysis with the design activities that typically occur during each major engineering stage.

Figure 2: Relationship of Human Factors to System Life Cycle
at Goddard Space Flight Center

CONCEPTUAL OR PLANNING STAGE: ANALYZING SYSTEM REQUIREMENTS

The decision to design a new system generally results from the identification of an existing problem, e.g., a desire to update a current system or to increase productivity by integrating new technology. After appropriate analytic field studies and comparative research, a preliminary concept of the parameters and functions of the system emerges. Requirements are then broadly defined for hardware, performance, personnel, and training. Constraints, criteria, interfaces, and subsystems are also specified.

It is at this point that human factors analysis most effectively aids in determining the user requirements tempered by any contingencies or constraints, e.g., cost. Progressively, the defined requirements move from preliminary concepts to more specific definitions. During this stage, the HF analysts complete the identification of subsystems and their relationships and a preliminary analysis of behavioral and informational requirements. Appropriate human factors tools include literature and documentation review, surveys and interviews, preliminary staffing and training studies, and ratings by experts.

DEFINITION STAGE: ANALYZING JOBS AND ALLOCATING FUNCTIONS

As planning continues and finer definition of system requirements begins, tradeoffs analyses of alternative subsystem configurations become a basis for allocating functions to humans and machines. During the definition stage, a preliminary determination of organizational structure should occur. At this point, general tasks, functions, and jobs can be described as performed by individuals and groups.

If a human factors analysis is introduced during the definition stage, there is a good chance that the ultimate system will provide for human requirements. At this

point in systems development, human factors analysts evaluate the acceptibility of preliminary function allocation by performing task and job analyses. Continuing human factors evaluation of alternative subsystem components contributes to the resolution of specific design issues such as use of color or choice of interactive devices.

Adequate human engineering of the system also demands studies of staffing and training requirements. Preparation of all external documentation, e.g., training manuals and user's manuals, requires analysis, evaluation, and critique of alternative formats; criteria of readability and inclusiveness should be applied to all documentation.

Throughout this stage, simulation or modelling of the system, based on previously established system requirements, provides feedback to the definition process. As human, machine, and environmental requirements are further defined, the simulation or model developed during the conceptual stage evolves from a gross representation of the system to a detailed facsimile. Results from analyses performed during the definition stage become decision aids in design evolution.

DESIGN AND PRODUCTION STAGE: INTEGRATING SYSTEM COMPONENTS

With further definition bringing system requirements into clear focus, the design and production stage incorporates the results of previously performed task analysis and other human engineering studies. This stage includes the presentation of preliminary and critical design reviews. Informal working sessions are held to consider designs of specific system sub-components. The results of human factors analyses should be incorporated and further refined as the design continues to evolve in a series of dynamic interactions. The goal at this point in systems development is to achieve integration or compatibility of hardware, software, personnel, and work

environment. The results of systems test and evaluation provide information required to achieve this goal.

If the physical system already exists when the human factors analysis is introduced, it will probably be too late for maximum HF effectiveness in achieving full integration of system components. Some retrofitting may be possible to the extent that any flexibility remains, although existing equipment will impose constraints on what can be done (Stewart et al., 1982). Despite difficulties, human factors analysts must attempt to identify all areas of flexibility, conduct their analyses, and offer realistic recommendations based on the human factors implications of alternative designs. Appropriate human factors tools include literature and documentation review, surveys and interviews, simulation using mockups, and tradeoffs analysis.

OPERATIONAL STAGE: EVALUATING AND MAINTAINING THE SYSTEM

Once the design is operational, with production completed and personnel trained, the system is implemented. For the HF analyst, this stage of system development allows field evaluations of human performance in the operational system and permits the identification of design problems not previously anticipated. Any required modifications are then incorporated into the design. User response to the system can be evaluated through measures of stress, fatigue, and job satisfaction. Human performance data should be collected for purposes of error analysis (Shneiderman, 1982). The integration of maintenance procedures should also be analyzed at this time. Suggested changes should be evaluated for their potential impact on the human-machine interface.

External documentation, e.g., maintenance and user's manuals, should be reevaluated from the user's perspective. Internal documentation of computer

software should be reviewed to ensure that future programmers can easily maintain and modify the code. The reliability of the system ensures its optimal use and acceptance. Human factors considerations should continue to receive attention for the life of the system in order to identify areas where enhancements would contribute to improved performance and productivity.

SUMMARY

At whatever point in system development that human factors analysis is introduced, a written contract is required to clarify and formalize the responsibilities and commitments of the HF team and the project. Following initial contact and contract development, an orientation period is required to familiarize analysts with the project. The identification and ranking of human factors criteria should occur prior to the initiation of any analysis or evaluative study.

The human factors analysis proceeds with the application of appropriate HF tools to the area or areas designated for analysis in the contract. The success of the analysis depends on allowing sufficient time in the design schedule. Documentation of the analysis includes thorough record keeping, written reports, and oral presentations to appropriate groups. Attention to human factors continues throughout the life of the system.

Ideally, a human factors analysis should begin during the conceptual or planning stage of system development when broad system requirements are established. In order to achieve the goal of compatibility among system components—hardware, software, personnel, and environment—a human factors analysis should commence no later than the definition stage. If the design is close to being finalized and system production is underway, full implementation of human factors recommendations will not be possible. The role of human factors analysis during the operational stage of the system life cycle is to evaluate effects on the human component for purposes of modification and enhancement.

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