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ANALYSIS TECHNIQUES FOR MAN-MACHINE SYSTEMS DESIGN

Panel 8 on the Defence Applications of
Human and Bio-Medical Sciences

RSG. 14 on Analysis Techniques for
Man-Machine Systems Design

ANALYSIS TECHNIQUES FOR MAN-MACHINE SYSTEMS DESIGN

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14. Abstract:

Human engineering (known in some countries as human factors in design or ergonomics) is a discipline by which data on human capabilities and limitations are taken into account during the engineering design and development process. NATO AC/243(Panel 8/RSG.14) completed a study of analysis techniques used for human engineering. The RSG collected information on the of known human engineering analysis techniques, compiled descriptions of thirty-one existing techniques, reviewed them to identify the need for new and improved techniques, reviewed the current state of standardization of such techniques, and compiled examples of functional decompositions of typical manned systems. The two volumes of this report review the state-of-the-art of human engineering analysis and its relationship to systems engineering.

CONSEIL DE L'ATLANTIQUE NORD
NORTH ATLANTIC COUNCIL

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TECHNICAL REPORT
AC/243(Panel 8)TR/7
Volume 1

DEFENCE RESEARCH GROUP

PANEL 8 ON THE DEFENCE APPLICATIONS OF HUMAN AND BIO-MEDICAL SCIENCES

Technical Report on Analysis Techniques for Man-Machine System Design

This is Volume 1 of the technical report on Analysis Techniques for Man-Machine System Design. The report was prepared by RSG.14. The Executive Summary of this report ("Yellow Pages") was also distributed under reference AC/243-N/359 dated 24 July 1992.

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ANALYSIS TECHNIQUES FOR MAN-MACHINE SYSTEM DESIGN

0. EXECUTIVE SUMMARY

"Because they do not take sufficient account of the limitations posed by man as well as other factors of real life, many complex systems requiring a high degree of integration of many functions ... will simply break down under the exacting conditions of a real dynamic battle ..."

P. Naslin, Head, NATO Defence Research Section, 1983

0.1 SUMMARY OF THE STUDY

i. *Human engineering* (known in some countries as human factors in design or ergonomics) is a discipline by which data on human capabilities and limitations are taken into account during the engineering design and development process. NATO AC/243 Panel-8/RSG.14 completed a study of analysis techniques used for human engineering. The RSG collected information on the of use of known human engineering analysis techniques, compiled descriptions of thirty-one existing techniques, reviewed them to identify the need for new and improved techniques, reviewed the current state of standardization of such techniques, and compiled examples of functional decompositions of typical manned systems. Volume 1 of this report reviews the state-of-the-art of human engineering analysis and its relationship to systems engineering. Volume 2 of this report contains reviews of thirty-one human engineering analyses and functional decompositions prepared to assist the application of human engineering in advanced development projects.

0.1.1 Background

ii. Human engineering is an essential speciality within the systems engineering effort directed at the integration of the human with hardware and software sub-systems through analysis, simulation, test and design. The analyses follow the same general pattern as those of systems engineering. They include: mission analysis, function analysis, function allocation, task analysis, and performance analysis.

iii. As weapon systems become more sophisticated and pressure to reduce military manpower increases, there is a severe risk that the unique skills and abilities of humans may not be exploited as effectively as they could be, thus degrading the potential performance of a system. Therefore, programmes in several NATO nations are directed at human systems integration (HSI). Human engineering is an essential activity in those programmes. For example, in the USA, total manpower, personnel and training costs are estimated to be 50% of the life-cycle costs of a weapon system. Thus life-cycle managers are interested in HSI from the viewpoint of reducing manpower requirements and personnel costs as well as obtaining a high level of system effectiveness. To assist in obtaining those goals, human engineering applications should start at the outset of a project and be updated throughout the development cycle, as with other engineering elements.

iv. In 1984, a NATO DRG Panel 8 workshop reviewed "Applications of systems ergonomics to weapon system development" and made thirty-six recommendations to improve the application of ergonomics (or human factors) technology, many of which were concerned with human engineering (Merriman et al., 1984). Subsequently an Exploratory Group, convened to review the recommendations of the workshop, recommended the formation of a Research Study Group to:

- review the state of knowledge of analytical techniques
- evaluate such analytical methods for their effectiveness, reliability and ease of use
- stimulate co-operative efforts for improving existing methods, determining where new techniques are needed, and for developing new techniques
- recommend courses of action for improving the standardization of techniques

Research Study Group (RSG) 14 was formed in October 1987 to work towards these objectives.

0.1.2 Survey of human engineering analysis techniques

v. RSG.14 compiled a list of twenty-four human engineering analysis techniques used for the analysis of Missions, Functions, Tasks, and Operator Performance. Many of these techniques are similar to analytical techniques used in other systems engineering activities, and might be expected to be in widespread use. The RSG surveyed the use of these techniques in thirty-three projects in seven countries (Chapter 2).

vi. It was found that the rate of application of the techniques was low and inconsistent, although increasing. The application to NATO projects was extremely limited. The overall level of knowledge of human engineering analysis techniques was very low also, and training courses in human engineering did not cover them. Therefore, the RSG decided to compile a guide to thirty-one human engineering analysis techniques for use by project managers and engineers in the NATO nations. Volume 2 Part 1 of this report represents the outcome of that work.

0.1.3 Review of human engineering analysis techniques

vii. Analysis is a widely used approach in systems engineering and system design/ development. This review covers analytical techniques used for human engineering (Chapter 3). The review does not deal with other human engineering techniques such as experimentation, modelling, man-in-the-loop simulation, rapid or virtual prototyping, test and evaluation, or field trials, although the relationship of those techniques to analysis is discussed in the report. The review contains descriptions of the most widely used techniques for six major types of analysis, which, typically, are used in sequence (Fig. 0.1).

viii. Modern approaches to design emphasize the functional aspects of systems. It has been found difficult to do this without the benefit of reference to earlier applications. To support this, examples of system decompositions were also compiled and are reported in Volume 2 Part 2. The material covers aircraft, ships, and army systems, and provide examples of seven different approaches to functional decomposition.

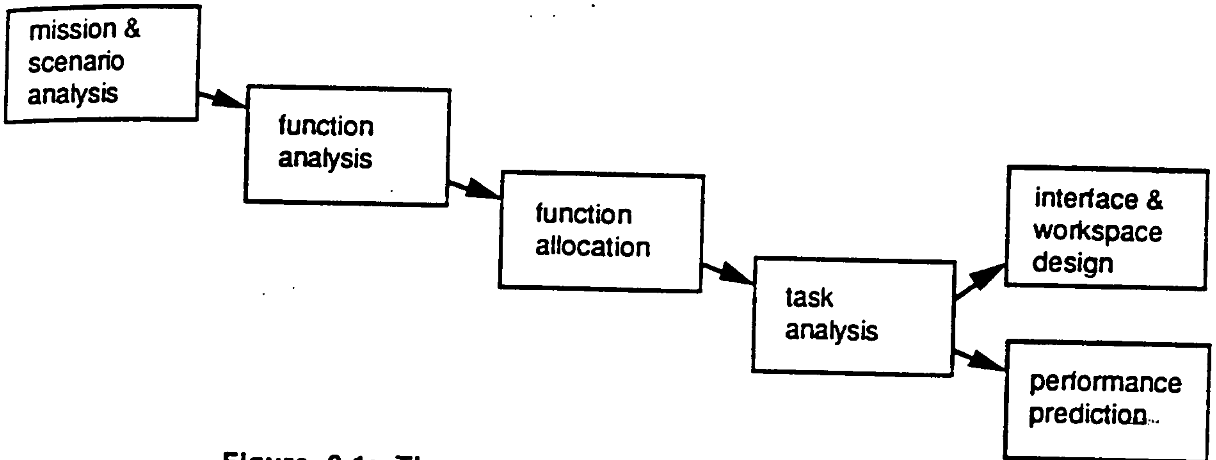

Figure 0.1: The sequence of human engineering analyses reviewed in the report

0.1.4 Need for new techniques

ix. Another aim of the RSG's work was to identify those analytical techniques which have a strong link to current developments in systems engineering, particularly the increasing use of structured analysis and design for software development. In addition to compiling the guide to existing human engineering analysis techniques, the RSG reviewed how the techniques might be integrated with other engineering activities, particularly those of software systems engineering (Chapter 4).

x. Technological changes will affect: the human machine interface; the kind of human factors problems which may arise in operating or maintaining new systems or equipment; and the approach to system design and development taken by designers and engineers. Several current developments in technology and in systems engineering will require corresponding developments in human engineering techniques. These developments include:

- the increasing importance of cognitive tasks in systems operation and maintenance
- increasing use of computer based decision aids and knowledge-based systems
- increasing use of computer simulation, rapid prototyping, and computer aided design as human engineering tools
- increasing use of software engineering techniques and computer-aided software engineering

xi. As reviewed in Volume 1 Chapter 5, all of these developments argue for a more integrated approach to systems development based on the analysis of system functions, the allocation of functions to sub-systems, the analysis of sub-system interactions, and feasibility studies within the context of systems engineering.

0.1.5 Need for standardization of techniques

xii. National and NATO standards governing the practice of human engineering were reviewed as part of the study. Within individual countries, the level of standardization of human engineering analysis techniques is low. Within NATO it is extremely low, and inconsistent. This situation is reviewed and recommendations for standardization are developed in Volume 1, Chapter 5.

0.2 MAJOR RECOMMENDATIONS

xiii. Based on the work outlined above, RSG.14 makes the following recommendations:

- Panel-8 should support research and development of function allocation and task analysis techniques to deal with cognitive behaviour, as discussed in Chapters 3 and 4.
- The DRG should collaborate with the NATO agencies responsible for standardization to ensure the application of human engineering in NATO projects through the development of standards, specifications, and guidelines which identify and describe human engineering analysis techniques, the latter based on Volume 2 of this report, as discussed in Chapter 5.
- The DRG should collaborate with the NAGs to explore how current technological developments can be used to integrate the human, software, and hardware aspects of project development in such a way that human engineering becomes an inseparable part of the design/development process based on the use of computer software, as discussed in Chapter 3.

0.3 MILITARY IMPLICATIONS

xiv. The following are the military implications of the work of the RSG:

- The effectiveness of a total system depends on the performance of the human components for planning, decision making, supervision, control, and maintenance.
- Manpower is an increasingly limited and expensive resource, and must be utilized to the most effective extent possible.
- The human components have a large influence on the life cycle costs, effectiveness, reliability, and readiness of weapon systems.
- Effective human sub-system utilization is obtained through the application of human engineering throughout the entire weapon system development process, including upgrading and updating.
- The human engineering analysis techniques described in this report are essential to that process and should be used in future development projects. Standardization of the approach to human engineering within NATO will facilitate the use of those techniques.

0.4 REFERENCES

1. Merriman, S.C., Muckler, F., Howells, H., Olive, B.R., & Beevis, D. (1984). Applications of systems ergonomics to weapon system development. (NATO DS/A/DR(84) 408). Brussels: NATO Defence Research Group.
2. Naslin, P. (1983). The human as a limiting element in military systems. In: Proceedings of the 24th DRG Seminar (Closing address). DS/A/DR(83) 170. Brussels: NATO Defence Research Group.

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CHAPTER 1
INTRODUCTION TO SYSTEMS DESIGN AND HUMAN ENGINEERING ANALYSES

"We have to design equipment to take full advantage of the capabilities of our personnel and we have to design equipment that will not overload, confuse or degrade personnel performance in achieving mission objectives ... We have to reduce design-induced human error which is so costly a component of accidents and operational failures. We have to plan for the wise and judicious use of the limited personnel and skill levels available to us by optimizing manpower requirement, and through more effective use of automation and expert systems. We have to design with greater efficiency and productivity in order to reduce costs to our services and to our nations."

Rear Admiral R. Horne, USN, 1990

1.1 INTRODUCTION

1. For a long time, humans have manufactured devices, equipment, and systems which permit the accomplishment of activities, whether work or combat, to satisfy increasingly demanding and complex objectives with increasing effectiveness and reliability. Up to the end of the 19th century, almost all manufactured items were made to measure by craftsmen who tailored the product to the user. The development of industrialization and the mass production of objects has forced manufacturers to make identical items for effective use by a large number of individuals. Today, the achievement of a specific objective often requires the efforts of several groups of individuals using several complex machines, some automatic, in a formal organization. Today, it is not possible to manufacture complex objects such as weapons without considering them as *systems*, defined as "the ensemble of elements capable of achieving a goal or a mission with autonomy" (Dictionaire Robert).

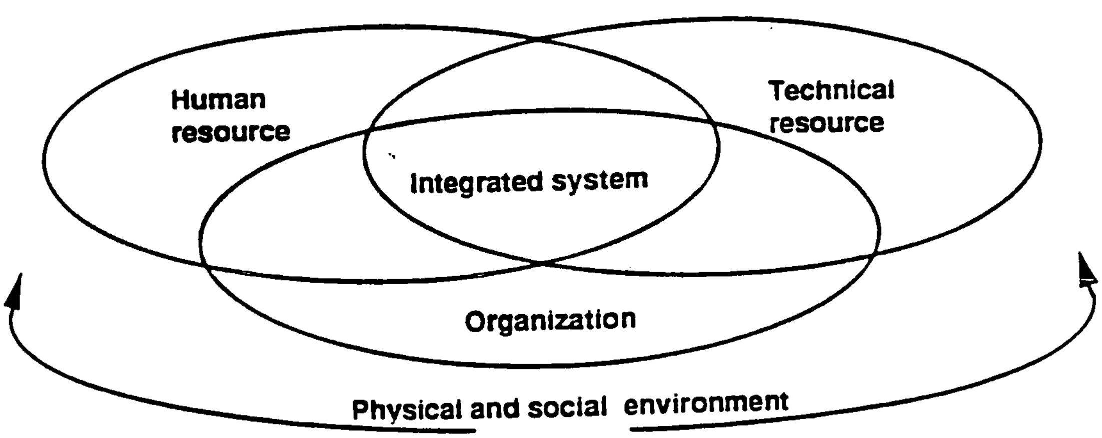

Figure 1.1: Three interacting sets of system resources

2. The effectiveness of mission accomplishment depends upon the exploitation of the various system resources, i.e., people, material, software, and organization in a physical and social environment. (Fig. 1.1). These resources provide the system elements, or sub-systems. The human resource is defined by the personnel who are available, their knowledge and skills, and their characteristics (manpower, personnel, and training). Successful exploitation of the system resources depends not only on their capability (sub-system performance) but on the quality of the interactions between them (sub-system compatibility, and sub-system communication). That is why designers must research the best interactions between the elements and combine them into an effective system, i.e., they must design an integrated system. The interactions which the designer must consider include those between the selection and training of the system operators and maintainers and the complexity of the hardware and software design (Fig. 1.2).

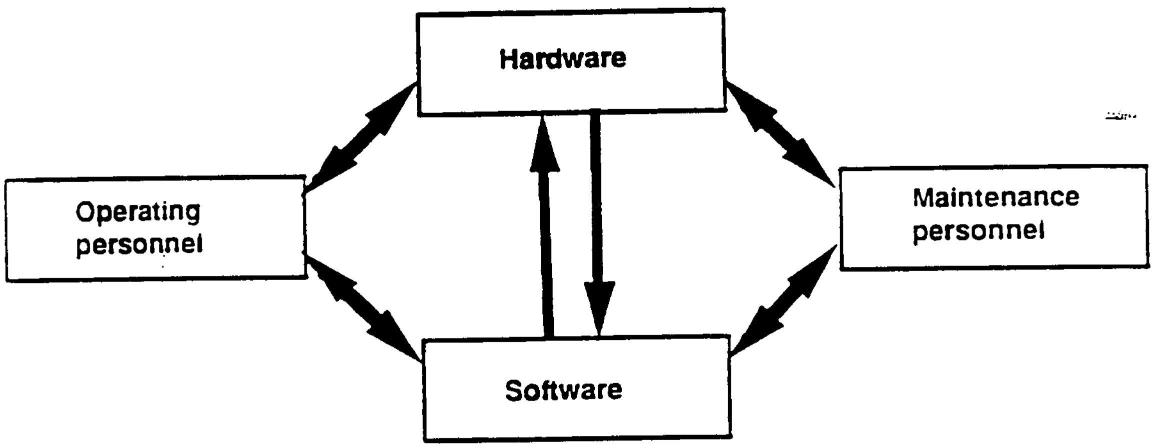

Figure 1.2: The human-machine system

3. While taking the human system components into account, the designer must remember that there are important variations from one human to another, whether anthropometric, physiological, psychological, or cultural. These human variations interact with one another, and, for any one individual, some characteristics change over time. In addition, human system elements may require protection from their working environment. The human sub-system factors which must be considered in the development of weapon systems comprise:

- Human factors and cognitive psychological information which defines the capability of operators and maintainers to do mental work, the nature and content of information for presentation, and the needs for training and practice.

- Physiological and biodynamic information which defines the capability of operators and maintainers to do physical work, their body positions and postures, the forces exerted on controls, the location of the components of the human-machine interface, the form and size of those components, for example, and requirements for physical protection.

- Anthropometry information which defines human physical dimensions, the dimensions of the work space and the location of controls and displays.

- Information from the foregoing disciplines which determines manpower requirements, the length of work period, and needs for and means of protection against environmental conditions and safety and health hazards.

4. This information must be considered in terms of the variance which it represents, and viewed in terms of the functions and tasks the operators must accomplish. In this context, the design problem can be expressed as follows: *ensure that manufactured hardware and software can be used by, and provide protection for, the maximum number of individuals from a population which is quite varied.* That is why, the more complex products become, the more it is necessary to use special methods to take human factors into account in the design and development of those products. This is the main task of *human engineering* (known in some countries as human factors in design or ergonomics) which involves consideration of the relevant human factors issues, the methods for analysis such as those described herein, and the means and the scheduling of effort to integrate the results in design and development of hardware and software.

5. Human engineering should be involved in the search for solutions which permit the optimal use of products (satisfaction of the need) by potential users (the human resource) while respecting the entirety of the latter in physical, psychological and moral terms. The benefits of human engineering can be very significant. Among them are reduced errors and reduction of uncertainty about how the system will operate, reduced system costs (both acquisition and life-cycle), reduced training costs, and manpower reduction compared to existing systems. For example, a US Navy Research Advisory Committee estimated that the proper application of human engineering can result in a 20% reduction in manpower in Navy surface ships. Efforts in progress in other navies provide further evidence of the gains which can be achieved by effective integration of humans and machines. The German, Norwegian and Netherlands navies all have active programmes to produce new ships with extensive attention to human-machine interfaces. The Netherlands Walrus II submarine has a crew size of 50, reduced from 70 persons in a previous, similar Zwaardvis class. It will have no decrease in capabilities, but some increase in training requirements. Similar results are being pursued in the new "M-Frigate" which has a complement of 156 compared to 190 in the older ST class. Considerable use is being made of automated monitoring and control systems, computerized displays, extensive man-machine design and testing, and on-board training and cross-training.

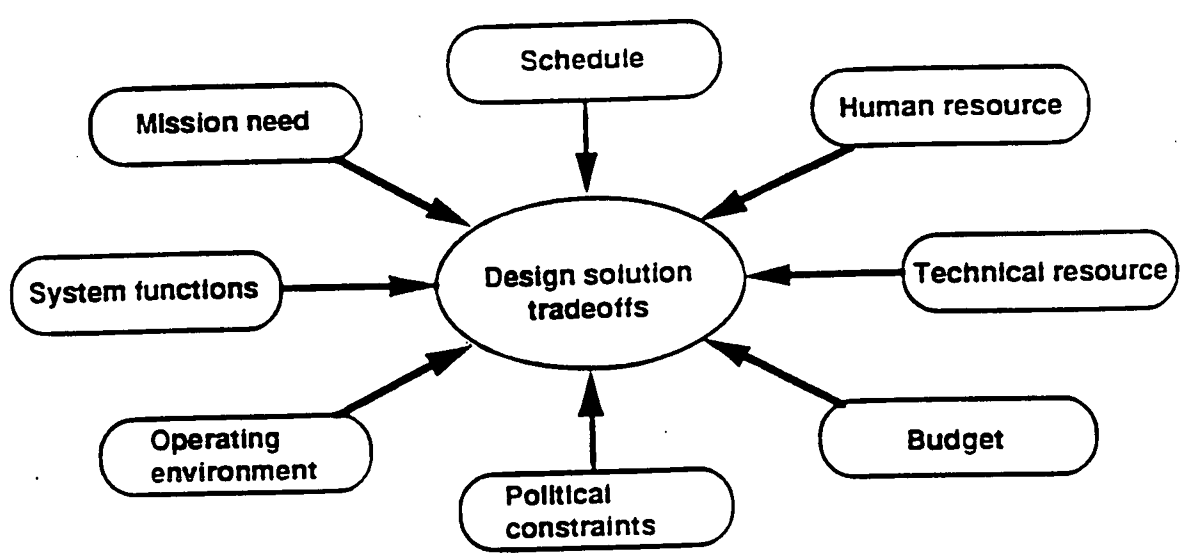

Figure 1.3: Factors influencing a design concept

6. The human engineering perspective is based on the concept of the system and the integration of the human in it. The role of human engineering specialists is to give engineers the means of choosing technical solutions necessary for the production of equipment and systems. The technical solutions chosen to implement a system will be the result of a compromise between different requirements, some of which may conflict. This compromise includes consideration of technical and financial possibilities and schedules (Fig. 1.3), and can be determined only from knowledge of the system mission, which permits the identification of the necessary functions, and by the same means, the operator's task demands.

7. The integration of the human subsystem involves many human factors considerations. It must be remembered that although adaptability and capacity for decision making make the human an irreplaceable system component, the human can be a weak link in the system due to variability in performance over time. Because of this, and because of the wide range of factors which affect human performance, human engineering cannot address all the risks of poor performance, incidents or accidents. For example, Figure 1.4 presents an Ishikawa (cause factor) diagram of factors rated by aircrew as influencing their flight safety and operational effectiveness. These factors include aircraft operations, training, personnel and organization, as well as human engineering issues.

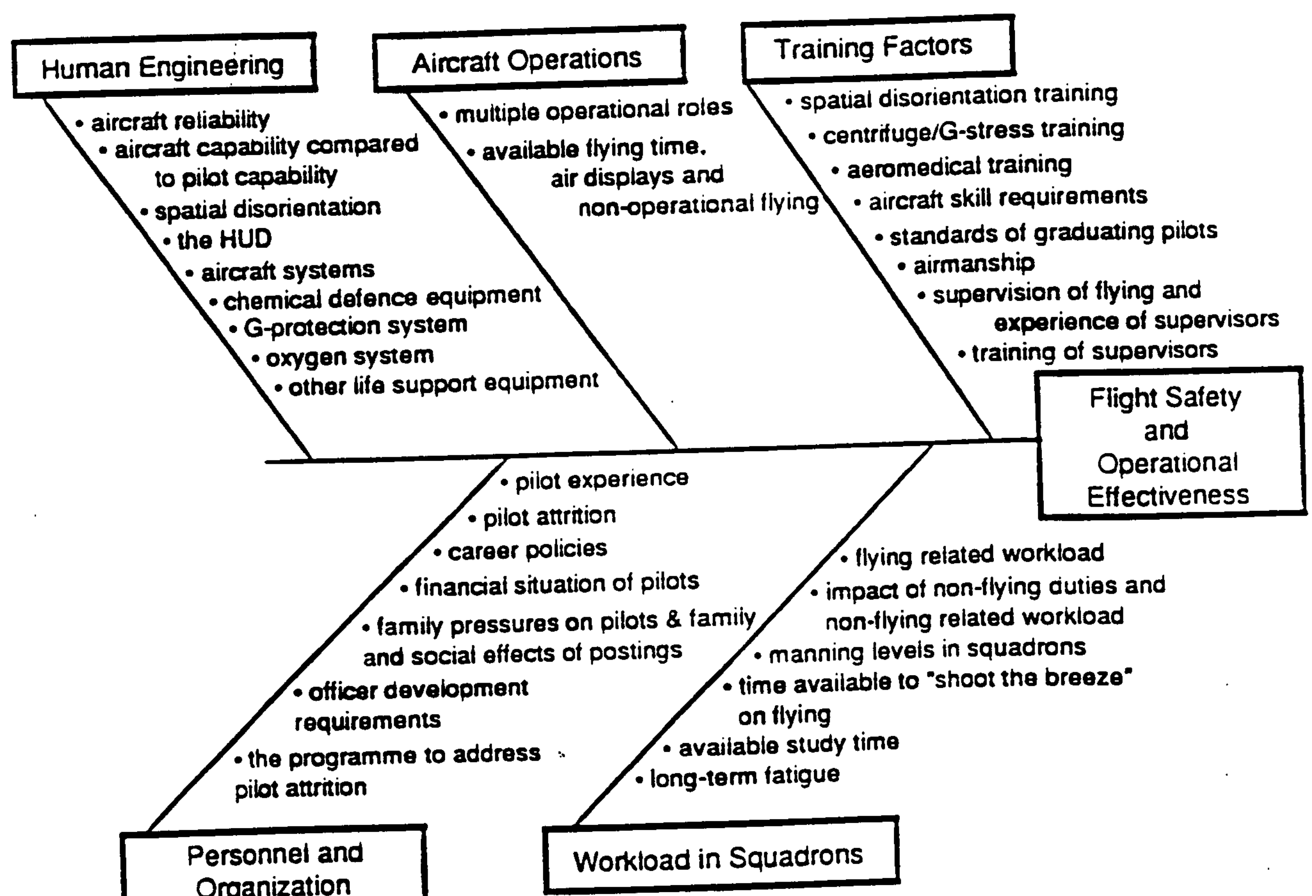

Figure 1.4: Factors found to influence flight safety and operational effectiveness (after Davidson et al., 1991)

1.2 THE OVERALL CONCEPT: THE SYSTEMS DEVELOPMENT PROCESS

8. In the development of military systems and equipment, human factors (human engineering, manpower, personnel, training, system safety and health hazards) must be included in the larger concept of the life cycle of the product. Several project management programmes have been developed for the integration of human factors with other systems design factors. Typical programmes include MANPRINT, developed by the US Army, IMPACT, developed by the US Air Force, and the human-systems integration programme being developed by the US Department of Defense. Other nations within NATO, including France, FRG, and UK, are adopting similar approaches which are being studied by NATO AC/243 Panel 8 RSG 21. These management programmes address manpower, personnel, training, safety and health hazards, and human engineering, to improve system performance, reduce human error, and minimize related costs (Booher, 1989).

9. Recently the systems development process has also expanded to include disciplines such as Concurrent Engineering and Total Quality Management. Concurrent Engineering focuses on the iterative character of the design process. The aim is to have designers consider the system throughout its life cycle, from project initiation to system disposal, taking into account all systems elements with regard to operation, maintenance, production and logistic support, as well as quality, costs schedules and user requirements (Winner et al., 1988). Human engineering can support this approach because the study of system operation and maintenance issues is central to human engineering activities. Total Quality Management (TQM) is an approach which seeks to minimize the variance in the quality of products through gearing the attitudes of personnel involved in the design and production process towards quality consciousness. Improved design techniques are conceived as results of these attitude changes (Demming, 1982). Human engineering can support the TQM approach by helping to identify the characteristics of the users and their requirements for systems and equipment. Human engineering can also contribute to TQM by identifying those features of human operator performance which contribute to variance in the system product or output, for example, reaction times, the correctness of procedures, correctness of operator decisions, or magnitude of operator errors.

10. The starting point of the systems development process for both equipment and personnel is the identification of operational needs of the system to be designed. System engineering transforms the operational need into a system description by following a series of steps involving analysis, synthesis, trade-off studies, and simulation and test. Although systems engineering texts do not agree on terminology, the essential steps (from Chambers, 1986) are :

- mission requirements analysis
- functional analysis
- function allocation
- synthesis of a system concept
- logistic engineering
- life cycle cost analysis
- optimization (including trade-off studies, cost effectiveness studies, and effectiveness modelling)
- generation of specifications

11. The systems development process seldom starts from an operational requirement to develop a system description by analysis alone. Usually, some concept of the system exists, for example, as the idea of an attack aircraft, or a sea-based surveillance system, or an existing

stem concept which can be upgraded or improved. As the systems engineers decompose the stem requirements and synthesize the system specification, they repeatedly check the results of eir analyses against their original concept, and modify the latter where necessary. A system (or roduct) exists in different forms at different stages of development (need, virtual, real and perational - Papin, 1992). The transition from one stage to another is a function of the evelopment process. That process involves different activities (analysis, specification, design, ıanufacture, evaluation, and use) (Fig. 1.5). The goal of this report is to review the techniques sed for the analysis of human-machine systems, from mission requirements analysis through to ıe generation of specifications.

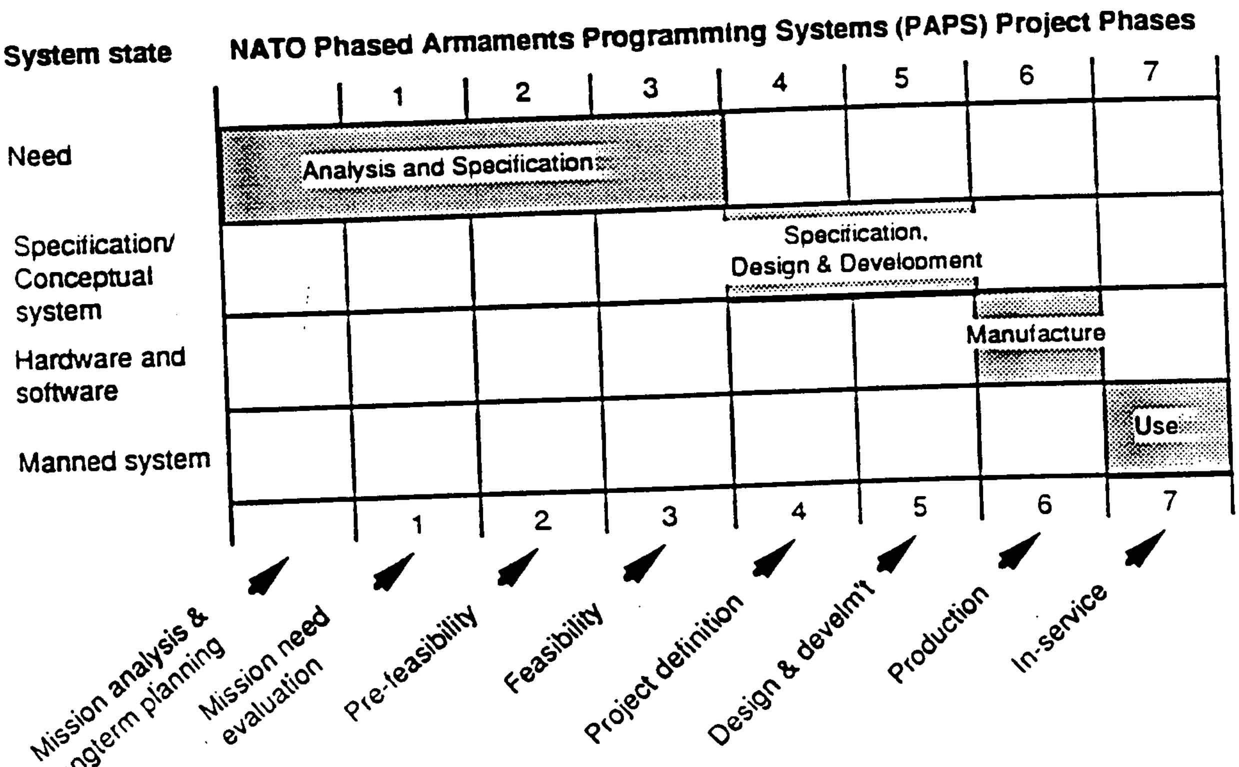

Figure 1.5: The system development process

12. Engineers and human engineering specialists have had a growing interest in accounting for human performance in system effectiveness. Both groups of specialists have developed tools for predicting human-machine performance. Engineers supply disciplines such as cybernetics, control theory and work study, while human engineering specialists use specific design methods, information theory, operational research and, in particular, test and evaluation methods, to account for human factors and human variance. The key to the involvement of human engineering in the systems development process is the description of human performance in ways which are compatible with the other engineering activities.

13. Approaches to describing human performance include real world observations, field studies, man-in-the-loop-simulator studies, laboratory experiment, and pure computer-simulation studies including simple representations of human behaviour. The first two approaches, which are relevant to both new and old systems, have the common drawback that they fail to consider and control an unknown number of variable factors which affect behaviour. Obviously, the

conditions in which real world observations and field studies are made are very close to actual operations. This is true to a lesser extent for simulator studies (see Fig.1.6). Generally, these approaches (real world observations and field trials) are suited to description and analysis of the mission, incidents and accidents and the operator's activities. Simulator and laboratory experiments are aimed at prediction of performance for routine and emergency conditions under controlled environmental conditions, but have the drawback of doubtful generalization from the artificial test conditions to reality.

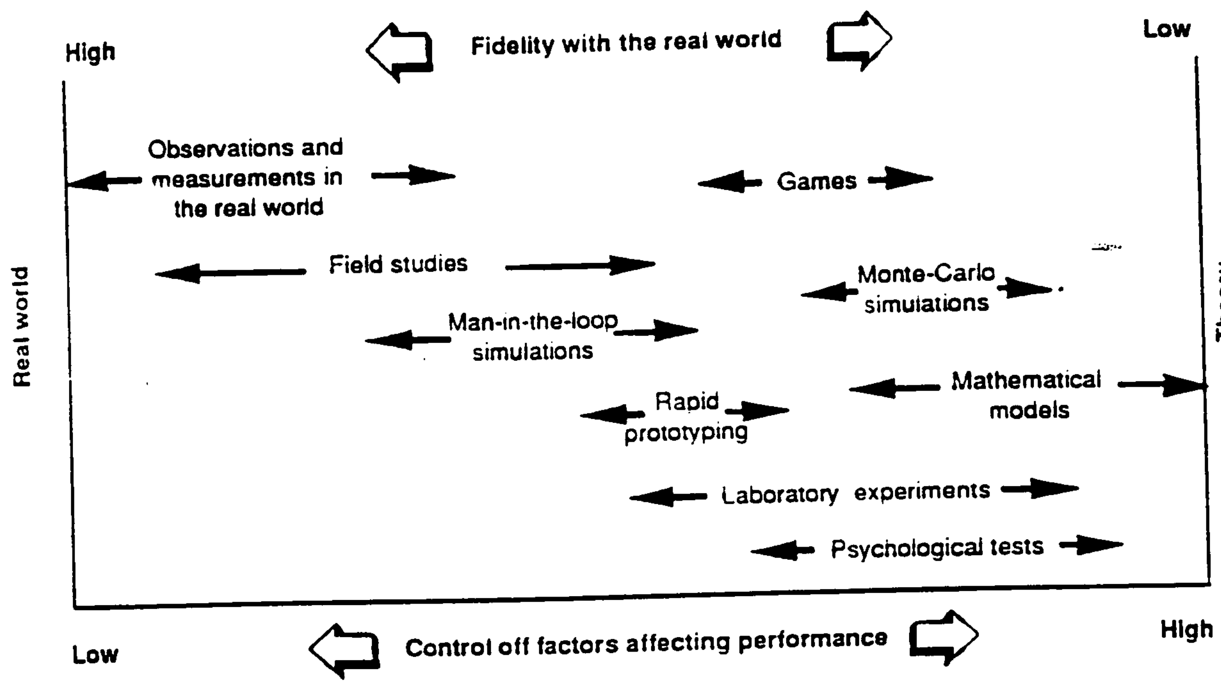

Figure 1.6: Hypothetical relationship between conditions to measure human-machine performance and control of factors affecting performance.
(after Chapanis & Van Cott. 1972)

14. From a methodological viewpoint there would be an optimum in simulator experiments, which have sufficient representation of the real world to generalize results for practical conditions and are sufficiently controlled to allow the interpretation of results. This type of experiment offers the opportunity to judge human variance in performance relative to the variance due to the use of alternative pieces of equipment, procedures, etc. Rapid prototyping involves the use of representations of human-machine interfaces in quasi-realistic scenarios. At the right hand side of Figure 1.6, representing the extreme of abstraction from the real world, are the pure computer-simulation studies which model human behaviour in a deterministic or stochastic way. Simulations using mathematical models may incorporate human characteristics, including a certain randomness in performance. In essence, however, models remain deterministic/stochastic and can reveal "unpredicted" interactions of behaviour with equipment to only a limited extent. Human performance models have been reviewed by another Research Study Group of NATO DRG Panel 8 (see McMillan et al., 1989; 1991).

15. From the systems engineering viewpoint, however, most activities in systems design/development involve analysis and synthesis of a design solution. Therefore, this report concentrates on human engineering analysis techniques. Those analyses can identify the human

tasks which may require close examination by field trials, simulation, experiments or mathematical modelling. As reported by Lovesey (Fig. 1.7), the estimates of a system's effectiveness are degraded successively from concept through field trials and initial introduction into service to routine and wartime operations. Appropriate use of human engineering in the overall design of a system will help to produce designs that are more compatible with the capabilities and limitations of personnel, thereby reducing the inevitable degradation in performance from system concept to the combat environment.

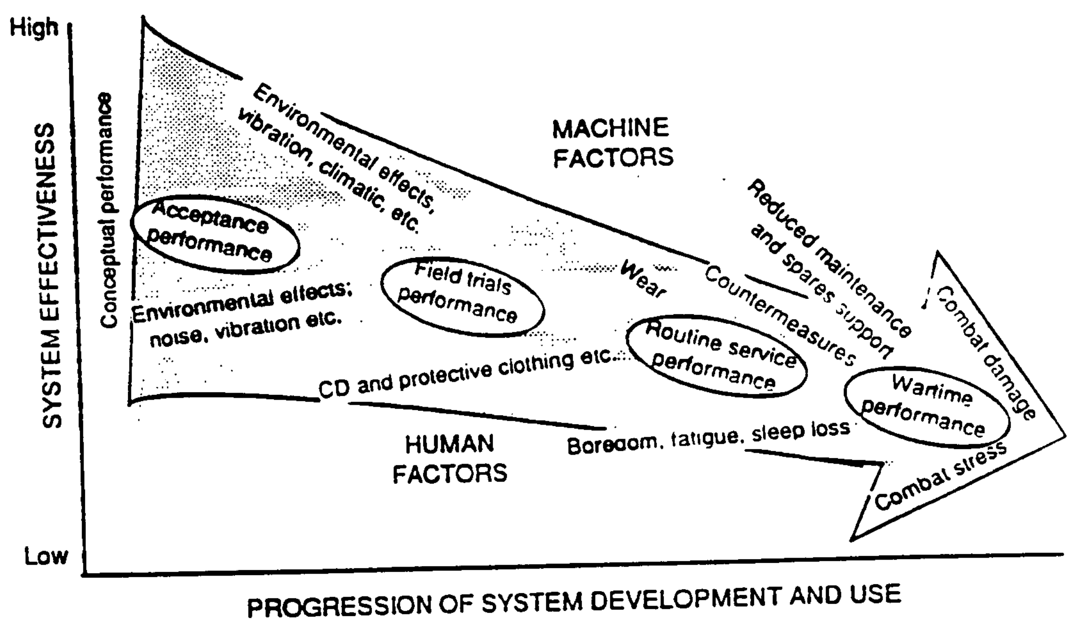

Figure 1.7: Some factors causing operational degradation (after Lovesey, 1987)

1.3 HUMAN ENGINEERING TECHNIQUES

16. Table 1.1 gives an overview of the main human engineering design steps in the systems development process (U.S. NAVSEA, 1990). These parallel the essential steps in systems engineering. When a system or equipment is being modified, without this being classified as a mid-life improvement, some of the early steps are not carried out fully, or may be omitted. The sequence of human engineering analyses follows the same general pattern as systems engineering, including: mission analysis, function analysis, function allocation, task analysis, and performance prediction. This human engineering process was recommended for adoption in the NATO Land Operations Study (NATO DRG, 1981). The sequence of analyses has been formalized in NATO STANAG 3994 AI (Application of human engineering to advanced aircraft systems) (NATO MAS, 1991). Some of the steps associated with human engineering analyses have been documented by NATO Naval Armaments Group Information Exchange Group 6, Sub-Group (IEG-6, 1991).

17. As noted in para. 11, a concept of the system may well have been established prior to any analysis being undertaken. Because of this, many designers and engineers have difficulty understanding the need for analysing systems from a functional viewpoint. The importance of such an approach is that it permits engineers and designers to look at the system concept in new ways, by identifying the functions which must be performed, rather than by identifying the

Table 1.1: Human factors/ergonomics steps during manned systems design
(after Pearce, 1990)

- Evaluation of "lessons learned" data
- Identification of prerequisites
- Determination of operational requirements

- **Mission analysis**
- **Function analysis**
- **Analysis of available operator/maintainer capabilities**
- **Function allocation**
- **Task analysis**
- **Man-machine interface requirements analysis**
- **Workload analysis**

Techniques reviewed in this report

- Identification of manpower requirements
- Verification of concordance with prerequisites
- Identification of training requirements
- Workspace/workplace requirements analysis and determination of workspace/workplace design parameters
- Environmental requirements analysis and determination of environmental design parameters
- Design of man-machine interfaces and job aids
- Implementation of habitability requirements
- Design of training programme
- Evaluation of operability/maintainability/supportability
- Preparation of "lessons learned"

sub-systems which may be required. This change of viewpoint (see Fig. 1.8) is particularly important if novel system designs are to be developed, for example, a tank with reduced manning, or a system with improved maintenance. If a function-oriented view is not taken, then development from one generation of system to the next will be evolutionary, rather than revolutionary. Even if revolutionary changes are not required, the quality of design is improved by taking a functional viewpoint.

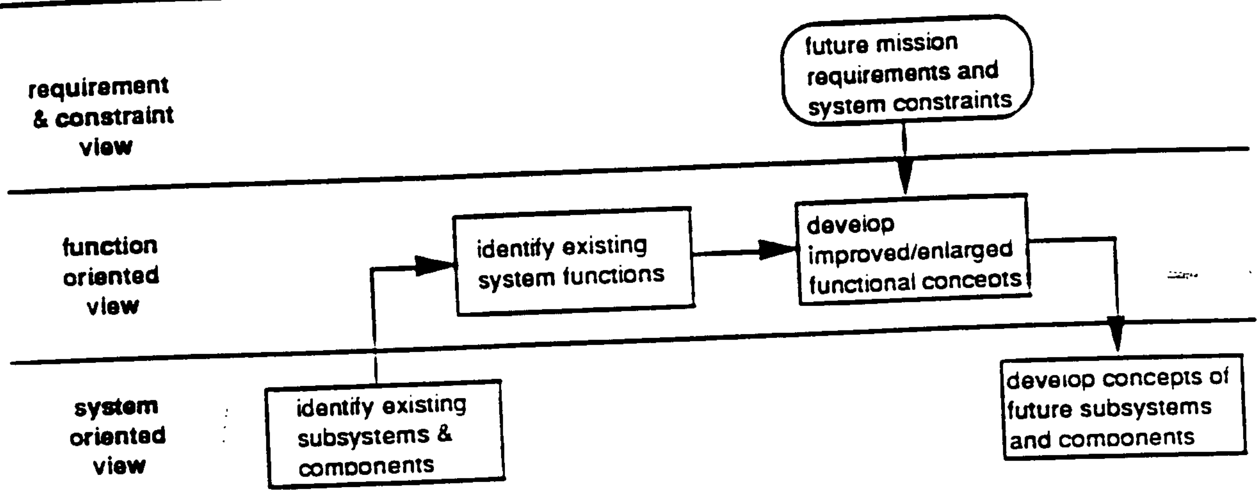

Figure 1.8: System and function viewpoints on development (after Haberfellner, 1978)

18. The design/development process should be iterative (Döring, 1983; Meister, 1985). This means that mission and function analysis, allocation of functions, and determination of tasks and interface requirements are repeated several times in the course of synthesis, analysis or design of the system (see Fig. 1.9). By analyzing the mission, system functions are determined. The analysis of system functions leads to functional requirements which are the basis for allocating the functions to humans and machines. The detailed function analysis identifies the task performance required of the operator and the required machine processes. Finally the analysis of the operator tasks and the machine processes gives the data for work station design, work environment design, workload evaluation, and personnel selection and training.

19. Despite the similarity in aims and procedure, human engineering analyses are not always conducted concurrently with other systems engineering activities. In current practice, the system concept is often developed well beyond the point of function allocation before human factors issues are considered. This makes the human engineering function allocation analyses of little value. Yet the increasing levels of automation in current systems make it more important that the roles and functions of the human operators been analyzed in detail. One of the aims of this report is to highlight those human engineering activities and analytical techniques which have a strong link to current developments in systems engineering, particularly the increasing use of structured analysis and design techniques for software development.

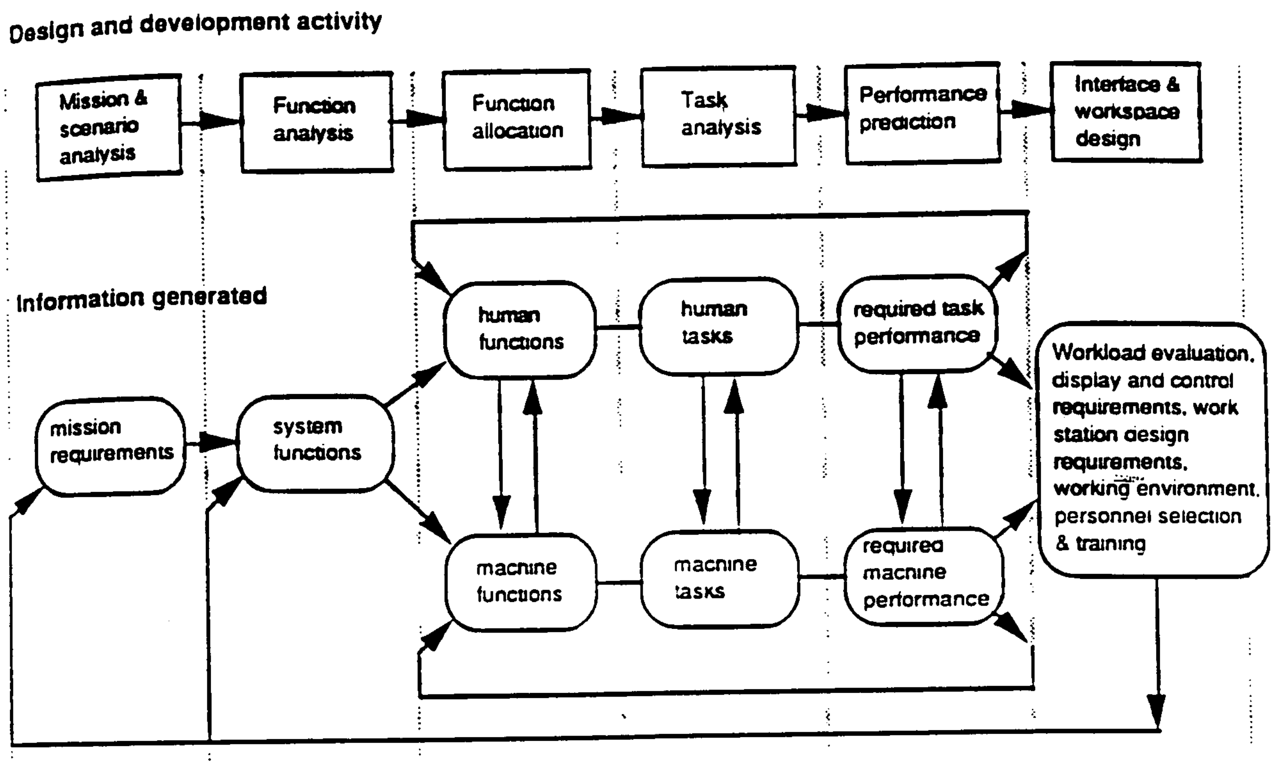

Fig.1.9: The systems ergonomics approach (after Döring, 1983)

1.4 TERMS OF REFERENCE

20. Despite a growing interest in the application of human engineering, there are few guides for either project managers or practitioners. In his report on "A Survey into the Response to a Proposal for the Distribution of Human Engineering Data to NATO Countries," Hardy (1975) recommended that "action be instigated to produce suitable (human engineering) handbooks" to help engineers and designers become familiar with human engineering principles and data. In a more thorough review of "Applications of Systems Ergonomics to Weapon System Development" a NATO DRG Panel 8 workshop concluded that existing human engineering techniques were not easy to use, and were not being used widely (Merriman et al., 1984).

21. Subsequently Research Study Group 14 was formed with the following terms of reference:

(a) To review the state of knowledge of analytical techniques for Mission Analysis, Function Analysis, Function Allocation, Task Analysis and Performance Prediction that are appropriate to the design of new weapon systems.

(b) To evaluate such analytical methods for their effectiveness, reliability and ease of use.

(c) To stimulate co-operative efforts for improving existing methods, for determining areas where new techniques are needed, and for developing new techniques where necessary.

(d) To recommend courses of action for improving the standardization of techniques for human-machine system design.

22. The RSG conducted a survey among major contractors and human factors specialists in each of the member nations, to sample the rate of use of "standard" human engineering analysis techniques and user experience with them. Following this survey, the RSG confirmed the following plan of work:

- Review existing analysis techniques, and the use made of them, and their compatibility with engineering processes.
- Review the limitations of existing techniques, and the need for new or improved techniques.
- Prepare examples to aid analysts in compiling system functions.
- Compile a directory of experienced analysts who can act as resource persons.
- Prepare recommendations for the standardization of human engineering/ergonomics analysis techniques.
- Produce a report based on the above work.

1.5 REFERENCES

1. Booher H.R. (Ed) (1990). MANPRINT: An approach to systems integration. New York: Van Nostrand Reinhold.
2. Chambers, G.J. (1986). The system engineering process: a technical bibliography. IEEE Transactions on DSMC. (5) 712 - 722.
3. Chapanis, A. & Van Cott, H.P. (1972). Human engineering tests and evaluations. In: H.P. Van Cott & R.G. Kincade (Eds.), Human engineering guide to equipment design. Chapter 15. New York: Wiley-Interscience.
4. Davidson, R.A., Beevis, D., Buick, F., Donati, A.L.M., Kantor, L., Bannister, S.H.R., Brook. E.A., Rochefort, J.A.P., & Turner, J.R. (1991). Human factors in the CF-18 pilot environment. (Report 91-11). Toronto: DCIEM.
5. Defense Systems Management College (1990). Systems engineering management guide. Washington, D.C.: U.S. Government Printing Office.
6. Demming, W.E. (1982). Quality, productivity and competitive position. Cambridge MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study.
7. Döring, B. (1983). Systems ergonomics, an approach for developing well-balanced, cost-effective man-machine systems. In: The human as a limiting element in military systems. Vol. 1. (NATO DRG DS/A/DR (83)170), Brussels: NATO Defence Research Group.
8. Haberfellner, R. (1978). Lebebsphasen eines systems. In: W.F. Daenzer (Ed.), Systems engineering. Koeln: Peter Hanstein Verlag Gmbh.
9. Hardy, (1975). A survey into the response to a proposal for the distribution of human engineering data to NATO countries. (Panel VIII EG Report), Brussels: NATO Defence Research Group.

10. Horne, R.Adm. R. (1990). Address to NATO AC/243 Panel-8/RSG.14. Washington D.C.: U.S. Naval Sea Systems Command.
11. Lovesey, E.J. (1987). An attempt to quantify some factors that affect the operational effectiveness of a system. Applied Ergonomics 18 (4), pp 305 - 310.
12. McMillan, G.R., Beevis, D., Salas, E., Strub, M.H., Sutton, R. & van Breda, L. (Eds) (1989). Applications of human performance models to system design. New York: Plenum. Defense Research Series Vol. 2.
13. McMillan, G.R., Beevis, D., Salas, E., Stein, W., Strub, M.H., Sutton, R., & van Breda, L. (1991). A directory of human performance models for system design. (Report AC/243 (Panel-8) TR/1), Brussels: NATO Defence Research Group.
14. Meister, D. (1985). Behavioral analysis and measurement methods. New York: John Wiley & Sons.
15. Merriman, S.C., Muckler, F., Howells, H., Olive, B.R., & Beevis, D. (1984). Applications of systems ergonomics to weapon system development. (NATO DS/A/DR(84)408). Brussels: NATO Defence Research Group.
16. NATO DRG (1981). LO/2000: Implications of new technologies for land operations in the NATO central region. (NATO AC/243-D/763: AC/243 (LTSS)D/30F). Brussels: NATO Defence Research Group.
17. NATO MAS (1991). Application of human engineering to advanced aircraft systems. (STANAG 3994 AI (Edition 1)), Brussels: NATO Military Agency for Standardization.
18. Papin, J.P. (1992). L'ergonomie de conception d'un produit. Anger, France: Direction des Armaments Terrestres, Service Facteurs Humains.
19. Pearce, F. (1990). Manned systems engineering in U.S. NAVSEA. Presentation to 7th meeting of NATO AC/243 Panel-8/RSG.14. Washington D.C.: U.S. Naval Sea Systems Command.
20. Winner, R.I., Pennell, J.P., Bertrand, H.E., & Slusarczuk, M.M.G. (1988). The role of concurrent engineering in weapon systems acquisition. (IDA R-338). Washington D.C.: Institute for Defense Analysis.

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CHAPTER 2
SURVEY AND REVIEW OF ANALYSIS TECHNIQUES

2.1 SURVEY OF USE OF HUMAN ENGINEERING ANALYSIS TECHNIQUES

23. To conduct the survey, human engineering analyses techniques identified in available human engineering guides and regulatory documents were categorized into one of five sequential stages of analysis. These stages were: Mission Analysis, Function Analysis, Function Allocation, Task Analysis, and Performance Prediction (Fig. 2.1). Twenty-four techniques described in human engineering guides were identified and assigned to one of these stages of analysis. The project phases used by the RSG member nations were identified and used to develop a common, five-phase, project development cycle. The phases were: Analysis of Existing Systems, Planning New Systems, Preliminary Design, Design, and Test & Evaluation. The five categories (stages) of human engineering analysis technique and the five project phases were used to create an applications matrix (Table 2.1). A questionnaire was issued to companies and organizations known to employ human factors specialists in the seven participating nations, asking them to identify those human engineering analysis techniques used in specific weapons system development projects, and to comment on their effectiveness, ease of use, and so on.

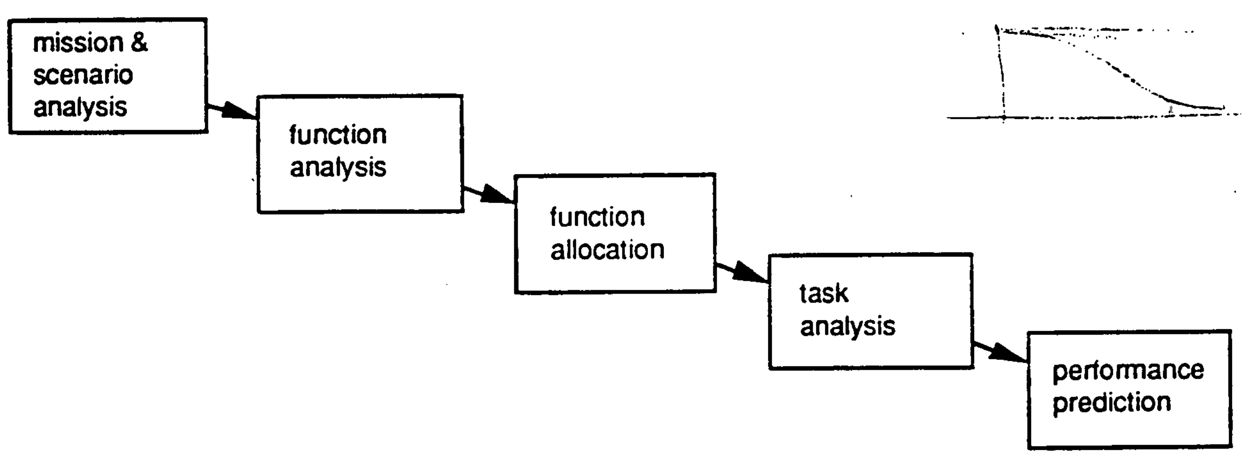

Figure 2.1: Stages of human engineering analysis

24. Responses were obtained for a total of 33 acquisition or development projects in the RSG member nations in which at least one of the 24 human engineering analysis techniques had been used. The projects included a wide variety of military systems: an infantry air defence system, tanks, aircraft, ships, submarines, and command and control systems. (No data were included from projects which did not use any human engineering techniques, as adding such data would reduce the sampled rate of application of each technique.) The rate and pattern of use of the human engineering techniques was found to differ widely between nations and between

individual users. The mean rate of use of the different classes of analysis technique is shown in Table 2.1. It was assumed that, for each project, at least one analysis technique would be used in each of the five stages (Mission Analysis, Function Analysis, Function Allocation, Task Analysis, and Performance Prediction). Thus, in theory, the mean rate (i.e., the number in each cell of Table 2.1) would be at least 1 and the column totals would be 5 or greater. (The total entries for all projects in any project stage would, therefore, be 165 (33 x 5).)

Table 2.1: Mean rate of use of different categories of analysis technique, in five project phases, in 33 projects (total for each category divided by 33)

Category of Analysis Technique Used	Project Development Phase					
	Analysis of existing systems	Planning new systems	Preliminary design	Design	Test and evaluation	Mean overall usage
Mission Analysis	.51	.54	.54	.48	.39	.49
Function Analysis	.7	.97	.97	.9	.48	.80
Function Allocation	.52	.9	.82	.76	.42	.68
Task Analysis	1.96	1.7	1.97	1.94	1.9	1.89
Performance Prediction	.9	1	1.18	.88	1.12	1.02
Mean across all stages	.92	1.02	1.1	.99	.86	.98

25. The overall usage rate reported is 98% of the expected value (162 entries out of 165 expected, or 4.89 out of an expected mean total of 5.0). This rate is the best estimate, because it does not include data from projects which did not use any human engineering analysis technique. In most countries the level of use for all techniques is significantly less than the expected value (from 54% to 78%) but the overall level of use is increased by data from the USA which show a level of use varying from 121% to 146%, depending on the project phase. This apparently higher level of use may be due to differences in reporting style. Several of the U.S. respondents reported general company capabilities, rather than use on specific projects. Differences between the expected and actual rates of use of the different categories of analysis technique are highly significant (X^2 test). Task analyses are reported almost four times more frequently than mission analyses and three times more frequently than function analyses: these differences are larger than reported previously, from a more limited survey (Beevis, 1987). The overall usage rate reported per project phase varied between 87% (test and evaluation) and 102% (preliminary design). It had been expected that the usage rates would vary widely across the five project phases, with most use being made of the analytical techniques for planning new systems and for preliminary design. In fact, the differences in reported rates of usage from one project phase to another are not significant (X^2 test).

26. The lower than expected usage rates pose the question of whether the techniques surveyed are really useful, particularly those for Mission Analysis and Function Analysis. De Greene (1970) noted that designers and managers tend to resist human factors analysis and that

in some cases that resistance is justified, citing the existence of "warehouses of useless task-analysis information." Users' comments about the effectiveness and contribution of the different analysis techniques varied widely, from "excellent" to "worthless, inaccurate nonsense." The comments on any one technique also ranged widely, for example, from "very high contribution" to "poor." This suggests large differences between applications or between the experience of the users. Only a few users commented on each technique, however, so that no specific conclusions can be drawn. Overall it appears that the potential contribution of some categories of technique is under-appreciated, and that some techniques require improvement.

27. The overall pattern of use of the techniques, illustrated in Figure 2.2, may be changing as users adopt techniques developed more recently than others. There were large differences between the rankings of the techniques from one country to another. In some countries there was a multi-project history of use of some techniques. In other countries the techniques had been used only in the most recent projects. Several respondents indicated that their use of some techniques was "exploratory." Overall, the techniques favoured by most respondents were Function Flow Diagrams, Narrative Mission Descriptions, Operational Sequence Diagrams, and Information Flow and Processing Analysis. The techniques least used were State Transition Diagrams, and Siegel-Wolf Simulation (of operator task-performance). Structured requirements analysis techniques such as SADT, CORE, and RDD, were also little used, but there were large rank order differences between user nations. Four other techniques had large rank order differences between nations. These were: Graphic Mission Profiles, Task Taxonomy (for task analysis), Input: Decision: Output: Feedback Tabulations (for task analysis), and Operational Sequence Diagrams (a task analysis technique).

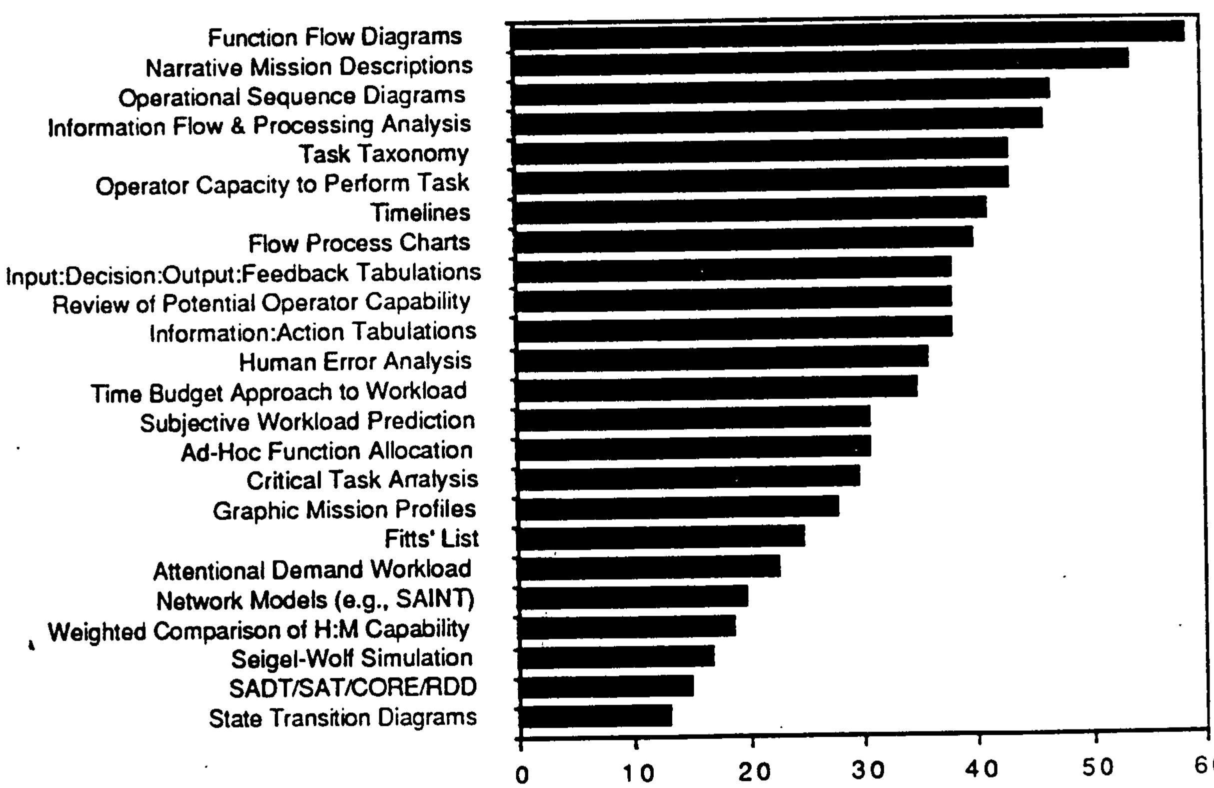

Figure 2.2: Overall number of applications of 24 human engineering analysis techniques in five phases in 33 projects

28. The application of these techniques in individual nations has been described elsewhere (Beevis, 1984; Behr, 1984; Döring, 1983; Kloster et al., 1989; Merriman et al., 1984; Papin, 1988, and Schuffel, 1984). Few data were obtained on the extent of use of the techniques in NATO projects. Use of available techniques appears to have been minimal, certainly at the concept development stage when such analyses can have the most impact. The NATO Frigate Requirement project (NFR-90) invited input for the development of a human engineering plan only when in its final stages. The early stages of the NATO Anti-Air Weapon System (NAAWS) project were completed without human engineering analyses, although assumptions had been made about the functions to be allocated to human operators.

29. The low rate of use of human engineering analysis techniques in NATO projects should be qualified with the observation that there has been little emphasis on such techniques in NATO publications. The NATO Ergonomic Design Guidelines (1982) do not mention them. Individual papers in AGARD symposia proceedings and reports have covered specific techniques (see for example Stringer, 1978). An AGARD Aerospace Medical Panel (AMP) study on the impact of future developments in electronic technology (Hunt et al., 1987) concluded that developments are needed in the area of crew station design methods to facilitate the inclusion of human factors issues. No single NATO publication has documented a complete set of techniques. This finding confirmed the intent of the RSG to document available techniques (see Volume 2 of this report).

30. The survey also obtained comments from users on the utility of the different techniques, and any limitations in their use. Several of the users' comments were common to different techniques. These included:

- the need to provide a high level of detail early in system development
- the need to reiterate and update analyses as designs evolve
- the lack of a good data base
- the lack of standardization

Three other comments were common to several of the techniques reviewed:

- they are labour-intensive and can take so long that they become out of step with the design/ development process
- there is need to develop computer programs supporting these different techniques, which make it easier to develop and modify the different analyses
- there is a high degree of subjectivity and/or experience involved in their use

31. The comments suggested that a more thorough understanding of the capabilities of the different techniques would be useful. The state of knowledge of the techniques did not appear to be very high in any nation (NATO RSG.14, 1988) although it is possible that some respondents were using some techniques under different names. In general, universities do not teach these techniques (Sanders & Smith, 1988), and the need to improve human factors education has been recognized (Hennesy, 1981). As is typical for other aspects of engineering and applied science, universities concentrate their teaching on the underlying sciences. Little information is available on how to practise human factors or human engineering (National Research Council, 1983). Those in industry who wish to use the techniques must train themselves. Possibly as a reflection of this situation, some users suggested that there should be a greater effort to foster the use of techniques which are already available, rather than developing new techniques.

32. Another suggestion, which reflected the experience of several members of the RSG, was that human engineering analyses should be integrated with other systems engineering activities. For example, the question "How was (the analysis) related to system performance requirements?" received a generally low response. Only 46%, 27% and 27%, respectively, of

the applications of the three most frequently used techniques reported how they related the results to system performance. Again this may reflect a deficiency of existing guides to human engineering, which do not make clear the connection with other engineering specialities such as systems engineering, reliability, logistics support, spares allocation, maintenance, training systems design, and test and evaluation. For those reasons, the RSG decided to concentrate its work on a review of existing human engineering analysis techniques and their compatibility with other engineering processes. See Volume 2 of this report for details of the individual techniques.

2.2 REVIEW OF HUMAN ENGINEERING ANALYSIS TECHNIQUES

33. As with many engineering specialities, human engineering is most effective if it is applied in the early stages of project development (Van Cott & Altman, 1956; Meister, 1985). Human engineering analysis techniques are applicable to those early stages through the analysis of the system concept. The techniques mentioned here, which are reviewed in Volume 2, are used for the analysis of system missions, functions and function allocation, the analysis of operator and maintainer tasks, and the requirements for human-machine interfaces. An additional category of technique, Interface and Workspace Design, has been included because of the importance of translating the task analysis information into a design (Fig. 2.3). It should be noted that not all possible analysis techniques are included in this report. The selection was dictated by the results of the preliminary survey, and by the experience of the RSG members and their colleagues.

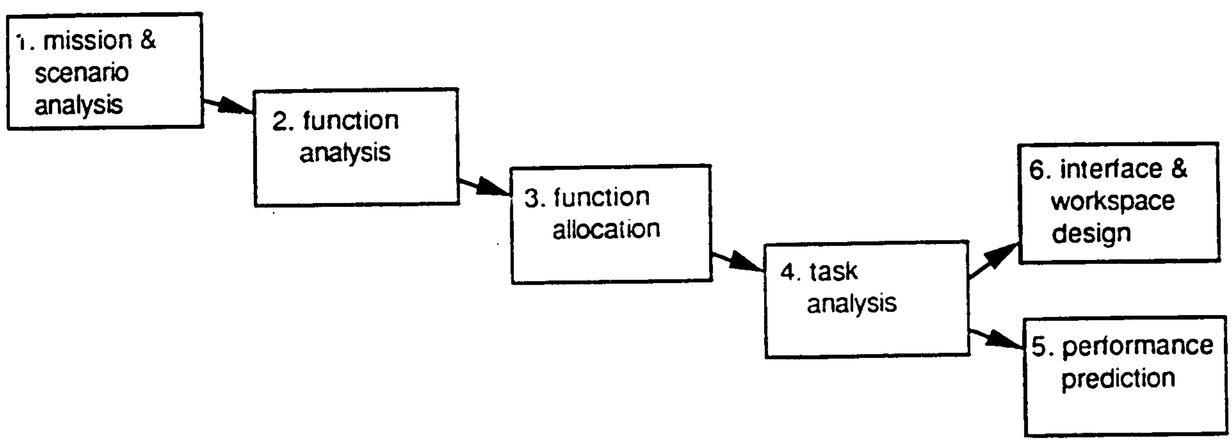

Figure 2.3: The sequence of human engineering analyses reviewed in the report

34. In this review the prediction of system performance and operator workload is approached only by analytical techniques. Those techniques, and task analysis in particular, can provide the basis for other human engineering or human factors activities such as mathematical modelling, experimentation, man-in-the-loop simulation or rapid prototyping, or field trials by defining performance requirements and identifying critical operator tasks. Those other human engineering activities (see Fig. 1.6) are not covered by this review. Mathematical models of human behaviour have been reviewed by another Research Study Group (McMillan et al., 1991). Man-in-the-loop simulator experiments, laboratory experiments, and techniques to simulate the environmental setting are beyond the scope of this review. It must be remembered, however, that the analytical approach assumes normative behaviour of operator and system.

Unpredictable effects due to the interaction of human behaviour (capabilities and restrictions) with the system in an uncertain operating environment are not identified by these techniques. In planning the human engineering activities for a project, the manager and the human engineering practitioner must consider how any analyses will be complemented by modelling, experimentation, simulation, or trials.

35. The sequence of analyses shown in Figure 2.3 represents a steady development of detail about operator and maintainer tasks, starting from the operational requirement and ending with the task analysis, performance prediction, and interface and workspace design. This sequence of analyses feeding into design activities parallels that of systems engineering in general (Fig. 2.4). The systems engineering approach has been defined as "a process that involves the application of appropriate scientific and technical knowledge:

(1) to transform an operational need into a system configuration with defined parameters, through an iterative process of analysis, design, test, and evaluation;
(2) to integrate all performance requirements, including reliability, maintainability, supportability, etc. into the total engineering effort; and
(3) to integrate related components to insure interoperability and optimum system performance." (Diamond, 1989).

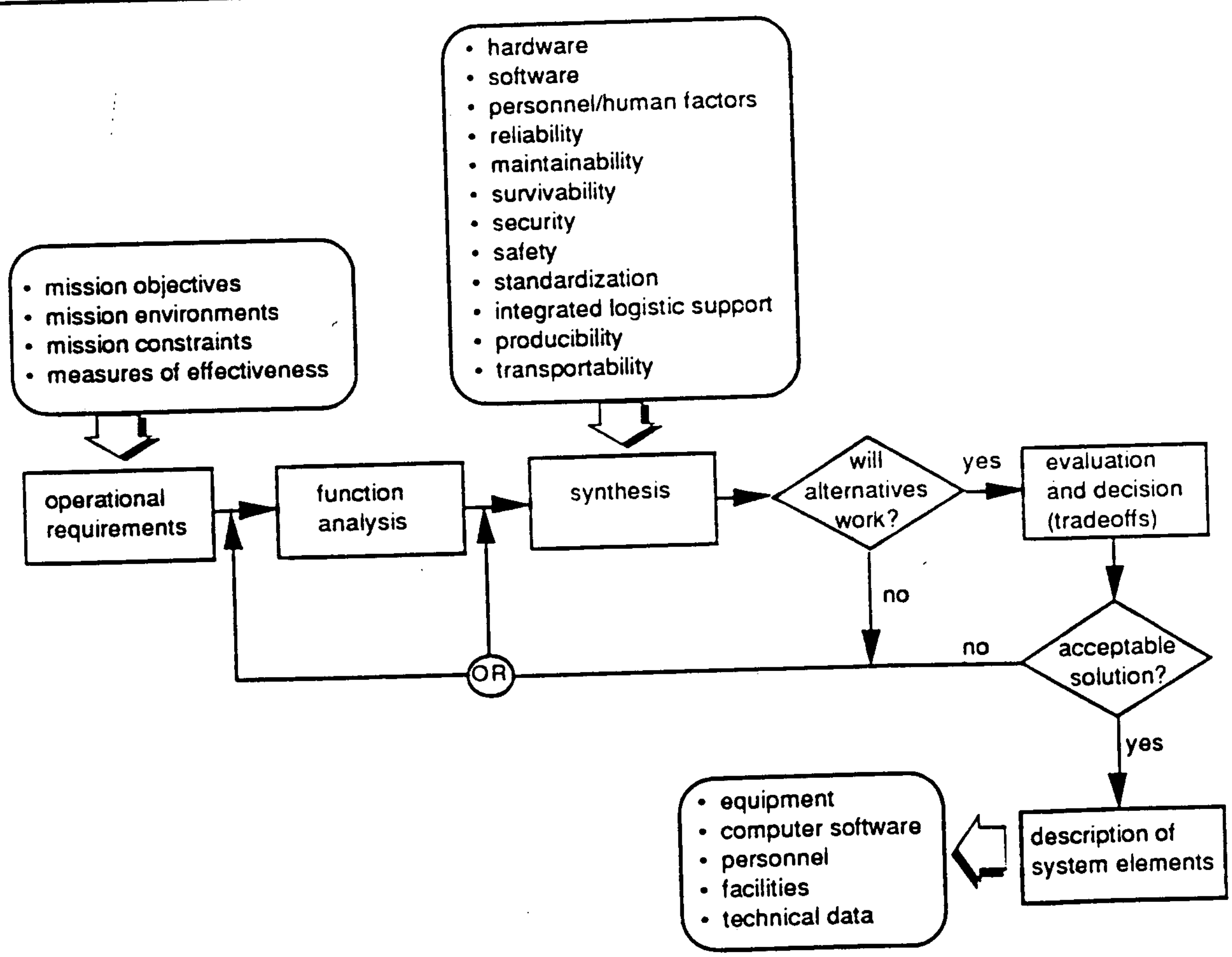

Figure 2.4: The systems engineering process
(after Defense Systems Management College, 1990)

36. The human engineering activities shown in Figure 2.3 are associated with the systems engineering activities shown in Figure 2.4. As shown in Figure 2.5, the sequence follows the iterative systems engineering process of analysis, synthesis, testing if the alternatives will work, and changing the allocation of functions, or the operator or maintainer tasks, to ensure that the operational requirements for the system are met. Thus, although the human engineering techniques are analytical, in the sense that they break down information about operator and maintainer activities and identify their components, the techniques are used in the context of synthesizing a system design solution. Each of the major classes, or stages, of analysis is reviewed in the next section, and reviews of specific techniques in each class are contained in Volume 2 of this report.

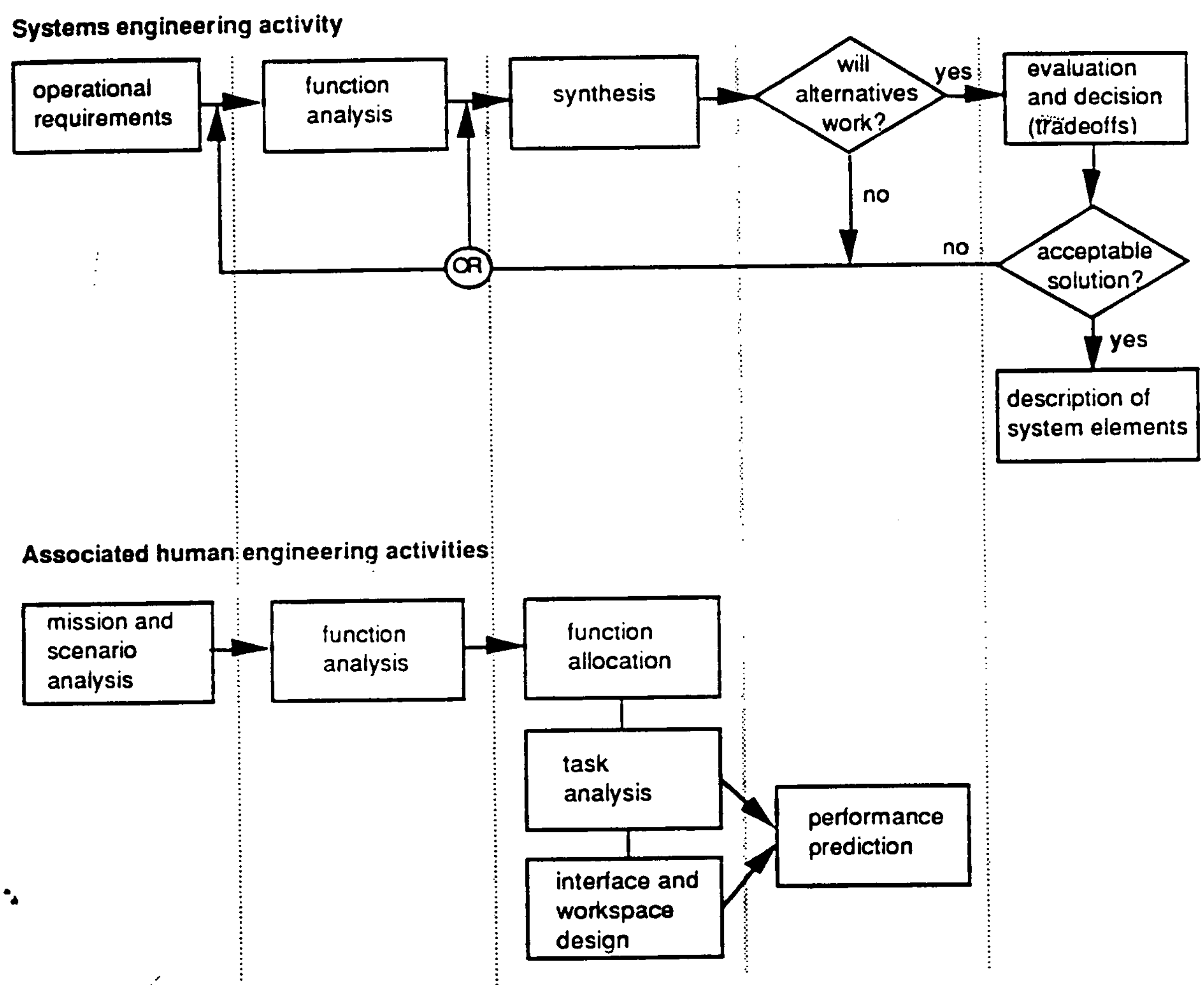

Figure 2.5: Human engineering activities associated with systems engineering

2.3 OVERVIEW OF HUMAN ENGINEERING ANALYSIS TECHNIQUES

37. Thirty-one human engineering analysis techniques, including most of the techniques reported by survey respondents, are reviewed to a standard format in Volume 2 of this report. The following is an overview of the six classes of technique reviewed.

2.3.1 Mission and Scenario Analysis

38. These analyses define the overall requirements of the system under development, in terms which provide information for subsequent human engineering analyses. They are used to define what the system must do (the operational requirements) and the circumstances and environment in which it must be done. Two techniques were reviewed:

- Narrative mission descriptions
- Graphic mission profiles

2.3.2 Functional Analysis

39. Functional analysis is an essential step in the systems engineering process. Analyzing the system in terms of the functions which must be performed, rather than in terms of a set of specific sub-systems, has become increasingly important as the software component of systems has grown. Complex modern systems are high on functionality but low on in-place objects (Tooze, 1989). For example, a menu-driven human-computer interface can make hundreds of control functions available to the user though two controls: a rollball (or joystick or mouse) and a selection key. Functional analysis has demonstrated value for coordinating the activities of system engineering and engineering specialists. Seven techniques were reviewed:

- Function flow diagrams
- Sequence and timing (SAT) diagrams
- Structured analysis and design technique (SADT)
- Information flow and processing analysis
- State transition diagrams
- Petri nets
- Behaviour graphs

2.3.3 Function Allocation Analysis

40. Typically, decisions about the functions performed by system operators and maintainers are made implicitly in the design process, or through the selection of equipment and software. Such decisions are made without systematic consideration of their impact on the roles, functions, and tasks of the human components of the system. A rational allocation of functions to people (liveware), hardware, or software is necessary for optimal system design. Function allocation analyses provide the basis for subsequent efforts relating to crew or operator task analysis and description, operator workload analysis, display and control selection or design (including communication systems design), and crew station design, development, and evaluation. In particular, decisions on the allocation of functions have a significant effect on crew or operator workload, system performance, manning, selection, and training requirements. Five techniques were reviewed:

- Ad-hoc function analysis
- Fitts' list
- Review of potential operator capabilities
- Function allocation evaluation matrix
- Requirements Allocation Sheets (RAS)

2.3.4 Task Analysis

41. Task analysis is one of the most common activities of the human engineering specialist. A completed task analysis specifies the activities of the operator, in the same way that other analyses specify what it is that the system hardware and software do. As illustrated in Figure 2.6, task analysis is central to the design of the system. For example, task analyses are used to implement performance prediction efforts which confirm or modify assumptions made about operator performance and the distribution of workload, whether between man and machine through automation, or between personnel in a multi-operator system. Task analysis also provides the basis for the requirements for the operator and maintainer displays and controls (the human-machine interfaces and workspaces), as well as information for training system development and procedures manuals.

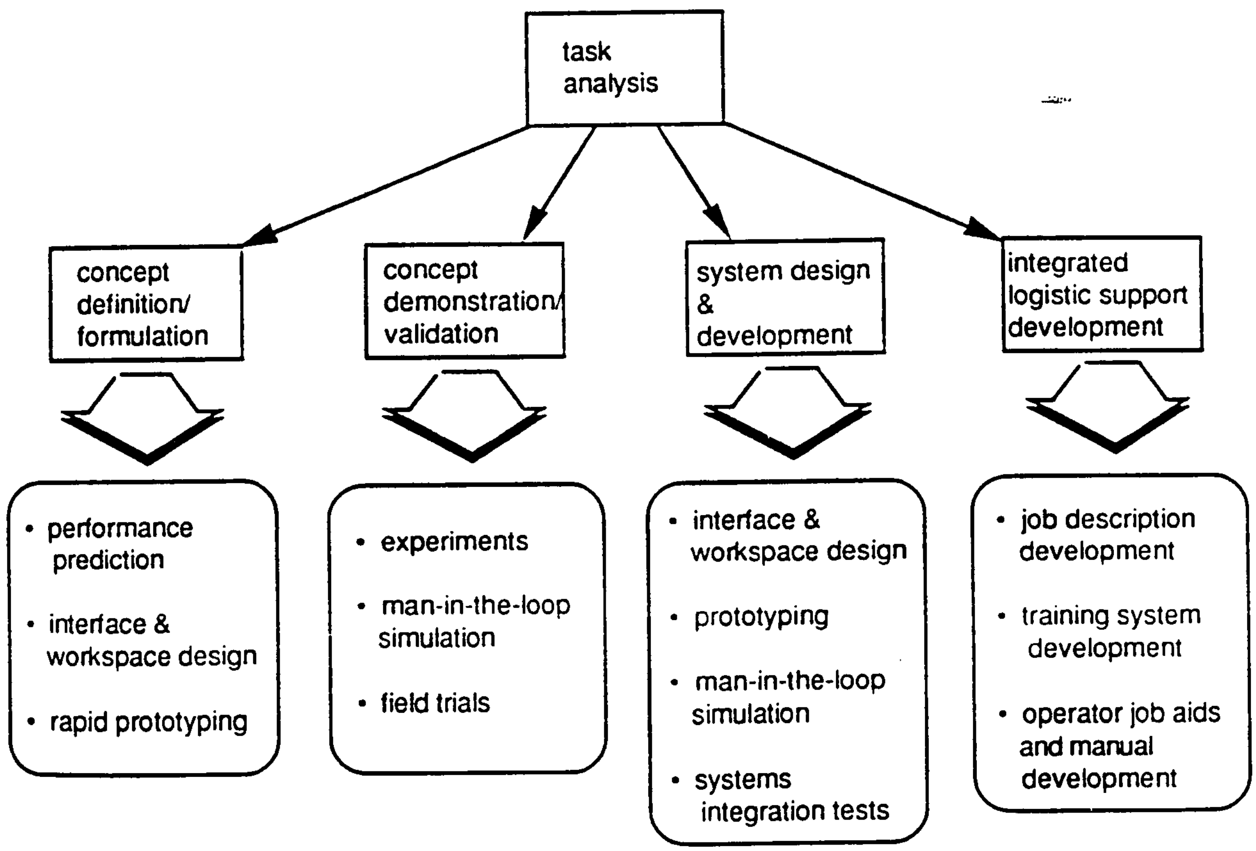

Figure 2.6: The contribution of task analysis to system development

Six task analysis techniques were reviewed:

- Time lines
- Flow process charts
- Operational sequence diagrams (OSDs)
- Information/action or Action/information tabulations
- Critical task analysis
- Decision tables

2.3.5 Performance Prediction

42. These techniques are used to predict how well the operator(s) will perform their assigned tasks once they have been defined by the techniques reviewed in the previous section. As shown in Figure 2.5, performance prediction is the means by which analysts can verify that the proposed system will work. To predict performance, some system concept must have been developed, as shown in Figure 2.5, because estimates of operator task times, probabilities of completion, or error are dependent on the features of the human-machine interface. Performance prediction, task analysis, and interface and workspace design are closely interelated, (Fig. 2.7) Performance prediction links the results of mission, function, and task analyses directly to system performance criteria by providing measures such as time (Time line analysis, SAINT, SIMWAM), probability of successfully completing a task (SAINT, SIMWAM, Error analysis) or operator workload (SAINT, SIMWAM, SWAT, NASA TLX). Eight techniques were reviewed, including two generic descriptions (Subjective Workload Ratings and Error analysis):

- Time line analysis of workload
- Systems Analysis by Integrated Networks of Tasks (SAINT)
- Simulation for Workload Assessment and Modelling (SIMWAM)
- Subjective workload ratings
- Subjective Workload Assessment Technique (SWAT)
- NASA Task Load indeX (TLX)
- Error analysis
- Analysis of human errors as causal factors in accidents

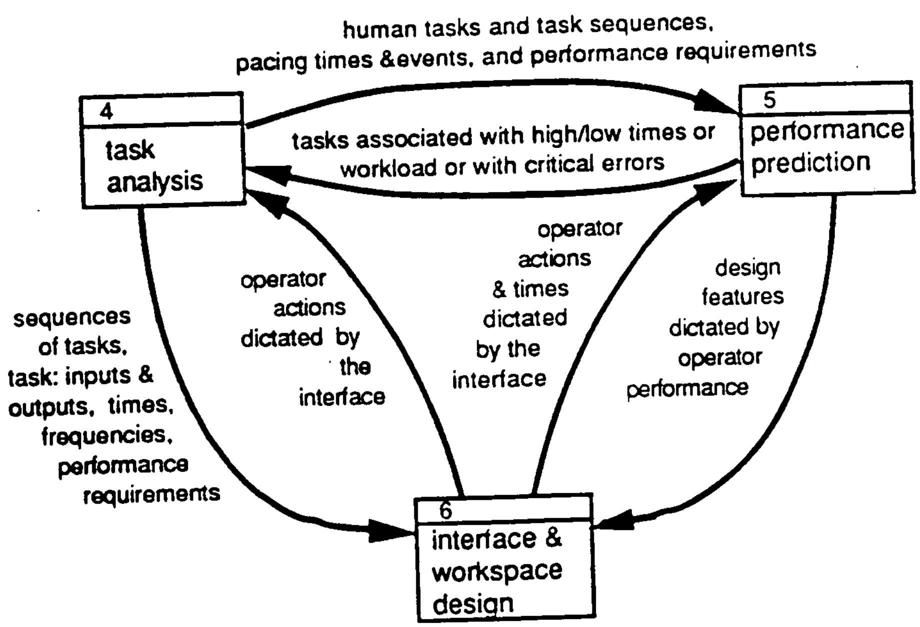

Figure 2.7: Relationship between task analysis, performance prediction and interface and workspace design

2.3.6 Interface and Workspace Design

43. The final goal of the human engineering analyses outlined above is to produce design drawings and specifications for an effective human-machine system. Task analyses specify what the system or equipment operators and maintainers will have to do: they have to be transformed into specifications for the displays and controls that the operators and maintainers will use and for the workspace in which they will do it, taking into account relevant human factors knowledge (see Fig. 2.8). Because the design process is a creative one, involving both top-down and bottom-up reasoning, the translation of task analyses into design requirements cannot be defined as a simple paradigm. Three techniques which can assist the translation were reviewed:

- Design option decision trees
- Critical design requirements
- Link analysis

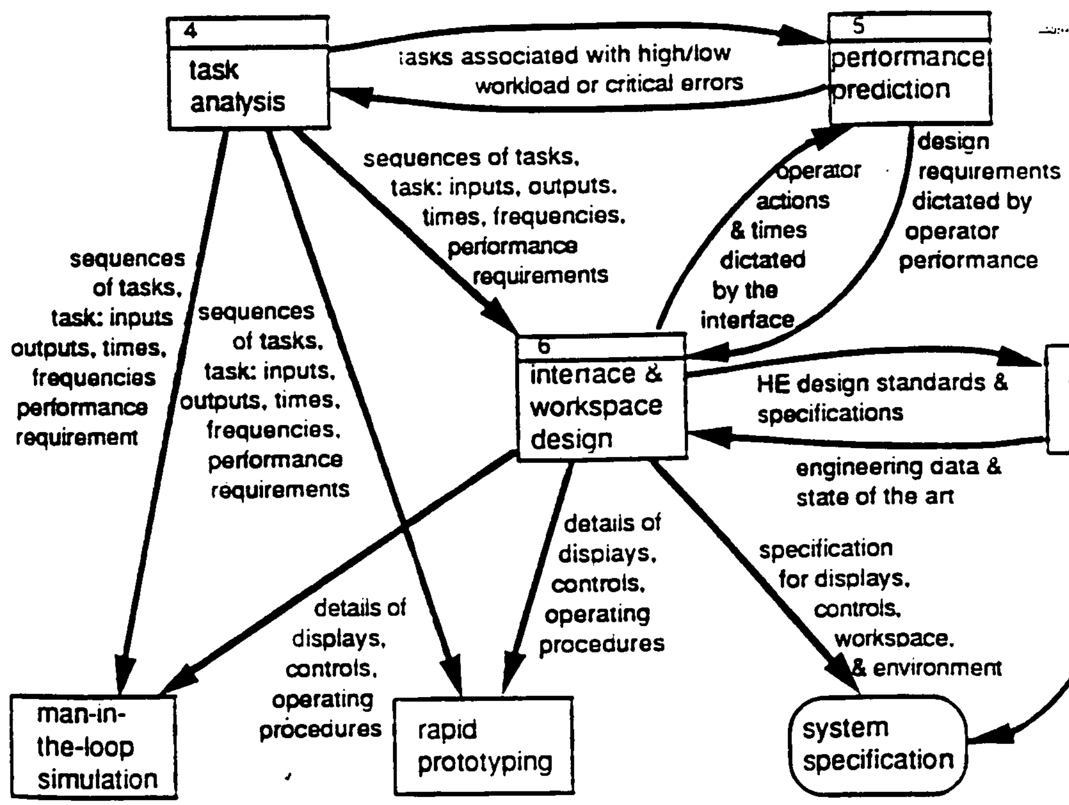

Figure 2.8: Flow of Information associated with interface & workspace design

2.3.7 Summary

44. Each of the six classes of human engineering analysis techniques introduced above and reviewed in Volume 2 is a stage in the development and verification of the system design. Each stage provides information for the subsequent stage, which, in turn, provides confirmation of some of the assumptions made in earlier stages of analysis. The flow of information from one

stage to the next is shown in Figure 2.9.

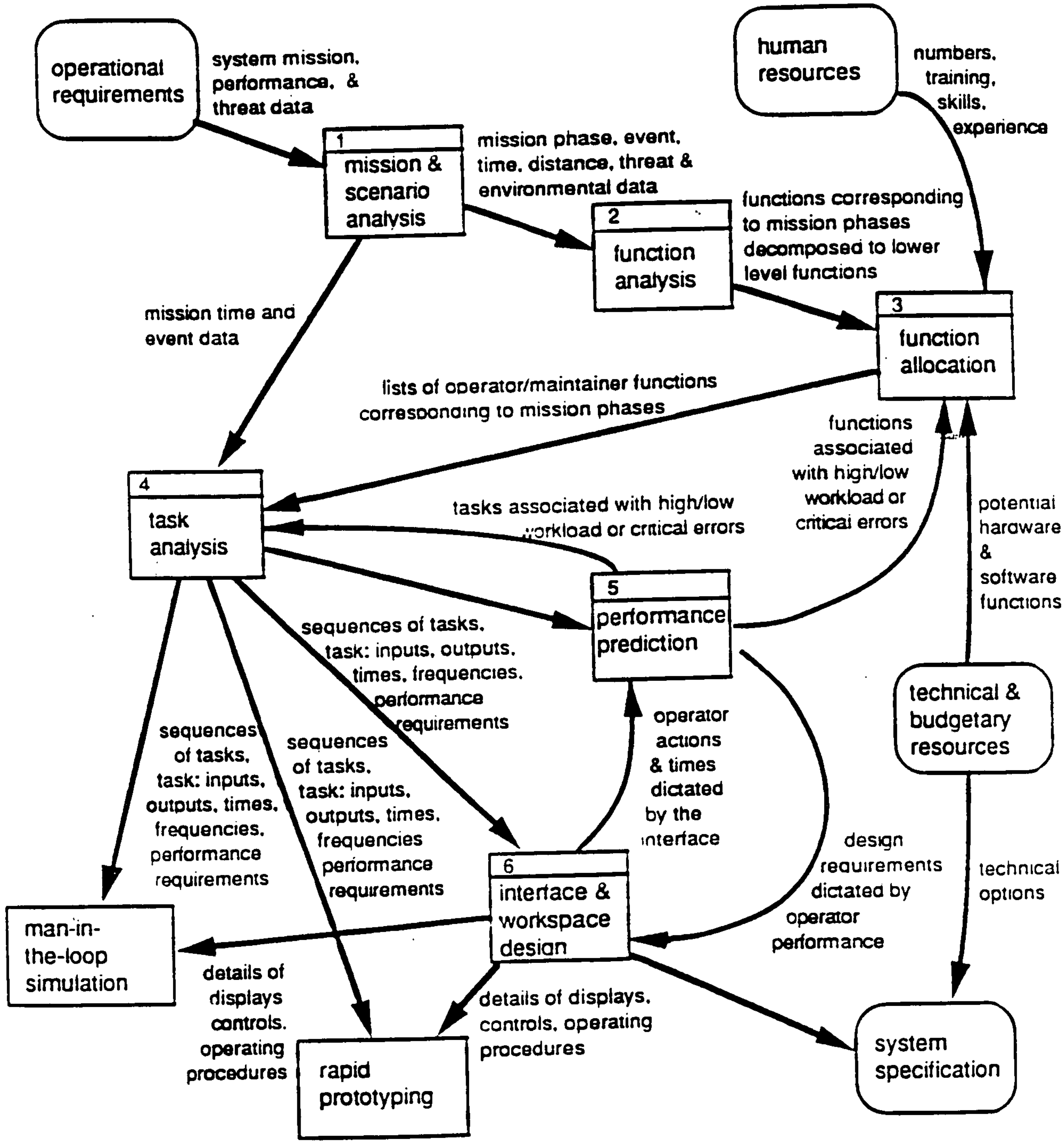

Figure 2.9: Flow of information generated by the six stages of human engineering analysis

2.4 APPLICABILITY OF TECHNIQUES IN SYSTEM LIFE-CYCLE PHASES

45. To relate human engineering analyses to the systems engineering process, the terms employed for the development phases used in each participating country were tabulated (Table 2.2). The phases were compared with the phases of the NATO Phased Armaments Programming System (PAPS) (NATO, 1989). A common set of terms was then developed to describe the project development phases (bottom line of Table 2.2). Note that the table does not cover system up-grading, down-grading or retirement.

Table 2.2: Development life-cycle phases used in different nations

Systems Engineering Texts (Chambers, 1986)						
Needs analysis/ identification	Conceptual	Definition		Detailed design	Production	Introduction
Human Engineering Texts (Meister, 1985)						
Mission analysis (planning)	Concept development	Competitive systems demonstration	Full-scale engineering development		Production & deployment	
RSG Member Nations						
Canada Requirements analysis	Concept development	Design definition	Contract definition	Full-scale development/ Test&Evalua'n	Production	Operations
France Evaluation of need	Feasibility	Definition		Development	Production	Use
FRG Preliminary		Definition		Development	Production	Use
Norway Preliminary	Concept	Definition		Development	Production	Use
U.K. Concept formulation	Preliminary feasibility studies	Project definition	Detailed design	Full-scale development and trials	Production and deployment	
USA Mission feasibility & concept formulation	Concept exploration	Concept demonstration & validation	Contract design	Full-scale development	Full-scale production & deployment	Post-production support
NATO PAPS Mission need evaluation	Pre-feasibility	Feasibility	Project definition	Design & development	Production	In-service
RSG.14 Preliminary system studies	Concept formulation	System definition	Concept validation	System design & development	Production	Operational use

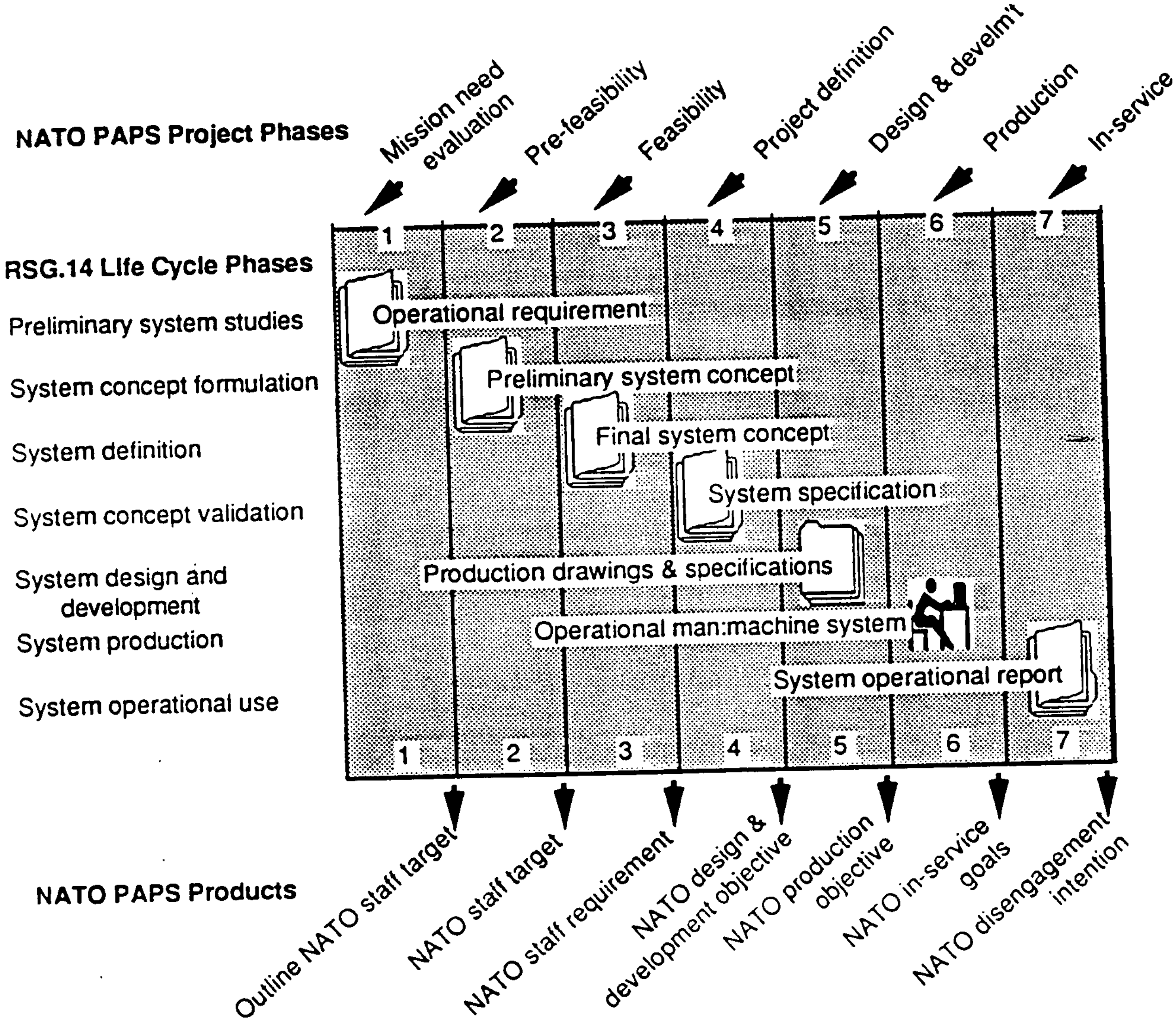

Figure 2.10: Products of the system life cycle phases

46. As discussed in Chapter 1, the systems and equipment development process moves through a series of phases or stages. The major phases in system or equipment development and their associated products are shown in Figure 2.10. The various human engineering analysis techniques are used in the different project phases as the system concept becomes more fully defined. A major concern of the study was to identify effective techniques and to avoid applications which provide a low return on the effort invested in them. Therefore, RSG representatives assessed the applicability of different human engineering techniques to four different types of system. These were:

- simple (e.g., a rifle or hand-held radio)
- medium-complexity (e.g., a one-person radar console)
- high-complexity single-operator (e.g., a single-seat attack aircraft)
- high-complexity multi-operator (e.g., a ship's combat information centre)

Using a consensus buliding technique, the responses were categorized as:

- "Not Recommended" (N/R)
- "Low"
- "Medium" or
- "High"

The pattern of responses shown in Table 2.3 is not unexpected. For simple systems, there is a recommendation to use only a few techniques. such as a narrative mission description and information-action tables or operational sequence diagrams. With growing complexity a larger number of more complicated techniques is recommended. Available techniques for function allocation are not highly recommended, because of their limitations.

47. Not all analysis techniques are relevant to all phases. Table 2.3 shows the overall opinion of the group, obtained through the same consensus building technique, rating the techniques for various project phases. The phases used were reduced to four principle ones:

- preliminary system studies
- concept formulation and validation
- design and development
- system use

The effectiveness of an application depends on the system complexity and the characteristics of a technique. As shown in the table, in most cases the effective use is limited to only one or two phases.

Table 2.3: Applicability of available human engineering

HUMAN ENGINEERING ANALYSIS TECHNIQUE	SYSTEM COMPLEXITY				
	SIMPLE SYSTEM				
System development phase	A	P	C	D	U
Mission analysis					
Narrative mission descriptions	H	H	H	M	I
Graphic mission profiles	N	N	N	N	N
Functional analysis					
Function flow diagrams	L	I	I	I	N
Sequence And Timing (SAT) diagrams	N	N	N	N	N
Structured Analysis and Design Technique (SADT)	N	N	N	N	N
Information flow and processing analysis	N	N	N	N	N
State transition diagrams	N	N	N	N	N
Petri nets	N	N	N	N	N
Behaviour graphs	N	N	L	N	N
Function allocation					
Ad hoc function allocation	N	N	L	N	N
Fitts' list	N	N	N	N	N
Review of potential operator capabilities	N	N	L	N	N
Function allocation evaluation matrix	N	N	N	N	N
Requirements allocation sheets	N	N	N	N	N
Task analysis					
Time lines	L	N	L	L	N
Flow process charts	L	L	L	N	N
Operational Sequence Diagrams (OSDs)	H	L	H	H	H
Information/action or Action/information tabulations	H	H	H	H	L
Critical task analysis	L	N	L	L	N
Decision tables	N	N	N	N	N
Performance prediction					
Time line analysis of workload	L	N	L	L	N
Systems Analysis by Integrated Networks of Tasks (SAINT)	N	N	N	N	N
SIMWAM	N	N	N	N	N
Subjective workload prediction	N	N	N	L	N
Subjective Workload Assessment Technique (SWAT)	L	N	L	L	L
NASA Task Load indeX (TLX)	L	N	N	L	L
Error analysis	L	N	L	L	L
Analysis of human errors as causal factors in accidents	L	N	L	L	L
Interface and workspace design					
Design option decision trees	L	L	L	N	N
Critical design requirements	M	L	M	M	L
Link analysis	N	N	N	L	L

A = averaged over all project phases
P = preliminary system studies phase
C = concept formulation and validation phase
D = design and development phase
U = use

H = high recommendation
M = medium recommendation
L = low recommendation
N = not recommended

analysis techniques per phase of the design process

SYSTEM COMPLEXITY														
MEDIUM COMPLEX SYSTEM					HIGH COMPLEXITY SINGLE OPERATOR					HIGH COMPLEXITY MULTI OPERATOR				
A	P	C	D	U	A	P	C	D	U	A	P	C	D	U
H	H	H	L	L	H	H	H	L	L	M	H	H	M	M
N	L	N	N	N	H	H	H	M	M	H	H	H	M	M
M	L	M	M	N	H	M	H	H	L	H	H	H	H	M
L	N	L	N	N	M	L	M	M	N	H	M	H	H	M
L	L	M	L	L	M	L	M	M	L	H	M	H	H	M
L	L	M	L	L	L	L	L	L	L	L	L	M	L	L
L	L	L	L	N	M	L	M	M	L	M	N	M	L	N
N	N	N	N	N	M	L	M	M	N	M	N	M	M	N
M	L	M	M	L	H	L	H	H	L	H	L	H	H	L
L	L	M	N	N	L	L	M	N	N	L	L	M	L	N
L	N	L	L	N	L	L	L	N	N	N	L	N	N	N
L	L	M	N	N	M	L	H	L	N	M	M	M	L	L
L	N	L	L	N	M	L	M	M	L	M	L	H	M	N
L	L	L	N	N	M	L	M	M	L	M	L	M	M	N
M	L	M	M	N	M	N	H	M	L	H	M	H	M	L
N	N	N	N	N	N	N	L	N	N	L	N	L	L	L
H	L	H	H	H	H	L	H	H	H	H	L	H	H	M
M	L	H	H	L	M	L	M	M	L	L	L	M	L	L
L	N	L	L	L	H	L	H	H	M	H	L	H	H	M
L	N	L	L	N	M	L	M	M	N	M	L	M	M	N
M	N	M	M	L	M	L	M	M	L	L	N	M	M	N
M	L	M	M	N	H	L	H	H	L	H	L	H	H	L
M	L	M	M	L	H	L	H	H	L	H	L	H	H	L
M	N	M	M	N	M	L	M	M	L	M	L	M	M	L
M	N	M	M	L	H	L	H	H	L	H	L	H	H	L
M	N	M	M	L	H	L	H	H	L	H	M	H	H	L
M	N	M	M	L	H	L	H	H	L	H	L	H	H	M
M	L	M	L	M	H	M	H	M	H	H	M	H	M	H
L	N	L	L	N	M	L	M	M	N	M	L	M	M	L
M	L	M	M	L	H	L	H	H	L	H	L	H	H	L
M	L	M	M	L	H	L	H	H	M	H	L	H	H	H

A = averaged over all project phases
P = preliminary system studies phase
C = concept formulation and validation phase
D = design and development phase
U = use

H = high recommendation
M = medium recommendation
L = low recommendation
N = not recommended

2.5 REFERENCES

1. Beevis, D. (1984). The ergonomist's role in the weapon system development process in Canada. In: Applications of systems ergonomics to weapon system development. Panel 8 Workshop, NATO DS/A/DR(84)408. Brussels: NATO Defence Research Group.
2. Beevis, D. (1987). Experience in the integration of human engineering effort with avionics systems development. In: The design, development and testing of complex avionics systems. AGARD CP 417.
3. Behr, E. (1984). On an integrated ergonomic procedure for the development and acquisition of defense materiel. In: Applications of systems ergonomics to weapon system development. Panel 8 Workshop, NATO DS/A/DR(84)408. Brussels: NATO Defence Research Group.
4. Defense Systems Management College (1990). Systems engineering management guide. Washington, D.C.: U.S. Government Printing Office.
5. De Greene, K.B. (1970). Systems analysis techniques. In: K.B. De Greene (Ed.), Systems psychology. New York: McGraw-Hill. pp. 79-130.
6. Diamond, F.I. (1989). Avionics System Engineering – An Introduction. In: Systems Engineering. AGARD-LS-164. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
7. Döring, B. (1983). Systems Ergonomics, An Approach for Developing Well-Balanced, Cost-Effective Man-Machine Systems. In: The human as a limiting element in military systems. Vol. 1. NATO DRG DS/A/DR (83)170. Brussels: NATO Defence Research Group.
8. Hennesy, R.T. (1981). Activities of the committee on human factors. Annual summary report. National Research Council, Washington, Contract No. N00014-81-C-0017.
9. Hunt, G.R., Bosman, D., Forshaw, S., Eggleston, R., Glickstein, I., Hollister, W., & Helie, P. (1987). Impact of future developments in electronic technology on cockpit engineering. AGARD-R-757. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
10. Kloster, G.V., Braathen, K., & Tronstad, Y.D. (1989). Defining complex man-machine systems: Problems and solutions. AFCEA Europe Oslo Symposium, 26-28 April.
11. McMillan, G.R., Beevis, D., Salas, E., Stein, W., Strub, M.H., Sutton, R., & Van Breda, L. (1991). A directory of human performance models for system design. Report AC/243 (Panel-8) TR-1. Brussels: NATO Defence Research Group.
12. Meister, D. (1985). Behavioral analysis and measurement methods. New York: John Wiley & Sons.
13. Merriman, S.C., Muckler, F., Howells, H., Olive, B.R., & Beevis, D. (1984). Applications of systems ergonomics to weapon system development. Report DS/A/DR(84)408.Brussels: NATO Defence Research Group.
14. National Research Council (1983). Research needs for human factors. Chapter 7: Applied methods in human factors. Washington, D.C.: National Research Council Committee on Human Factors. January 19.
15. NATO (1982). Ergonomics design guide-lines. Report DS/A/DR(82)350. Brussels: NATO Defence Research Group.
16. NATO (1989). Handbook on the phase armaments programming system (PAPS). Volume 1: PAPS framework and procedures. Volume 2: PAPS related activities and management considerations. Report AAP-20. Brussels: NATO International Staff – Defence Support Division.
17. NATO RSG.14 (1988). Analysis techniques for man-machine system design: interim report on the utilization of existing techniques. Brussels: NATO Defence Research Group, Panel-

8.
18. Papin, J.P. (1988). Ergonomie: cours superior des systems d'armes terrestres. Cours superior d'armament. Ministere De La Defense, Direction Des Armaments Terrestres, Service Facteurs Humains.
19. Sanders, M.S., & Smith, L. (Eds). (1988). Directory of undergraduate programs. The Human Factors Society, Santa Monica, CA.
20. Schuffel, H. (1984). The ergonomist's role in the design of workspaces on vessels of the Royal Netherlands Navy. In: Applications of systems ergonomics to weapon system development. Panel 8 Workshop, NATO DS/A/DR(84)408. Brussels: NATO Defence Research Group.
21. Stringer, F.S. (Ed) (1978). Optimization of avionic system design, AGARD-AR-118. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
22. Tooze, M.J. (1989). Avionic system design methodology. In: Systems engineering. AGARD Lecture Series No. 164. Neilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
23. Van Cott, H.P., & Altman, J.W. (1956). Procedures for including human engineering factors in the development of weapon systems. WADC TR 56-488. Ohio: Wright Air Development Center. AD-97305.

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CHAPTER 3
HUMAN ENGINEERING ANALYSIS TECHNIQUES

3.1 INTRODUCTION

48. The classes of analysis reviewed in section 2.3 are described in Volume 2 of this report. Each analysis was reviewed to a standard format, including:

- what the techniques do
- inputs/outputs of the techniques
- when to use
- related techniques
- resources required
- advantages/disadvantages
- relative contribution
- applications
- quality assurance considerations
- relationship to system performance requirements

These issues are summarized in the following sections.

3.2 CHARACTERISTICS OF THE TECHNIQUES

3.2.1 What the techniques do

49. The purposes of these techniques have been discussed in chapters 1 and 2. The analysis techniques permit designers and developers to define:

- system missions
- system functions
- system operator and maintainer activities and tasks
- required capabilities and workload of the system personnel
- requirements for displays, controls, workspace and inter-personnel communication

50. For the most part, the techniques are ways of structuring and decomposing this information: they are not algorithms which transform input data. Thus they require some learning or experience. Historically, many human engineering techniques described a system as a network of functions or a sequence of operator tasks. More recent developments permit the description of systems obtained through function and task analysis to be checked for logical consistency, or treated as a model for computer simulation (Bråthen et al., 1992).

3.2.2 Inputs/outputs of the techniques

51. The basic inputs to the analyses is the information on the operational requirement. As shown in Figure 3.1, the outputs of one class of analysis provides the inputs to others. In general, inputs and outputs involve events, sequences, times, functions, conditions, tasks, performance requirements, and display and control information. For example, a SAINT

simulation requires information on precedence relationships and conditions required to activate or release a task.

3.2.3 When to use

52. As noted in Section 2.2, the sequence of human engineering analyses should be initiated as early in the project development cycle as possible. As shown in Table 2.3, some techniques are more appropriate to some project phases than to others and some techniques are more appropriate to certain types of systems than to others. Normally, the individual analysis techniques should be used in the sequence shown in Figure 3.1, because they are developed in sequence. This is particularly important when there are to be major changes in a system concept (revolutionary development). For example, the application of new technologies often leads to major changes in mission requirements (e.g., twenty-four hour operations) and system and operator functions (e.g., increased automation). The behaviour required by the operators in such systems cannot be predicated on the basis of previous systems.

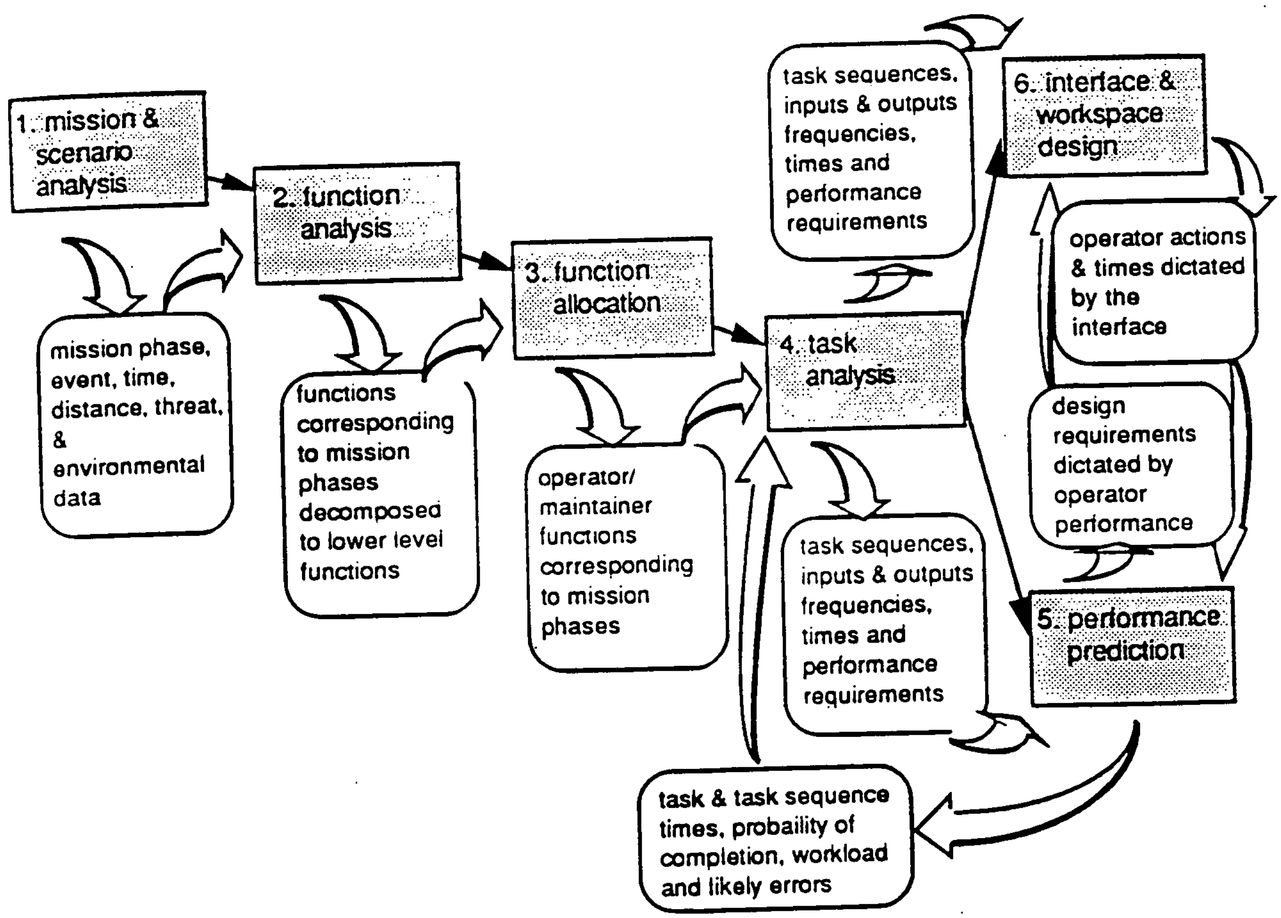

Figure 3.1: Information generated by the sequence of human engineering analyses

53. The amount of analysis performed at each stage may differ widely from project to project. With current technology, the development of a design solution involves definition of both the functional, or behavioural, characteristics of a system and the implementation, or component, characteristics of the system (Harel & Pnueli, 1985). The amount of development, or searching, along either of those dimensions can differ widely, depending on the project constraints (Fig. 3.2). Extreme examples are the L shaped pattern of development, when the system components are defined at the outset and effort is put into making them function together, and its complement, the ¬ shaped pattern, where the functional characteristics of the system are developed completely before looking for sub-systems which will perform them. Neither of these extremes is recommended (Harel & Pnueli, *ibid*). Experience suggests that the development of the functional characteristics and the component characteristics be linked, so that the search path lies close to the diagonal. This reflects the discussion of Chapter 1, section 1.2, and Chapter 2, section 2.2.

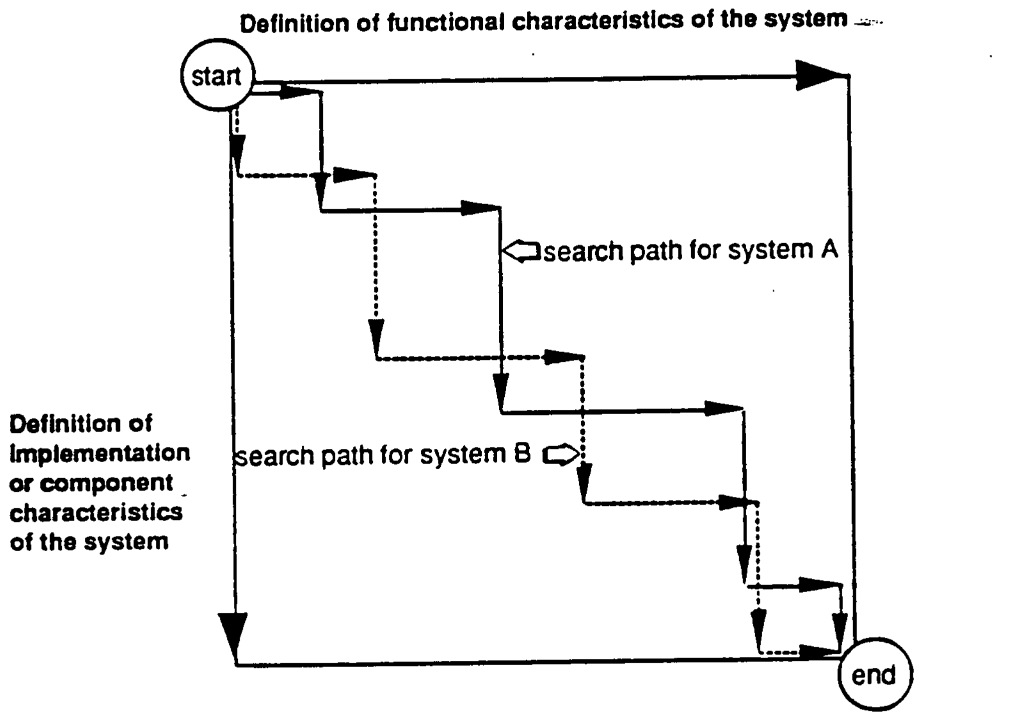

Figure 3.2: Different patterns of design development
(after Harel & Pnueli, 1985)

54. In some projects, the sequence of human engineering analyses may have to be modified. For example, the evolutionary development of the driver's compartment of a conventional new fighting vehicle is unlikely to involve major changes in the assignment of system functions to the driver, but is very likely to involve problems of workspace design, because the crew compartments of fighting vehicles are space-limited. In such a case, the human engineering specialist is likely to start with the workspace design problem, and move from that to task analysis by way of a very simple function analysis (see also, Table 2.3). Whatever the approach used, the analyses should be reiterated. In selecting the techniques to use, analysts are advised to work backwards through the chain of analyses. For example, if one of the prime

goals is to run a SAINT simulation, then the analysis should generate a description of the task network from Operational Sequence Diagrams (OSDs) or a similar technique.

3.2.4 Related techniques

55. As indicated in Figure 3.1, the classes of analysis are related to one another. Similarly, within each class, techniques tend to be related. For, example two techniques for function analysis, Sequence and Timing Diagrams (SATs) and Function Flow Diagrams (FFDs), are related; in task analysis, Operational Sequence Diagrams (OSDs) are developments of Flow Process Charts with symbols for operator actions added.

56. In reviewing the various human engineering techniques, one objective was to examine their compatibility with other engineering processes. Several of the techniques reviewed are related to, or used for, systems engineering analyses. As might be expected, most of those techniques are used in the early stages of analysis. Such common techniques include Mission and Scenario Analysis, FFDs, SATs, Structured Analysis and Design Technique (SADT), State Transition Diagrams (STDs), Petri Nets, and Behaviour Graphs. The latter is an integral part of a systems engineering approach called Requirements Driven Development (Alford. 1989).

57. None of the human engineering techniques used for the function allocation stage of analysis is used for mainstream systems engineering studies, although the basic technique of comparing the capabilities of different design solutions is by no means unique to human engineering. It is tempting to conclude that human engineering specialists are the only ones concerned with the systematic allocation of functions to humans, and that other engineering specialities do it by default, through the selection of hardware and software (Chapanis, 1970; Meister, 1985). However, the Requirements Allocation Sheet, described in some systems engineering texts (Defense Systems Management College, 1990) is one technique which combines the functional allocations for hardware, software and personnel by identifying sub-system and personnel performance requirements.

58. Several techniques for task analysis are common to other engineering analyses. These include Time Lines, Flow Process Charts, Decision Tables, Systems Analysis by Integrated Networks of Tasks (SAINT), and Error Analysis. In the area of interface and workspace design, only one of the three techniques reviewed, Critical Design Requirements, can be said to be used for other engineering analyses.

59. Overall, it can be concluded that there is a fairly high level of commonality between human engineering and systems engineering analyses. Fifteen out of the thirty-one techniques reviewed are used for other engineering analyses, including the two most frequently used human engineering analyses (Function Flow Diagrams and Narrative Mission Descriptions). This should facilitate communication between human engineering specialists and other members of the design/development team. Despite the use of common techniques, however, different specialities conduct their analyses from different viewpoints. For example, systems engineering activities may analyse scenarios, or complete functional decompositions, without including the human operator (Beevis, 1987). Thus the human engineer may have to revise or modify analyses conducted by other specialities in order to highlight human factors in system or equipment design.

3.2.5 Resources required

60. Most of the techniques reviewed can be conducted using simple "paper and pencil" resources. For only five of the techniques reviewed was the use of a computer mandatory. Petri Nets and Behaviour Graphs require Computer Aided Software Engineering (CASE) tools to

keep track of the analyses and ensure that logic requirements are maintained. SAINT, SWAT, and SIMWAM are software-based tools which require computing facilities (SIMWAM is proprietary, but is included because of its widespread use by some services).

61. Human engineering analyses produce large amounts of information. For example, a system functional decomposition typically starts with seven to ten functions at the uppermost level. Decomposing those functions through three levels results some 1000 functions at the lower level. If the analyses are to be reviewed and reiterated (Figure 1.9) then a computer is essential to keep track of the data and facilitate modification. For these reasons, some analysts are now using relational data bases for all the human engineering analyses. The reviews of eleven of the analysis techniques suggest that computer-based record keeping is desirable.

62. Other resources which are required include information and experience. Information from subject matter experts (i.e., operators or ex-operators of similar systems) is important, especially for the analyses used in early stages (Mission Analysis, Function Analysis and Allocation) and for detailed task analyses such as Decision Tables. It is also important that the human factors specialist be an expert in the relevant land, sea or air system and operations. Information on possible technical solutions, (i.e., the hardware and software to be used), is also important. All analyses benefit from experience in using the relevant technique, and functional decompositions in particular benefit from experience of previous analyses. A few, for example, SADT, Petri Nets, Behaviour Graphs, and SAINT, require a thorough understanding of the theory underlying the technique.

3.2.6 Advantages/disadvantages

63. The reports from users of some of the techniques show that their effectiveness can vary widely between individual applications (see Section 2.1). The more general advantages and disadvantages identified for each technique reviewed in Volume 2 also vary widely. Two comments which appear frequently are that the analyses can become labour intensive, therefore time-consuming, and that there is an element of subjectivity in them. This latter comment is particularly true of functional decomposition techniques, which can be influenced by the viewpoint of the analyst. This can be seen in the examples of functional decompositions included in Volume 2. In general, the mission and function analysis techniques are good for communicating with other engineering specialities (as noted in comments on Related Techniques, above), and for traceability of design features. Because these techniques try to represent what are multi-dimensional concepts in only two dimensions, however, they present a limited view of systems.

64. In general, the function allocation techniques are simple to perform. This advantage incurs the corresponding disadvantage that they are simplistic. Also, they can require a great deal of knowledge which is not easily available. Task analysis techniques can be fast and easy to apply, but they can become overly detailed, therefore labour intensive and hard to understand or review. The advantages and disadvantages of performance prediction techniques are not easy to summarize. In general they are flexible and easy to apply provided that the supporting analyses have been completed. They suffer from a lack of demonstrated validity for many applications. The three techniques reviewed for interface and workspace design are effective for presentation and for accounting for design decisions. They can be labour intensive and subjective.

3.2.7 Relative contribution

65. The relative contributions made by the different techniques are dependent on the project phase and the type of application. For example, some types of task analysis are highly recommended as a basis for a Test and Evaluation Plan. The relative contribution of any one

technique also depends on the other techniques which were used for the human engineering analyses. For example, the contribution of mission analysis is high if the information is used in subsequent analyses, but not otherwise: performance prediction using Subjective Workload Ratings or SWAT is good for the comparison of competing design concepts, but not for the development of one design.

66. Possibly because of these dependencies, little coherent information was received from users on the relative contribution of the different techniques. No information was collected for nine of the thirty-one techniques reviewed in Volume 2. In general, users' comments about techniques were positive, reflecting the expectation that only effective techniques would be used. The most negative comments were directed to techniques for Function Allocation, although one user reported Ad hoc Function Allocation as "the best." Because of these differing reports, the applicability of the different techniques has been rated by RSG members, to provide user guidance (see Table 2.3 and Volume 2).

3.2.8 Applications

67. The overall rates of use of the different techniques are reported in Table 2.1, and the pattern of use of the techniques in the survey is shown in Figure 2.2. Reports of specific applications varied widely, from army weapons, aircraft and ships, to command and control systems and training systems and equipment. Overall, there were more reports of applications to aircraft systems than to navy or army systems. This may reflect the greater importance which has been attached historically to aircrew tasks and aircrew error.

68. Over seventy percent of reported applications of techniques were for the design of complex, multi-operator systems, as defined in section 2.4. Only two reports mentioned applications used for simple systems such as rifles or personal communication systems (techniques applied were State Transition Diagrams and Critical Design Requirements). The information reporting and sampling, however, may well be biased in favour of large "high profile" projects. No conclusions can be drawn about the rate of use of specific techniques.

3.2.9 Quality assurance considerations

69. The quality of the product is of obvious concern to practitioners and project managers. *Quality* can be defined as "the totality of features and characteristics of a product or service that bear upon its ability to satisfy given needs" (NATO CNAD). Quality has two aspects: *quality of design* reflects "the process of task recognition and problem solving with the objective of creating a product or service to fulfill given needs"; *quality of conformance* is "the fulfillment by a product or service of specified requirements." Thus, the quality of human engineering analyses would be a function of how well they contribute to the design of an effective system (quality of design), and how well they provide accurate, timely, usable information for the design/development team (quality of conformance). Most comments from users have addressed the latter aspect of quality.

70. Quality Assurance (QA) comprises "the activities and functions concerned with and necessary for providing confidence in attainment of quality." To some extent, this could be said to be a formal implementation of lessons learned from experience. Indices such as schedules and deadlines can be used as part of a quality assurance process. Therefore, quality assurance of human engineering analyses could use evidence which includes the following criteria:

- schedules which show that the analyses will be timely
- organization charts which indicate that the human engineering effort will be integrated with other systems engineering and Integrated Logistics Support (ILS) activities
- use of metrics and measures of effectiveness which are compatible with each other and with other engineering activities
- compliance with a relevant specification (see Chapter 5: there are few specifications which are relevant to the QA of human engineering analyses)

71. Some of these items are addressed in the volume on Quality Assurance in the British Human Factors Guidelines for the design of Computer-Based Systems (Ministry of Defence, 1988). However, most of the criteria listed in that publication are subjective (e.g., "Are the proposed design teams satisfactory? If not, why not?"). Some of the above evidence is covered in the exhaustive checklists contained in a report on human factors in system acquisition produced for the U.S. Navy (Malone et al., 1986). The entries under "Quality Assurance Considerations" in the reviews of individual analysis techniques (see Volume 2) were based on experience and on comments from users. They show a general pattern of reference to "completeness," "consistency" (with either the statement of requirements (SOR), preceding analyses, or internally), and "accuracy" (e.g., of task time estimates). "Review by experts" is also referred to but does not represent a criterion because, presumably, the "experts" have their own criteria for judging the analyses. Figure 3.3 shows the ranking of the QA criteria reported in Volume 2. The criteria average 1.4 checks for each analysis technique reviewed (36 checks for 26 techniques).

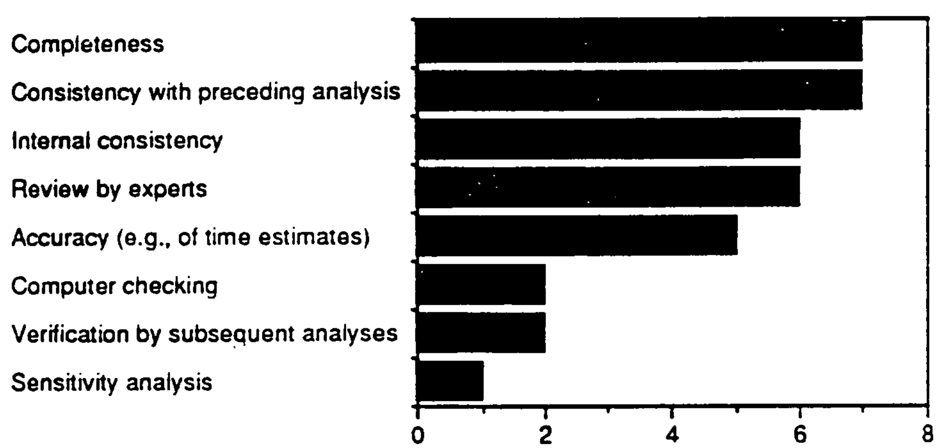

Figure 3.3: Number of quality assurance criteria used for human engineering analyses reviewed in Volume 2

72. None of the entries on the techniques reviewed in Volume 2 refers to checking the analyses for timeliness, or for compatibility with other systems engineering or ILS activities. No entry refers to checking the analysis against a specification for such analyses. Such considerations should be included in the development of the plan for the human engineering analyses. The project manager and/or the analyst should employ the following QA criteria:

- completeness
- consistency
- timeliness
- compatibility with other engineering analyses

3.2.10 Relationship to system performance requirements

73. The results of human engineering efforts must be related to system performance. Erickson (1986) argues that system component and operator performance are not explicit in the upper levels of any systems analysis. He describes an approach to developing a "capability hierarchy" starting with a functional analysis, and decomposing the performance requirements from that level. He notes that it is necessary to go down at least two levels in the hierarchy before operator performance criteria become apparent (see Fig. 3.4). Therefore, there may be no direct relationship between system performance criteria and operator task performance unless the connection is made explicit by analysis.

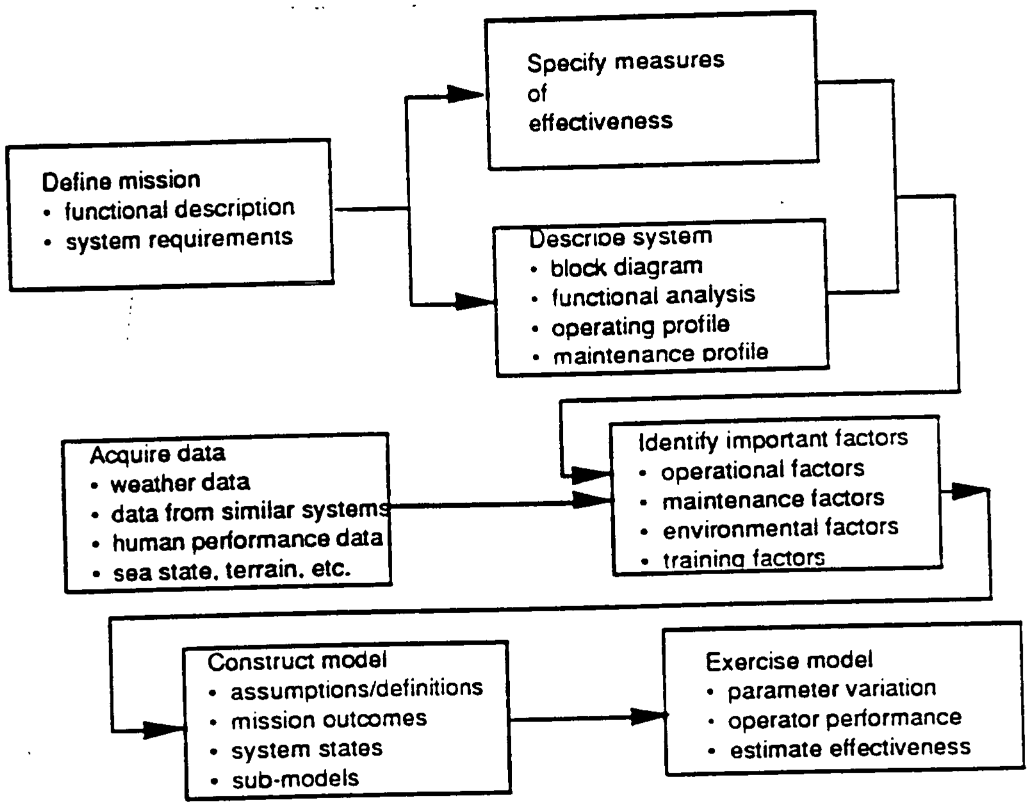

Figure 3.4: Principal activities required to evaluate systems effectiveness (after Erickson, 1986)

74. Table 3.1 shows the links between the individual human engineering analyses and system performance criteria identified for the techniques reviewed in Volume 2. The information appears to support Erickson's analysis. In most cases the link from human engineering analyses to system performance requirements is not direct. The analyses differ in the scale of measurement used (Siegel, 1956). Functional analysis techniques are restricted to either nominal scales, i.e., the identification of classes or categories of function, or ordinal scales, i.e., qualitative measures of performance. Distances and clock times in a mission profile, or the number of tokens in a Petri net, are interval scale measures because they are not related to a zero point by ratios. Techniques such as SAINT provide ratio scale data such as task completion times and probabilities. Many of these measures require an analysis of system performance requirements to identify the influence of operator performance on the system.

75. From Table 3.1 it can be seen that the majority of techniques available for functional analysis and function allocation provide only nominal or ordinal measurements. Those analyses which do have a direct link to system performance requirements use interval or ratio scale measures. It can be concluded that the techniques used for function allocation are not yet mature, and that the complete sequence of analyses must be completed and reiterated if they are to address system performance.

3.3 CONCLUSIONS FROM REVIEW OF HUMAN ENGINEERING ANALYSIS TECHNIQUES

76. The work of the RSG has shown that a wide variety of human engineering analysis techniques are available. The review covered thirty-one typical examples: it is not an exhaustive review of all the existing variants of those techniques. More extensive lists of techniques are available if required (Bogner, 1989).

77. The techniques fall into six categories of analysis: mission analysis, function analysis, function allocation, task analysis, performance prediction, and interface and workspace design. Normally, the classes of technique should be used in sequence. The actual starting point in the sequence may depend on project constraints and priorities and the extent to which human engineering has been accepted into the project. In selecting the techniques to use at each stage of analysis, users are advised to work backwards through the chain of analyses; e.g., if one of the prime goals is to run a SAINT simulation then the analysis should develop a description of the task network from OSDs or a similar technique.

78. Half of the techniques reviewed are similar to, or related to, techniques used for systems engineering analysis. Obviously, some techniques are used more than others (see Section 2.1). Applications depend on the size of the project, position in project cycle, and scope for innovation in the design. There are few reports of the application of these techniques to simple systems. Applicability of a specific technique also depends on the chain of analyses, as outlined above.

79. The effective use of the techniques is based on a decomposition of the system design problem area which results in defined functions, sub-systems, or states. The characteristics of these functions, sub-systems, or states are then defined and validated. The items are then combined to predict the system performance and operator/maintainer workload. In general, it is assumed that the prediction of system performance is valid if it is based on the validated performance of sub-systems.

80. Most analyses require few resources and can be performed with paper and pencil, but nearly all benefit from use of a computer for tracking, editing and analysing the data. There is a need for such programs to be integrated, rather than stand-alone, so that data are not re-entered many times. Few computer tools have been developed to date, but they are growing in number.

81. The quality assurance aspects of the various techniques are not widely understood. Managers and practitioners should pay more attention to quality assurance factors.

82. The link from human engineering analyses to system performance requirements is not explicit, in most cases. The majority of the "classic" human engineering analyses do not have a direct relationship to system performance requirements and, to be made relevant, they require additional analysis of system performance. Those analyses which have a direct link to system performance requirements use interval or ratio scale measures. The least mature techniques, in terms of their relationship to system performance, are those used for function allocation.

Table 3.1: Links between types of analysis and system performance

Technique	Output	Link to system performance	Scale of measurement
Mission Analysis			
Narrative mission descriptions	events, sequences, times, distances, probabilities	derived directly but not expressed as measures of effectiveness (MOE)	nominal, ordinal, interval, ratio
Graphic mission profiles	events, sequences, times, distances, speeds etc.	derived directly but not expressed as MOE	nominal, ordinal, interval, ratio
Functional analysis			
Function flow diagrams	functions required to perform mission	indirect: direct link to system goals	nominal or ordinal (functions & resources)
Sequence and timing (SAT) diagrams	functional sequence and sub-systems	indirect:direct link to system goals	nominal or ordinal (functions & sub-systems)
Structured analysis & design technique (SADT)	functions, their sequence, controls & resources	indirect: direct link to system goals	nominal or ordinal (functions, resources, controls)
Information flow and processing analysis	information flow & key decisions	indirectly related to mission description & profile	nominal or ordinal
State transition diagrams	required systems states & state logic	indirect link to system goals	nominal (states); ordinal (sequences)
Petri nets	logic of system conditions & states	indirect link to system goals	nominal (states) interval or ratio (token counts)
Behaviour graphs	functions, their sequence, and times, sub-systems	indirectly related to mission description & profile	nominal or ordinal (functions, subsystems, states); ratio (times)
Function allocation			
Ad hoc function allocation	functions allocated to sub-systems	indirect link via functions	ordinal (better/worse criteria)
Fitts' list	functions allocated to sub-systems	indirect link via functions	ordinal (better/worse criteria)
Review of potential operator capabilities	functions allocated to sub-systems	indirect link via functions	ordinal (better/worse criteria), ratio (times)
Function allocation evaluation matrix	functions allocated to sub-systems	indirect link via functions	ordinal (better/worse criteria) based on ratio scale ratings
Requirements allocation sheets	functions allocated to sub-systems	identifies subsystem performance requirements	nominal, ordinal, interval, or ratio scale

Technique	Output	Link to system performance	Scale of measurement
Task analysis			
Time lines	sequences & times of operator tasks	direct link to mission times	ratio
Flow process charts	sequences & types of operator tasks	indirect link to missions profiles & descriptions	ordinal
Operational sequence diagrams (OSDs)	sequences of operator tasks; can include times	direct link to mission profiles & descriptions	ordinal: (ratio if annotated with time)
Information/action or Action/information tabulations	sequence & types of operator tasks	indirect link to mission profiles & descriptions	ordinal
Critical task analysis	task sequences, times & tolerances	direct link to system performance by operator error	ordinal to ratio
Decision tables	key decisions & criteria for making them	indirect link via functions	nominal (conditions)
Performance Prediction			
Time line analysis of workload	task sequences & times	direct link to mission times	ratio
Systems analysis by integrated networks of tasks (SAINT)	task sequences, times & probabilities	direct link to mission times & probabilities	ratio
SIMWAM	task sequence s, times & operator loading	direct link to mission times	ratio
Subjective workload ratings	workload of operators	indirect link to system performance	interval or ratio
SWAT	workload of operators	indirect link to system performance	ordinal transformed into an interval scale
NASA TLX	scores of operator workload	indirect link to system performance	ordinal expressed on a ratio scale
Error analysis	errors which may be made by operators	indirect to mission goals	nominal (categories of errors) or ratio (probabilities)
Analysis of errors as causal factors in accidents	tree of human error and causal conditions	indirect link to mission effectiveness	nominal (categories of errors) or ratio (probabilities)
Interface and workspace design			
Design option decision trees	human factors data related to design choices	direct link to functions; indirect link via operator performance	nominal to ratio
Critical design requirements	design criteria (dimensions, coordinates etc)	indirect link via operator performance	nominal to ratio
Link analysis	coordinates of a workspace or interface	indirect link via operator performance	ordinal (link importance) ratio (link frequencies)

3.4 REFERENCES

1. Alford, M. (1989). Implementing scenario definition techniques using RDD-100. Proceedings of the IEE Real Time System Symposium. IEEE Press.
2. Beevis, D. (1987). Experience in the integration of human engineering effort with avionics systems development. In: The design, development and testing of complex avionics systems. AGARD CP 417, (pp. 27-1 – 27-9). Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
3. Bogner, M.S. (1989) Catalogue of MANPRINT (Manpower-Personnel Integration) Methods. Report ARI-RP-89-09. AD-a 208-236,. Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences.
4. Bråthen, K., Nordø, E., and Veum, K. (1992). An integrated framework for task analysis and systems engineering: approach, example and experience. In: Proceedings of the 5th IFAC/IFIP/IEA/IFORS Symposium on analysis, design and reduction of man-machine systems. The Hague, June 9-11.
5. Chapanis, A. (1970). Human factors in systems engineering. In: K.B. DeGreene (Ed.) Systems psychology. (pp. 51-78). New York: McGraw-Hill.
6. Defense Systems Management College (1990). Systems engineering management guide. Washington, D.C.: U.S. Government Printing Office.
7. Erickson, R.A. (1986). Measures of effectiveness in systems analysis and human factors. Warminster, PA: Naval Air Development Center. Report NWC TP 6740.
8. Harel, D., Pnueli, A. (1985). On the development of reactive systems. In: K.R. Apt, (Ed.) Logics and models of concurrent systems. Berlin: Springer-Verlag, in Cooperation with NATO Scientific Affairs Division.
9. Malone, T.B., Kirkpatrick, M., Kopp, W.H., & Heasly, C.C. (1986). Human Factors in System Acquisition: Program Initiation through Milestone II. Fairfax, VA: Carlow Associates Inc. (US NAVSEA 61R).
10. Meister, D. (1985). Behavioral analysis and measurement methods. New York: John Wiley & Sons.
11. Ministry of Defence (Procurement Executive) (1988). Human factors guidelines for the design of computer-based systems. Volume 6. Human factors quality assurance. London: HMSO.
12. NATO CNAD. Glossary of terms used in QA STANAGs and AQAPS. AQAP-15. Brussels: NATO.
13. Siegel, S. (1956). Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill.

CHAPTER 4
REVIEW OF NEED FOR NEW OR IMPROVED TECHNIQUES

4.1 INTRODUCTION

83. The objective of this chapter is to review developments in technology which require modifications to the approaches reviewed in Volume 2, or which will require new techniques to be developed. These developments include changes in human tasks (the increase in cognitive tasks, increasing use of decision aids), trends in software engineering, and developments in system integration tools and techniques.

4.2 CHANGES IN HUMAN TASKS

4.2.1 Increase in cognitive tasks

84. Technological advances have interposed new information handling and display devices between the human operator and the rest of the system. Those developments have increased both the amount of information displayed to the operator (Lovesey, 1977) and the information "density" per area of the human-machine interface (Price et al., 1980). At the same time, progress in "automation" has driven the functions performed by humans increasingly towards monitoring, supervising, and decision making. These trends are exemplified by the steady increase in the proportion of a warship's complement employed in the Operations Room, by increasing concern with command and control problems in the army (NATO 1983), and by the development of aircraft systems which can fly the aircraft and deliver weapons to a pre-defined target automatically (Stubben, 1987).

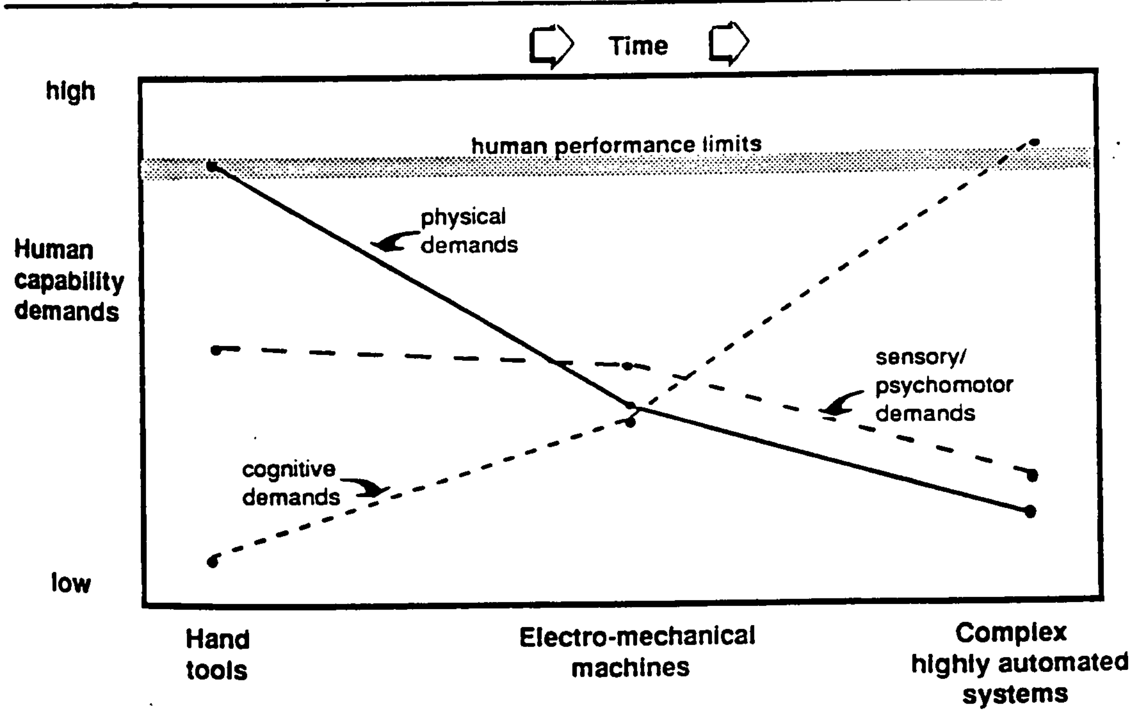

Figure 4.1: Human capability demands (after Hawley & Risser, 1986)

85. As illustrated in general terms in Figure 4.1, it is generally assumed that new advanced systems place high demands on the cognitive aspects of operator and maintainer behaviour, i.e., on all aspects of knowledge, including perceiving, remembering, imagining, conceiving, judging, and reasoning, and reduce demands on other human capabilities. The importance of sensory/psychomotor demands, however, may be underestimated in that figure. The trend toward increased cognitive task demands was recognized by a US DoD survey of human factors in the late 1970s (Topmiller, 1981), and by the NATO AC/243 Panel-8 Workshop on Applications of Systems Ergonomics to Weapons Systems Development (Merriman et al., 1984). The workshop concluded, among other things, that the trend required a coordinated response from the human factors/ ergonomics research and development community in NATO. The workshop also concluded that there was a deficiency in methods for studying cognitive performance.

86. Most function and task analysis techniques (Volume 2, Part 1, Sections 1.3, 1.4) lend themselves to the description of skilled behaviour, not cognitive behaviour. These terms refer, for instance, to a taxonomy of activities developed by Rasmussen (1976). A skill based behavioural level refers to controlling activities, related directly to perception of signals in the outside world. Generally, behaviour is performed unconsciously at this level and needs little attention. Rule based behaviour, as an intermediate level, refers to sequences of activities which are controlled by stored rules or procedures in familiar work situations. A knowledge based behavioural level refers to planning activities in unfamiliar situations, involving interpretation of the actual environmental status, definition of goals, and planning of actions. The processing of information on this level needs conscious attention (see Table 4.1). Real world tasks comprise all of these levels of behaviour in differing proportions.

Table 4.1: Skill, rule, & knowledge based behaviour (see Rasmussen, 1976)

TYPE OF ACTIVITIES	TYPE OF BEHAVIOUR
planning and decision making	knowledge based
supervisory and monitoring	rule based
controlling	skill based

87. Although several attempts at developing a task analysis technique for decision making have been reported in the literature (Johnson et al., 1985; Diaper, 1989; Terranova et al., 1989), and although there are several current studies in that area, no single technique has emerged as the most promising approach (Redding, 1989; Grant & Mayes, 1991). More work will be required to develop such human engineering techniques.

4.2.2 Increasing use of decision aids and knowledge-based systems

88. As noted above, state of the art systems place a growing emphasis on the human operator functions of monitoring, supervising, and decision making. At the same time, the development of what is termed the fourth era of computer software (Pressman, 1987), including, for example, expert systems, decision aids, neural nets, and natural language processing, requires that the human engineering analysis techniques be able to allocate "cognitive" functions between operators and hardware and software, as well as analysing and documenting human interaction with such systems.

89. Operators of complex systems can be supported by intelligent interfaces. Key functions within such a support architecture include information management, error monitoring and adaptive aiding. A central knowledge source underlying this functionality is an *operator model* that involves a combination of algorithmic and symbolic models for assessing and predicting an operator's activities, awareness, intentions, resources and performance (Rouse, Geddes, & Curry, 1988). An example of what can be achieved today is reported by Banks & Lizza (1991), who describe lessons learned in building a cooperative, knowledge based system to help pilots make decisions (Pilot's Associate).

90. When using knowledge-based engineering technology it is important to maintain an operator-centred automation philosophy that overcomes limitations, enhances abilities, and fosters acceptance. A purely technology driven development can produce unintended and unforeseen consequences, e.g., an obscured responsibility distribution between man and machine (see Kraiss, 1989). It is important to realize that the introduction of a decision aid is not without cost. Analytical modelling techniques can be used in order to investigate potential applications of decision aids. Weingaertner and Levis (1989) provide an example of the application of a computer simulation model to predict operator workload with different levels of use of a decision aid. They show how operator workload is a function of full or partial reliance on the decision aid. As the application of decision aids and knowledge-based systems spreads, so the need for suitable analytical techniques will increase.

4.3 NEW DEVELOPMENTS IN SYSTEM AND SOFTWARE ENGINEERING

4.3.1 Computer-supported structured analysis/design methods

91. Software development is the largest single item in the development budget of many modern systems. Software development also incurs major problems in quality control, reliability, and testing. Consequently there is a growing use of design approaches which structure both the identification of requirements, and the development of system software (see, for example, Pressman, 1987; AGARD 1987, 1989; Yourdon, 1989). Examples of such requirements development methods are SADT™ (Connor, 1980; Bachert, Evers & Rolek, 1983) and its variant IDEF® developed by the USAF, and the CORE (Controlled Requirements Expression) technique developed in the U.K. (Price & Forsyth, 1982; SD-Scicon plc, 1988). Typically, structured analysis techniques employ top-down decompositions of system functions. Thus they are similar to the functional decomposition techniques used by human engineering specialists. Although the potential for integrating human engineering techniques with such analyses is apparent, the majority of human engineering activities conducted in current projects appear to take place independently of other systems engineering activities.

92. The growing use of computer aided software/system engineering (CASE) tools is part of an increased emphasis on taking a fully integrated approach to systems development (see, for example, Wallace, Stockenberg, & Charette, 1989). As Schimsky has noted (1987), there is a trend towards an integrating "front end" software specification tools with "back end" test tools to form an integrated progression from specification tool, to semi-formal specification, to prototype, to simulation, to test tool. CASE tools support the development and modification of system requirement specifications. In general, they offer graphical support and can improve the specification quality by checking its syntax and consistency. Furthermore, they offer functions for program structuring and system design. Many available tools are based on the Essential Systems Analysis described in detail by McMenamin and Palmer (1984). This method is a

further development of the systems analysis approach that has been developed over the last two decades (Yourdon, 1989). To summarize, CASE tools offer several possible benefits to systems engineering:

(1) A database representation of the system description (e.g., elements, attributes and relationships) where specifications can be traced to user requirements and design decisions.
(2) A uniform description for all development phases which can be modified easily.
(3) Rapid analysis of the impact of potential changes.
(4) Automatic consistency and completeness checks according to a selected level. Engineers are not forced to produce "complete" specifications, but are encouraged to consider all parts of the system and their interface in a systematic way.
(5) Automatic production of documentation according to standards or some user's individual requirement.
(6) A formal description makes it possible to automate to a large extent the generation of simulation models and prototypes.

93. Available tools do not provide all of these features. The growing emphasis on taking a truly integrated approach to project development, including an integrated project data base, argues for finding a common approach to the definition of system functional and performance requirements in order to include human factors in system performance.

4.3.2 Rapid Prototyping and User Interface Management Systems (UIMS)

94. In the computer science and human-computer interaction communities there is a growing emphasis on the use of *rapid prototyping* and *user interface management systems* (UIMS). These tools permit the rapid creation and modification of the human-machine interface without the need to realize the underlying application software or hardware. The prototype interfaces primarily serve to enhance communications and feedback between designers and users (see for example, Wilson & Rosenberg, 1988). This overall approach parallels one recommended for software code development (Pressman, 1987). A report of the US Defense Science Board Task Force on Military Software (1987) recommended strongly that rapid prototyping be applied early in projects to validate the specifications. The more effective prototyping tools permit the prototype software code to be transferred to the system development model (Nordwall, 1991). Most rapid prototyping tools require support facilities and application specific software to represent mission scenarios and operation dependent aspects of the human-machine interface, such as maps and mission event generators.

95. The rationale for rapid prototyping is that system interactions and user requirements cannot be predicted completely. It is argued that it is more effective to produce the equivalent of a *dynamic mockup* and study how prospective users interact with the system, then modify it and thus develop it iteratively, than to analyse all requirements exhaustively. User evaluation is essential to evolutionary development. Human engineering test and evaluation tends to emphasize subjective measures, apparently because objective measures require more effort to implement (Meister, 1986). A review of rapid prototyping applications confirms that there is a risk that evaluations may be reduced to little more than judgments of appearance, rather than an evaluation of functionality (St. Denis, Bouchard, & Bergeron, 1990). Some human factors specialists have reservations about the importance placed on user opinion in the evaluation of rapid prototypes (see, for example, NATO RSG.12, 1990). Their reservations are based on the possibility of "negative transfer" of existing skills and knowledge, resulting in design which incorporates obsolete or obsolescent features. This is because some users find difficulty in

understanding or are unaware how new technology can be exploited. These problems are best dealt with by persuading the customer to choose user representatives who are both flexible in their approach to new technologies, based on their training and education, and able to compare new equipment with existing items, when this is possible. This will be achieved only when the value and importance of sound human factors practice becomes more widely accepted.

96. The emphasis of rapid prototyping is on setting to work a basic representation of the system, which can be evaluated, refined, and elaborated, without a time-consuming series of analyses (see, for example, Tanik & Yeh, 1989). However, rapid prototyping does not make analytical techniques redundant. Just as in other areas of engineering, the complexity of modern systems requires that the developer analyse the user's need, and document how the system will be used. This is achieved best through some form of task analysis. A review of the use of rapid prototyping in six large-scale projects showed that four system developers had used some form of task analysis to define the user-machine interface in advance of creating the prototype (St. Denis, Bouchard, & Bergeron, 1990). Different techniques had been used to analyse the operators' tasks, including function-flow analysis, operational sequence diagrams, display "frame" analysis (similar to a "story-board" approach), and augmented transition network (ATN) formalisms. The challenge, then, is to find the most effective way to combine task analysis and rapid prototyping, and to use them within a design process that is more iterative than previous ones. Overall, what appears to be required is a task analytical approach which represents what the operator will be doing with a new system, coupled with a "usability" analysis which indicates how the user expects the system to behave, followed by prototyping and rigorous evaluation.

4.4 NEED FOR INTEGRATION OF SYSTEM DEVELOPMENT ACTIVITIES

4.4.1 Increased emphasis on trade-off studies

97. Most systems engineering texts emphasize the importance of conducting trade-off studies to identify the most promising design solution. This is typified by the requirement that "Engineering Decision Studies" shall consist of "engineering decisions regarding design alternatives ...(reflecting) ... system cost effectiveness analysis based on the specified figure(s) of merit, performance parameters, programme schedule, resource constraints, producibility, and life cycle cost factors" (US MIL-STD-499A). In the past, such studies were often of limited scope, and were seldom iterated during the development process. The growing cost of modern systems, coupled with the diversification of technological solutions, increases the emphasis being placed on system trade-off studies (see, for example AGARD, 1989). Such "parametric studies" will require a complementary approach to human engineering analysis. This is likely to emphasize function-allocation studies, as a prelude to trade-offs between simplicity of operation, selection, training, and operator job-aids.

98. Current approaches to trade-off studies treat system performance requirements independently. Typically the requirements are decomposed into a tree (see, for example, Malchow & Croopnick, 1985). Separate branches of the tree deal with "reliability," "maintainability," and "performance," with the latter split into "operations" and "mission parameters" etc. This independent treatment of performance terms is not appropriate for human engineering issues because human performance tends to affect many aspects of system operation. For example, the skill requirements for system operation may determine the skill level available for first-level maintenance. Thus the approach taken to human engineering in such

analyses must cut across different trade-off study areas. This will require improvements to human engineering analysis techniques to make them compatible with parametric studies. The work of NATO AC/243 Panel-8/RSG.21 on "Liveware Integration" may contribute to defining the extent of this problem.

4.4.2 User centred system design

99. McLaughlin (1987) has reported an approach which emphasizes iterative development through user evaluation of a prototype. His "user engineering methodology" has been combined with traditional system engineering techniques to develop complex man-machine systems. The approach is intended to gather data about the potential system users and incorporate those data into the design process as early as possible. The methodology, which parallels the approach recommended for human factors engineering, emphasizes, defines, validates, and maintains the user's view of the system being developed. Similar approaches have been called "user centred system design" (Norman & Draper, 1986), and "usability engineering" (Whiteside, 1988). Typically these approaches involve the development of specifications which include "usability" requirements, development and iteration of user procedures, evolution of the design through iteration, and testing the design using "usability" criteria, as it evolves. A generic approach includes seven steps:

(1) mission and operational concept definition
(2) user/system data extraction
(3) user analysis (establishment of a representative profile of the user)
(4) task analysis
(5) human-computer interface analysis
(6) prototype validation
(7) users' design review

100. This approach parallels that recommended for the application of human engineering described earlier in this report. The approach also parallels the systems engineering process, thereby providing the opportunity for collaboration with systems engineers and developers. Typically, however, the *user analysis* is not performed in military systems engineering studies. This analysis is conducted prior to task analysis to derive a model of the user group. This is because customer requirements for complex man-machine systems are often subjective, vague, incomplete, or unknown (McLaughlin, 1987; Pressman, 1987). A representative profile of the user group is formed from results of interviews, from observations, and from cognitive, work style and personality measures. It should be noted that user analysis has been placed on the human-machine systems research agenda only recently and it will be a long time before methods appropriate for design are established. However, what is important is to be aware that designers implicitly assume a user profile when designing systems, and this profile should be formulated more explicitly.

101. In the user centred approach to design, extensive prototyping, with a lot of developer/end-user interaction, is substituted for the preparation of detailed requirements documents. McLaughlin (1987) claims that "new procurement procedures are needed in order to insure that these activities are conducted early. Formal documentation deliverables in contracts must initially yield to the delivery of prototypes, and the analysis surrounding their development and trial use." Following the user design review more traditional (formal, top-down) system design methods are used.

102. In summary, more widespread use of user centred design approaches and user analysis may require developments or modifications to existing task analysis techniques. The

documentation of a satisfactory design in the form of a prototype, rather than a system specification, presents additional challenges.

4.4.3 Integration of system development activities

103. As the work of NATO AC/243 Panel 8/RSG.9 has shown (McMillan et al., 1989), the use of CAD systems for human factors/ergonomics studies of operator work-space design is increasing steadily. Typically, such systems represent the size range of potential operators and their movement abilities, and permit comparisons of those operators with three-dimensional representations of the work-space (McDaniel & Hoffman, 1990). Advanced versions of such CAD systems permit the representation of a sequence of operator actions.

104. While they do not integrate human factors into the weapon systems acquisition process (WSAP), a variety of human engineering CAD tools exist which integrate human engineering standards or data into the system design. These tools generally assist human engineering practitioners in:

- analyzing requirements for designs
- generating designs
- evaluating designs in terms of reach, clearances and other types of anthropometric assessments

Some examples of state-of-the-art CAD tools are (Booher & Hewitt, 1990):

- CADET (Computer Aided Design and Evaluation Techniques)
- EDG (Engineering Design Graphics system)
- SAMMIE (System for Aiding Man-Machine Interaction Evaluation
- MIDAS (Man-machine Integration Design and Analysis System)

105. Related developments in CAD systems may influence the approach taken to the application of human factors engineering on large systems. Computer-aided Acquisition and Logistic Support (CALS) is a US DoD and industrial initiative to facilitate and speed up the use and integration of digital product information from CAD systems in military procurements, including construction, production, evaluation and maintenance. The long-term goal within CALS is to establish an integrated database covering all aspects of a military system that are common to procurement agency and supplier. CALS technology is currently being evaluated in several projects, e.g., USAF's Advanced Tactical Fighter and the Centurion submarine. Currently, there is a project to include human factors data in CALS. That project may lead to standard human factors data elements and formats. This development is being monitored by NATO AC/243 Panel-8/RSG 21. The US Army's MANPRINT programme parallels CALS in many ways, but the focus is on the engineering more than logistics. Although integrated software tools for human engineering have been developed, the only available set of human engineering tools which are explicitly tailored to MANPRINT is the US Army's MANPRINT IDEA (Integrated Decision/Engineering Aid) which is also being used on an exploratory basis in France, The Netherlands, and the U.K.

106. The developments outlined above suggest the possibility for a much more integrated approach between the human-, system-, and software-engineering aspects of project development. Additional important activities include the development of specifications. The quality of the work done in developing systems specifications is crucial to later success, and greatly affects the system's operational usefulness and life-cycle costs. Increasingly, the importance of systems specifications is being recognized among system developers and users. Given the operational requirements, a general description of the development of specifications might be as follows:

(1) Analyse missions to specify operational mission requirements.
(2) Identify those system functions that are necessary to fulfill mission requirements.
(3) Analyse system functions to determine functional requirements. Decompose functions to an appropriate level, in order to:
(4) Allocate system functions to the various subsystems, e.g., sensor, weapon, command and control sub-systems and to their respective human and machine elements. Consider several alternatives.
(5) Consider those functions which are additionally introduced by the interface between sub-systems and elements (basic types human-human, human-machine, and machine-machine).
(6) Perform a feasibility study of alternatives with regard to costs, reliability, development risk, required quantity and quality of personnel, workload etc. (The human engineering/ergonomics part of the feasibility study includes task analysis and human performance prediction).
(7) Iterate 1-6 until satisfied.

107. These steps paralleled the human engineering analyses which are discussed in Chapters 2 and 3, and described in Volume 2. The weakness of function allocation techniques identified in Chapter 3 argues for improvements to them. Current developments in software engineering may contribute to such improvements. Guidelines are used in structured analysis/design to determine which modules (basic software components), and which interactions between them, will best implement the functional requirements. This parallels the allocation of functions to operators. The guidelines might therefore be described as a function allocation technique.

108. The more important guidelines which are relevant to human engineering are the principles of *cohesion*, *coupling*, and *span of control* (Yourdon, 1989).

Cohesion reflects the need for activities to he related. The content of a software module (task) should contain a single, well-defined activity, not a combination of unrelated activities. Cohesion should be high.

Coupling reflects the degree to which modules (tasks) are interconnected with, or related to one another. The stronger the coupling between modules (tasks) in a system, the more difficult it is to implement and maintain the system (operate the system). The coupling should be low.

Span of Control reflects the number of lower level modules (sub-tasks): the number called by a module should be limited, in order to avoid complexity. The span of control should be limited.

Computer software is available that can assist function allocation, based on these guidelines.

4.5 CONCLUSIONS

109. Available task analysis techniques cannot deal effectively with knowledge-based behaviour. More work is required to develop effective function allocation and cognitive task analysis techniques.

110. As the application of decision aids and knowledge-based systems spreads, so the need for suitable user task-analytical techniques will increase.

111. The growing emphasis on taking a truly integrated approach to project development, including an integrated project data base, argues for finding a common approach to the definition of system functional and performance requirements, in order to include human factors in system performance.

112. There is a need to find the most effective way to combine task analysis and rapid prototyping, and to use them within a design process that is more iterative than previous ones.

113. More widespread use of user centred design approaches and user analysis may require developments or modifications to existing task analysis techniques.

114. The steps recommended for developing systems specifications parallel those for human engineering. The techniques discussed in Chapter 2 and described in Volume 2 are an important means of developing a specification for the human system components. Improvement of existing techniques may benefit from the application of approaches used for structured analysis/design of software.

4.6 RECOMMENDATIONS

115. Panel-8 should support research and development of improved function allocation techniques and task analysis techniques to deal with knowledge-based behaviour.

116. The DRG should collaborate with the NAGs to explore how current technological developments such as CASE and CALS can be used to integrate the human, software, and hardware aspects of project development in such a way that human engineering becomes an inseparable part of the design/development process.

4.7 REFERENCES

1. AGARD (1987). The design, development and testing of complex avionics systems. Conference Proceedings No. 417. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
2. AGARD. (1989). Systems engineering. AGARD Lecture Series No. 164. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
3. Bachert, R.F., Evers, K.H., & Rolek, E.P. (1983). IDEF/SAINT SAM simulation: hardware/human submodels. Proceedings, National Aerospace Electronics Conference (NAECON)
4. Banks, S.B., & Lizza, C.S (1991). Pilot's associate: a cooperative knowledge-based system application. IEEE Experts.
5. Booher, H.R. & Hewitt, G.M. (1990). MANPRINT tools and techniques. In: H.R. Booher (Ed.), MANPRINT: An approach to systems integration (pp. 343-390). New York: Van Nostrand Reinhold.
6. Connor, M.F. (1980). SADT™ structured analysis and design technique introduction. 1980 IEEE Engineering Management Conference Record (pp.138-143).
7. Diaper, D. (Ed.) (1989). Task analysis for human-computer interaction. Chichester, U.K.: Ellis Horwood Ltd.

8. Grant, A.S., & Mayes, J.T. (1991). Cognitive task analysis? In: G.R.S. Weir & J.L. Alty (Eds.) Human-computer interaction and complex systems (pp. 147-167). New York: Academic Press Ltd.
9. Hawley, J.K, & Risser, D.T (1986). A practical approach to MANPRINT. Alexandria VA: U.S. Army Institute for the Behavioral and Social Sciences.
10. Johnson, P., Diaper, D., & Long, J. (1985). Tasks, skills and knowledge: task analysis for knowledge based descriptions. In: B. Shackel (Ed.), Human-computer interaction – INTERACT '84 (pp. 499-503). North Holland: Elsevier Science Publishers B.V.
11. Kraiss, K.F. (1989). Human factors aspects of decision support systems. In: Operational decision aids for exploiting or mitigating electromagnetic effects. AGARD Conference Proceedings No. 453. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
12. Lovesey, E.J. (1977). The instrument explosion – a study of aircraft cockpit instruments. Applied Ergonomics 8 (1), 23-30.
13. Malchow, H.L., & Croopnick, S.R (1985). A methodology for organising performance requirements for complex dynamical systems. IEEE Transactions on Engineering Management, EM-32 (1).
14. McDaniel, J.W., & Hoffman, M.A. (1990). Computer-aided ergonomic design tools. In: H.R. Booher (Ed.), MANPRINT: An approach to systems integration (pp. 205-235). New York: Van Nostrand Reinhold.
15. McLaughlin, L. (1987). User engineering, a new look at system engineering. TRW Defense Systems.
16. McMenamin, S.M., & Palmer, J.F. (1984). Essential systems analysis. New York: Yourdon Inc.
17. McMillan, G.R, Beevis, D., Salas, E., Strub, M.H., Sutton, R., & Van Breda, L. (1989). Applications of human performance models to system design. New York: Plenum Press.
18. Meister, D. (1986). A survey of test and evaluation practices. In: Proceedings of the Human Factors Society 30th. Annual Meeting. Santa Monica, CA: Human Factors Society, 1239-1243.
19. Merriman, S.C., Muckler, F., Howells, H., Olive, B.R., & Beevis, D. (1984). Workshop on applications of systems ergonomics to weapon system development. Volume II. DS/A/DR(84)408. Brussels: NATO.
20. NATO (1983). Long term scientific study on the implications of new technologies for land operations in the central region (LO/2000). NATO AC/243-D/830. Brussels: NATO.
21. NATO RSG.12 (1990). Final report from RSG.12 on computer-human interaction in command and control. AC/243 (Panel 8/RSG.12) D/7. Brussels: NATO Defence Research Group.
22. Nordwall, B.D. (1991). A340 electronic displays created with automated software system. Aviation Week & Space Technology, February 4, pp. 56 - 57.
23. Norman, D.A., & Draper, S.W. (Eds.). (1986) User centred system design: new perspectives on human-computer interaction. Hillsdale, N.J.: Lawrence Erlbaum Associates Inc.
24. Pressman, R.S. (1987). Software engineering: A practitioners approach. New York: McGraw-Hill.
25. Price, C.P., & Forsyth, D.Y. (1982). Practical considerations in the introduction of requirements analysis techniques. In: Software for avionics. AGARD CP-330. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
26. Price, H.E., Fiorello, M., Lowry, J.C., Smith, G., & Kidd, J. (1980). The contribution of human factors in military system development: methodological considerations. (Technical Report 476). Alexandria, Virginia: U.S. Army Research Institute for the Behavioral and Social Sciences.

27. Rasmussen, J. (1976). Outlines of a hybrid model of the process operator. In: T.B. Sheridan & G. Johanssen (Eds.), Monitoring behaviour and supervisory control. London: Plenum Press.
28. Redding, R.E. (1989). Perspective on cognitive task analysis: the state of the art of the state of the art. In: Proceedings of the Human Factors Society 33rd Annual Meeting. Santa Monica, CA: Human Factors Society, 1348-1352.
29. Rouse, W.B., Geddes, N.D., & Curry, R.E. (1988). An architecture for intelligent interfaces: An outline of an approach to supporting operators of complex systems. In: Human Computer Interaction, 1987-88. (3), (pp. 87-122). Hillsdale, N.J.: Lawrence Erlbaum Associates.
30. Schimsky, D. (1987). Technical Evaluation Report. In: The Design, Development and Testing of Complex Avionics Systems. Conference Proceedings No. 417 (pp. viii - xiv). Neuilly-sur-Seine, France: Advisory Group for Research and Development.
31. SD-Scicon plc. (1988). Controlled Requirements Expression. Camberley, Sy: U.K.
32. St. Denis, G., Bouchard, J.C., & Bergeron, G. (1990). How to facilitate the process of translating system requirements into a virtual prototype: VAPS, the design process, and human engineering. Virtual Prototypes Inc., Montreal. Toronto: DCIEM Report.
33. Stubben, M.A. (1987). AFTI/F-16 – Impact of cockpit automation on pilot acceptance. In: The man-machine interface in tactical aircraft design and combat automation. AGARD-CP-425, pp. 32-1 – 32-10. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
34. Tanik, M.M. & Yeh, R.T. (1989, May). Rapid prototyping in software development: Guest editors' introduction. Computer, pp 9-10.
35. Terranova, M., Snyder, C.E., Seamster, T.L. & Treitler, I.E. (1989). Cognitive task analysis techniques applied to airborne weapons training. In: Proceedings of the Human Factors Society 33rd Annual Meeting, 1358 -1362.
36. Topmiller, D.A. (1981). Methods: past approaches, current trends and future requirements. In: J. Moraal & K-F. Kraiss (Eds.), Manned System Design: Methods, Equipment, and Applications. New York: Plenum Press.
37. US Defense Science Board Task Force on Military Software. (1987). Report.
38. Wallace, R.H., Stockenberg, J.E., & Charette, R.N. (1989). A Unified Methodology for Developing Systems. New York: McGraw-Hill.
39. Weingaertner, S.T., & Levis, A.H. (1989). Analysis of decision aiding in submarine emergency decisionmaking, Automatica, 25, (3), 349-358.
40. Whiteside, J. (1988). Usability engineering: our experience and evolution. In: M. Helander (Ed.), Handbook of human-computer interaction, (Chapter 39). North Holland: Elsevier Science Publishers B.V.
41. Wilson, J., & Rosenberg, D. (1988). Rapid prototyping for user interface design. In: M. Helander (Ed.), Handbook of human-computer interaction, (Chapter 39). North Holland: Elsevier Science Publishers B.V.
42. Yourdon, E. (1989). Modern structured analysis. Englewood Cliffs, N.J.: Yourdon Press.

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CHAPTER 5
RECOMMENDATIONS FOR STANDARDIZATION

5.1 INTRODUCTION

117. The objective of this chapter is to review the current state of standardization of human engineering analysis techniques and identify any problems regarding the specification of analytical techniques and the need for standardization within NATO, and to suggest an approach to such standardization.

5.2 STATE OF STANDARDIZATION OF HUMAN ENGINEERING ANALYSIS TECHNIQUES

118. The current extent of NATO standardization of human engineering analysis techniques was reviewed in three steps. These steps examined:

- the status of human engineering standardization
- the status of human engineering analytical techniques within existing standards
- the description and use of analytical techniques within requirements documents

119. In addition, trends or changes in the approach to requirements documentation were examined. Chief of these are the use of application-specific requirements documents, and the use of commercial specifications. In addition, the implications of the growing use of computers for systems design and development were reviewed.

5.2.1 Human engineering standardization

120. The status of human engineering (HE) standardization was addressed by reviewing 51 applicable standards, specifications, guidelines, and other relevant documents used by the RSG member nations to control the application of human engineering. The requirements documents and the countries which use them are shown in Appendix A. Based on this review and on communications with users it was concluded that the majority of the nations represented in the RSG apply human engineering requirements documents in their weapon system acquisition projects. Not all nations have their own national requirements documents.

5.2.2 The status of human engineering analytical techniques

121. A review was made of the material listed in Appendix A and of additional standards provided by member countries to identify those standards covering human engineering analysis techniques. Most of the documents reviewed specify design criteria. Fourteen requirements documents which reference analytical techniques were identified (see Table 5.1). The current status is that some RSG.14 member nations have a single requirements document that identifies some techniques, while a few member nations identify techniques and describe them in detail in national HE guidelines or handbooks. Standards, specifications, and directives are mainly management documents and, in general, they do not provide technical details on a technique. Guidelines or handbooks, on the other hand, provide technical details on the techniques.

Table 5.1: Requirements documents which reference analytical techniques

1.	This report
STANDARDS	
2.	STANAG 3994 Application of human engineering to advanced aircraft systems (NATO)
3.	DEF STD 00-25 Human factors for designers of equipment: (Part 12) Systems (UK)
SPECIFICATIONS	
4.	MIL-H-46855B Human engineering requirements for military systems, equipment and facilities (US)
5.	DI-HFAC-80740 Human engineering program plan (US)
6.	DI-HFAC-80742 Human engineering dynamic simulation plan (US)
7.	DI-HFAC-80745 Human engineering system analysis report (US)
8.	DI-HFAC-81197 Task performance analysis report (US)
GUIDELINES & HANDBOOKS	
9.	ANEP-20 Human factors/ergonomics in the development and acquisition of ship weapon systems (NATO)
10.	Human factors guide DGA/MAQ/4114 (FR)
11.	DoD-HDBK-763 Military handbook: human engineering procedures guide (US)
12.	DoD Directory of design support methods (US)
13.	Advanced human factors engineering tool technologies (US)
14.	Guide for performing functional analysis DEN/CMQ 88610 (FR)
DIRECTIVES	
15.	Directive - Ergonomics in the Federal Armed Forces (GE)

5.2.3 The description of analytical techniques within requirements documents

122. The documents listed in Table 5.1 were analysed to identify the analytical techniques which they referenced or described. The major analytical techniques described were categorized as:

- systems engineering analysis techniques
- general human engineering or human performance analysis techniques
- human factors analysis techniques
- specific sub-field human engineering techniques, e.g., noise, visual displays, etc.

In order to develop the list of human engineering analytical techniques covered by the documents, the choice was made to:

- include systems engineering techniques which are analogous to, or include, a human engineering component

- include general human engineering analytical techniques
- include human systems integration techniques which are analogous to, or include, a human engineering component
- exclude analytical techniques specific to a technical sub-field such as noise, lighting, vibration etc.

123. Table 5.2 shows the human engineering techniques reviewed in this report and the requirements documents listed in Table 5.1 which refer to or describe specific techniques.

Table 5.2: Human engineering techniques referenced & described in standards, specifications and guides

Technique	Referenced in *	Described in
Narrative mission descriptions	1, 7	1
Graphic mission profiles	1, 4,11	1, 11
Function flow diagrams	1, 2, 3, 4, 11, 13	1, 3, 11,14
SAT	1, 2, 3	1
SADT/IDEF/CORE	1, 2	1
Information flow and processing	1, 4, 7	1
State transition diagrams	1	1
Petri nets	1	1
Behaviour graphs	1	1
Ad-hoc function allocation	1, 2, 3, 4, 5, 7, 9, 11, 15	1, 11
Fitts' list	1	1, 11
Review of operator capabilities	1, 2, 4, 7, 9, 15	1, 2
Function allocation evaluation matrix	1, 11	1, 11
Requirements allocation sheets	1	1
Time lines	1, 2, 4, 11,	1, 11
Flow process charts	1, 11	1, 11
Operational sequence diagrams	1, 2, 3, 11, 15	1, 3, 11
Information/action tabulations	1, 11	1, 11
Critical task analysis	1, 3, 4, 8, 11	1, 3, 8, 11
Decision tables	1	1
Time line analysis of workload	1, 11, 13 (TLA-1, WAM)	1, 11, 13
SAINT	1, 11, 12 (MicroSAINT), 13	1, 12, 13
SIMWAM	1, 12, 13	1, 12, 13
Subjective workload ratings	1, 13 (OWL)	1
SWAT	1, 2, 3, 4, 6, 9, 10, 11, 13	1, 11, 13
NASA -TLX	1, 13	1, 13
Error analysis	1, 2, 3	1, 3
Analysis of human error in accidents & incidents	1	1
Design option decision trees	1	1
Critical design requirements	1	1
Link analysis	1, 3, 11	1, 3, 11

* Refers to document number in Table 5.1

5.2.4 Use of application-specific and commercial standards

124. In France, Germany, and the United States there are trends, with respect to design and management standards, to develop specifications and standards for specific service applications, e.g., the USAF MIL-STD-1800 and the French Military Service Directives. This reverses the trend towards a single, tri-service standard or specification, which was the norm in the past decade. Within NATO the main standardization effort in human-machine systems is in design. Applicable human engineering requirements documents include STANAGs and ANEPs. There is some work in progress in NATO to standardize human engineering analysis techniques for specific applications, e.g., NNAG AC 141 (IEG/6) SG/8 on The Influence of Human Factors on Ship Design (see Table 5.3). However, no effort to produce a general standard for human engineering analysis within NATO is known. The three military components within NATO (Army, Navy, and Air Force) appear to be taking different approaches to standardizing human engineering techniques. The army component has developed a standard for the test and evaluation of land vehicles and is developing similar standards for other army systems; the air force component is supporting NATO MAS AIP STANAG 3994; and the navy component is supporting NNAG IEG/6 S/G-8 Allied Naval Engineering Publications (ANEPs) on human factors.

Table 5.3: Allied Naval Engineering Publications (ANEPs) concerning human factors in ship design

ANEP #	TITLE
20.	Human factors/ergonomics in the development and acquisition of ship weapon systems.
21.	Procedure for ships manning for NATO surface ships.
22.	Human factors considerations for the determination of automation policy.
23.	The influence of maintenance on manning.
24.	Guidelines for shipboard habitability requirements for combatant surface ships.
25.	Guidelines for environmental factors in NATO surface ships.
26.	Ergonomics data for shipboard space design in NATO surface ships.
27.	Human factor guidelines for the design of man/machine interfaces in operational rooms.
28.	Guidelines for the development of Operational Stations Book (OSB) for NATO naval vessels.

125. In the USA, there is a trend towards the use of commercial specifications for specific applications, in particular for non-developmental items, Government Furnished Equipment (GFE), and other off-the-shelf equipment. American Society of Testing and Materials (ASTM) Standard Practice 1166 is an example of a requirements document that has been developed to address non-developmental items and equipment. Such an approach may become more widespread, particularly for computing equipment and vehicles. NATO should consider adopting international commercial standards, such as appropriate ISO standards.

5.2.5 Growing use of computer-based analysis techniques

126. As discussed in Chapter 4, there is a growing amount of software which can be used for the integration of systems development activities, including human engineering analyses. The largest and most ambitious attempt to do this is CALS. Such systems will impose standard data structures and terminology on systems developers and project managers. Standardization within NATO would be a useful development. Computer software could be developed and used to:

- establish a NATO-agreed data base with personal computer (PC) access, for the techniques covered in this report
- integrate human engineering analytical techniques into and as part of a NATO-agreed system engineering analysis technique data base with PC access
- develop analytical techniques in an expert system format for ease of application and cost savings
- develop modules which can be integrated into NATO CAD/CAM processes

5.3 PROBLEMS AND THE NEED FOR STANDARDIZATION OF ANALYTICAL TECHNIQUES

127. The second stage of the review concentrated on reviewing problems associated with the specification of human engineering analysis techniques, and with standardization within NATO. Three problem areas were identified:

- lack of requirements documents addressing human engineering analysis techniques
- lack of a common definition of human engineering
- lack of documents tailored to specific users

5.3.1 Lack of requirements documents addressing analysis

128. The first problem that can be identified from Appendix A and Table 5.1 is that there is a lack of adequate documents within NATO and within most member nations which govern human engineering analysis techniques. The vast majority of human engineering requirements documents are concerned with design criteria. Table 5.2 shows that most of the techniques which are reviewed in Chapter 3 and described in Volume 2 are referenced in only a few specifications and standards. Technical descriptions of these techniques appear in even fewer documents. Table 5.4 shows the number of references to specific techniques and the number of techniques described in the requirements documents listed in Table 5.1. As might be expected, some techniques described in this report are referenced more frequently than others. Overall, of the 31 techniques described in Chapter 3, only nine (29 %) are referenced in any national or international standard.

129. Detailed descriptions of the techniques are even more scarce: only four of the requirements documents listed in Tables 5.1 and 5.4 describe only more than one technique, and half describe none. This may reflect the attitude of many procurement agencies that the contractor shall not be told how to perform the work required. Nevertheless, it could be expected that requirements documents would list the generic stages of human engineering analysis, as outlined in Chapter 3. That is not the case: only STANAG 3994, U.K. DEF-STD-00-25 Part 12, the French "30 Questions" and U.S. MIL-H-46855B cover all the generic steps in human engineering analysis.

Table 5.4: Number of analysis techniques referenced and described

	Referenced	Described
1. This report	31	31
STANDARDS		
2. STANAG 3994	9	1
3. DEF-STD-00-25 Part 12	7	5
SPECIFICATIONS		
4. MIL-H-46855B	8	0
5. DI-HFAC-80740	2	0
6. DI-HFAC-80742	1	0
7. DI-HFAC-80745	4	0
8. DI-HFAC-81197	1	1
GUIDELINES & HANDBOOKS		
9. ANEP-20	3	0
10. Human Factors Guide DGA/MAQ/4114	1	0
11. DoD-HDBK-763	13	13
12. DoD Directory of design support methods	2	2
13. Advanced HFE tool technologies	6	5
14. Guide for performing functional analysis DEN/CMQ 88610	1	1
DIRECTIVES		
15. Directive - Ergonomics in the Federal Armed Forces	3	0

130. Although the relevant guidelines and handbooks should complement the standards and specifications by providing amplifying information, there are few which describe the more than two or three techniques. The most comprehensive guide, U.S. DoD-HDBK-763, describes only 42% of the analysis techniques reviewed in this report. Within NATO, ANEP-20 is directed to ship design applications, but mentions only three techniques. These findings strongly support the need for NATO documents which provide information for project managers on human engineering analysis tools and when to use them, and describe the techniques in detail for the professional specialist who will employ them.

5.3.2 Differences in terminology

131. There are differences in the terminology used by member nations to cover the area of human engineering. In their standards, the U.K. uses the term Human Factors, France and

the FRG use the term Ergonomics, and the U.S., Canada, and NATO STANAG 3994 use the term Human Engineering. The reader is referred to the Glossary for definition of these terms. Since the mid-1960s, all U.S. specifications and standards have used the term Human Engineering (HE). In the U.S., the area of Human Factors (HF) or Human Systems Integration (HSI) area is defined by the DoD to include Manpower, Personnel, Training, Systems Safety, Health Hazards and Human Engineering. Human Factors Engineering is a term that is also being used in recent DoD standards (U.S. MIL-STD-1800). The major specifications and standards use the term Human Engineering but include analytical techniques that are common to Human Engineering and other Human Factors disciplines. The issue of terminology will have to be dealt with if NATO standards, specifications and guidelines are to be developed.

132. In addition to differences in terminology, a number of the analytical techniques addressed in Chapter 3 and Volume 2 of this report and in requirements documents listed in in Table 5.1 are primarily systems engineering analysis techniques.

5.3.3 Lack of documents tailored to specific users

133. In engineering practice, *standards* establish engineering or technical limitations for designs, materials, processes, or methods; *specifications* describe the technical requirements for items, materials or services; and *guidelines and handbooks* provide advice. Consistent with this, the standards reviewed cover design requirements, the specifications reviewed list analysis techniques to be used in the development process, and the guidelines and handbooks describe analysis techniques in detailed terms for technical personnel. The standards and specifications that cover analytical techniques do not define decision criteria as to when to employ the technique or other salient technical comparison factors of interest to a project manager. Most handbooks and guidelines are written for the technical specialist and emphasize detailed technical descriptions of individual techniques; most do not include effort and schedule information.

5.4 AN APPROACH TO THE DEVELOPMENT OF NATO REQUIREMENTS DOCUMENTS

5.4.1 An approach for a standard

134. The lack of requirements documents that address human engineering analysis techniques demonstrates the need for a NATO standard to address this requirement. This need can be best achieved by using the documents that do address such techniques as a basis for creating a NATO management document or a requirements document. The candidates in that regard are U.S. MIL-H-46855, U.K. DEF STD 00-25, and STANAG 3994. In addition, NATO should consider the adoption of international commercial standards, such as appropriate ISO standards for non-developmental items.

5.4.2 An approach for specifications and guides

135. In the material submitted for this chapter by RSG.14 members, most analysis techniques are merely listed or described in a cursory manner. It is apparent that human engineering analysis techniques must not only be addressed in requirements documents but they must also be described in greater detail along with assessments of value and usage. Detailed technical descriptions and technical trade-offs among competing methods need to be addressed in specialist handbooks. In addition to the material in Volume 2 of this report, DoD-HDBK-763, the DoD Directory of Design Support Methods, and Advanced HFE Tool Technologies are the primary guides that provide the information required.

136. There is a need to develop handbooks for both management and specialists. The management handbooks need to clearly and simply address usage criteria such as when the technique should be employed as well as cost and value comparisons, i.e., what the programme manager needs, based on the NATO-agreed life cycle phases used in this report. Sawyer et. al (1981) provide some guidance on the contents of a manager's handbook. The specialist handbooks should give technical descriptions of the specific processes and technical value comparisons between them. Such information is included in Volume 2 of this report and U.S. DoD-HDBK-763. Those documents provide the basis for NATO handbook development.

5.4.3 An approach for computer based system development

137. Within the context of the development of CAD, MANPRINT-IDEA, and the CALS systems, NATO agencies should consider the development and application of computer software to facilitate the application of a standard approach to human engineering analysis and to provide computer-aided guidance to project managers and system developers.

5.4.4 Approach summary

138. The steps recommended in this developmental process are to:

(1) Review and combine the information in the existing NATO and national specifications into a NATO standard which lists and describes the generic techniques.

(2) Develop a NATO programme manager-oriented guide or handbook which covers technique and employment characteristics, with particularly emphasis on phases of application and cost-benefit parameters.

(3) Develop a NATO technical human engineering analyst-oriented handbook which not only identifies and clarifies analytical techniques but also describes them in detail.

(4) Study the development of computer based standards, specifications and guidelines to facilitate the application of human engineering in NATO projects.

5.5 CONCLUSIONS

139. From the review of national and NATO standards, specifications and guides covering human engineering issues, the following conclusions are drawn:

1) There are few requirements documents which govern human engineering analytical techniques: most are design criteria specifications.

2) Of the few national or NATO specifications that cover analytical techniques, most only identify or list the technique and do not provide additional employment or technical information.

3) Existing handbooks and guides are not tailored to specific users of the information, and none cover information required by all users, e.g., programme managers, human engineering specialist designers, and operational personnel.

4) The development of computer software tools for human engineering analyses and of application-specific human engineering specifications, and the growing use of commercial specifications for procurement, will require modifications to the current approach to human engineering standardization in NATO.

5.6 RECOMMENDATIONS

140. The RSG makes the following recommendations with respect to the standardization of human engineering analysis techniques:

(1) The NATO agencies responsible for standardization should consider the development of standards and specifications which identify human engineering analysis techniques.

(2) The DRG should consider publication of Volume 2 of this report as NATO guidelines for human engineering analysis techniques, and as a basis for the development of user specific guidelines.

(3) The NATO agencies responsible for standardization should consider the use of computer software, application-specific specifications, and commercial specifications in future procurement projects.

5.7 REFERENCES

1. Bognor, S., Kibbe, M., & Lane, R. (1990). Directory of design support methods. San Diego, CA: US Department of Defense, Manpower and training Research Information System.
2. Department of Defense. (1979). Human engineering requirements for military systems, equipment, and facilities. MIL-H-46855B. Washington D.C.: US Army Missile R&D Command.
3. Department of Defense (1987). Human engineering procedures guide. DoD-HDBK-763. Washington D.C.
4. Department of Defense (1987). Human engineering program plan. DI-DFAC-80740. Washington D.C.
5. Department of Defense (1987). Human engineering dynamic simulation plan. DI-HFAC-80742. Washington D.C.
6. Department of Defense (1987). Human engineering system analysis report. DI-HFAC-80745. Washington D.C.
7. Department of Defense (1987). Task performance analysis report. DI-HFAC-81197. Washington D.C.
8. DGA. Human factors guide. DGA/MAQ/4114.Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament, Mission assurance de la qualité.
9. DGA (1988). Guide for performing functional analysis.DEN/CMQ No. 88610. Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament.
10. Fleger, S., Permenter, K. & Malone, T. (1987). Advanced HFE tool technologies. Falls Church, Virginia: Carlow Inc.
11. MoD PE (1987). Human factors for designers of equipment: Part 12 systems. DEF STD 00-25. London: Ministry of Defence Procurement Executive.
12. NATO MAS (1991). Application of human engineering to advanced aircraft systems. (STANAG 3994 AI (Edition 1)), Brussels: NATO Military Agency for Standardization.
13. NATO NNAG (1992). Human factors/ergonomics in the development and acquisition of ship weapon systems. Brussels: NATO Naval Armaments Group, Information Exchange Group 6.
14. Sawyer, C.R., Fiorello, M., Kidd, J.S. & Price, H.E. (1981). Measuring and enhancing the contribution of human factors in military system development: case studies in the

application of impact assessment methodologies. Appendix B. Technical Report 519. Alexandria, Virginia: US Army Institute for the Behavioral and Social Sciences.

15. __________(1989). Directive: ergonomics in the Federal Armed Forces. Bonn: Federal Office for Military Technology and Procurement.

Appendix A to Chapter 5: Human engineering requirements documents in use in member nations

Appendix A to Chapter 5

	SYSTEM DEVELOPMENT PHASE		
	Preliminary studies	Concept formulation	Concept validation
STANDARDS			
All STANAGS	–	FR	FR
Aircraft Instrument Panel STANAGS	–	CA	CA
STANAG 3217	UK	UK	UK
STANAG 3705	–	NL, UK	NL, UK
STANAG 3994	CA, NL, UK	CA, NL, UK	CA, NL, UK
STANAG 4239D	–	NL	NL
STANAG 7020	–	NL, UK	NL, UK
DIN and Defence Equipment Standards (GE)	–	GE	GE
DEF STD 00 12 (Climate) (UK)	UK	UK	UK
DEF STD 00 25 (Parts 1-12) (UK)	UK	UK	UK
DEF STD 00 27 (Noise) (UK)	UK	UK	UK
BS 6841 (Vibration) (UK)	UK	UK	UK
DEF STD 00970 (UK)	–	NL	NL
MIL-STD-250D (US)	–	US	US
MIL-STD-850B (US)	–	US	US
MIL-STD-1333B (US)	–	US	US
MIL-STD-1472D (US)	–	CA, FR, GE, NL, UK	CA, FR, GE, NL, NO, UK
MIL-STD-1478 (US)	–	–	US
Naval Engineering Standards (US)	–	–	–
ASTM 1166 (US)	–	–	–
NASA-STD-3000 (US)	–	–	–
SPECIFICATIONS			
MIL-H-46855B (US)	CA, UK, US	CA, FR, GE, UK, US	CA, FR, GE, UK, US
DI-HFAC-80740 (US)	CA, US	CA, US	CA, US
DI-HFAC-80741 (US)	CA	CA, US	CA, US
DI-HFAC-80742 (US)	CA, US	CA, US	CA, US
DI-HFAC-80743 (US)	–	–	CA, US
DI-HFAC-80744 (US)	–	–	CA
DI-HFAC-80745 (US)	CA, US	CA, US	CA, US
DI-HFAC-80746 (US)	–	–	CA, US
DI-HFAC-80747 (US)	–	–	CA, US
DI-HFAC-81197 (US)	–	–	US

Appendix A to Chapter 5

SYSTEM DEVELOPMENT PHASE				
Definition	Design & development	Production	Operational use	Up/down grading, retirement
FR	FR	FR	–	FR
CA	CA	–	–	CA
UK	UK	–	–	–
NL, UK	NL, UK	–	–	–
CA, NL, UK	CA, NL, UK	–	–	CA, UK
NL	NL	–	–	–
NL, UK	NL, UK	–	–	UK
GE	GE	GE	–	GE
UK	UK	–	–	UK
UK	UK	–	–	UK
UK	UK	UK	UK	UK
UK	UK	–	–	UK
NL, UK	NL, UK	UK	–	UK
NL	NL	–	–	–
NL	NL	–	–	–
NL	NL	–	–	–
CA, FR, GE, NL, NO, UK	CA, FR, GE, NL, NO, UK, US	CA, FR, GE, NL, UK	US	CA, UK, US
US	US	–	–	–
	US	US	–	–
	US	US	US	US
	US	US	US	US
CA, FR, GE, UK, US	CA, FR, GE, UK, US	FR, US	–	CA, UK
CA, US	CA, US	CA, US	–	CA, US
CA, US	CA, US	–	–	–
CA, US	CA, US	CA, US	–	CA, US
CA, US	CA, US	–	–	CA, US
CA	CA	–	–	CA
CA, US	–	–	–	CA, US
CA, US	CA, US	–	–	CA, US
CA, US	CA, US	–	–	CA, US
US	US	–	–	–

Appendix A to Chapter 5

	SYSTEM DEVELOPMENT PHASE		
	Preliminary studies	Concept formulation	Concept validation
GUIDELINES & HANDBOOKS			
NATO NAG ANEPs 20-28	CA, NL	CA, GE, NL	CA, GE, NL, US
Engineering Data Compendium	UK	CA, UK	CA, UK
Ergodata (FR)	FR	FR	FR
Guide d'Ergonomie (FR)	FR	FR	FR
Les 30 Questions qu'il Faut Se Poser (FR)	FR	FR	FR
Handbook of Ergonomics (GE)	-	FR, GE	FR, GE
Design/Construction Guidelines (Ships) (GE)	-	GE	GE
Mod/DTI HF Guidelines (UK)	UK	UK	UK
MIL-HDBK-759A (US)	-	NL	NL
MIL-HDBK-763 (US)	CA, GE, US	CA, GE, US	CA, GE, US
MISCELLANEOUS DOCUMENTS			
AFNOR (FR)	-	FR	FR
Directive IMN 01514 (FR)	FR	FR	FR
Air Force Directive (FR)	FR	FR	FR
Navy Directive (FR)	FR	FR	FR
Army Directive (FR)	FR	FR	FR
Directive - Ergonomics in Fedrl Forces (GE)	GE	GE	GE
General Ergonomic Requirements (GE)	-	GE	GE
Checklist BWB AT II (GE)	-	-	-
Job Instruction "Engineering" AWT 341 (GE)	-	GE	GE
Navy Requirement No. 8 (GE)	-	GE	GE
Health & Safety Executive (Toxicity) (UK)	UK	UK	UK
NAVSTAR Code (US)	-	-	-

Appendix A to Chapter 5

SYSTEM DEVELOPMENT PHASE				
Definition	Design & development	Production	Operational use	Up/down grading, retirement
CA, GE, NL, US	CA, GE, US	GE, US	–	CA, GE, US
CA, UK	CA, UK	–	–	CA, UK
FR	FR	FR	FR	
FR	FR	FR	FR	FR
FR	FR	FR	–	FR
FR, GE	FR, GE	FR, GE	FR, GE	GE
GE	GE	GE	–	GE
UK	UK	–	–	UK
CA, NL	CA, NL	–	–	–
CA, GE, US	GE	GE	–	GE
FR	FR	FR	–	–
FR	FR	FR	FR	FR
FR	FR	FR	FR	FR
FR	FR	FR	FR	FR
FR	FR	FR	FR	FR
GE	GE	GE	GE	GE
GE	–	GE	GE	–
GE	GE	–	–	–
GE	GE	–	–	–
GE	–	–	–	–
UK	UK	UK	UK	UK
UK	–	–	–	–

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CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

141. In the development of military systems and equipment, human factors (human engineering, manpower, personnel, training, system safety and health hazards) must be included in the life cycle of development. A survey of the application of human engineering analysis techniques in thirty-three projects in seven NATO nations showed that patterns of use vary widely between nations and between individual users. The techniques fall into six categories of analysis: mission analysis, function analysis, function allocation, task analysis, performance prediction, and interface and workspace design. The mean level of application of different classes of analysis technique was lower than might be expected. The use of the various classes of technique differed widely: task analyses were reported four times more frequently than mission analyses.

6.2 AVAILABLE HUMAN ENGINEERING ANALYSIS TECHNIQUES

142. RSG.14 therefore reviewed human engineering analysis techniques which are available to assist system designers and developers. The review has shown that a wide variety of human engineering analysis techniques are available; it covers thirty-one typical examples. The review is not an exhaustive survey of all the existing variants of those techniques. More extensive lists of techniques are referenced in Chapter 3 and Volume 2.

143. The techniques provide a decomposition of the system design problem area which results in defined functions, sub-systems, or states. These functions, sub-systems, or states are then characterized and validated. When recombined, these items allow the prediction of the system performance and operator/maintainer workload. In general, it is assumed that the prediction of system performance is valid if it is based on the validated performance of functions or sub-systems.

144. Half of the techniques reviewed are similar to, or related to, techniques used for systems engineering analysis. Normally, the classes of technique should be used in sequence. Selection of a particular technique will depend on the size of the project, position in project cycle, and scope for innovation and design. The actual starting point in the sequence may depend on project constraints and priorities and the extent to which human engineering has been accepted into the project. In selecting the techniques to use at each stage of analysis, users are advised to work backwards through the chain of analyses to ensure the continuity of information flow.

145. There are few reports of the application of these techniques to simple systems. Applicability of a specific technique also depends on the chain of analyses, as outlined above. Most analyses require few resources and can be performed with paper and pencil, but nearly all benefit from use of a computer for tracking and editing the data. There is a need for such programs to be integrated, rather than stand-alone, so that data are not re-entered many times. Few computer tools have been developed to date, but they are growing in number.

146. The quality assurance aspect of the various techniques are not widely understood. Managers and practitioners should pay more attention to quality assurance factors. The link from human engineering analyses to system performance requirements is not direct. in most cases. The majority of the "classic" human engineering analyses do not have a direct relationship to system performance requirements. Those analyses which have a direct link use interval or ratio scale measures. The techniques used for function allocation are not yet mature, and the full sequence of analyses must be completed and reiterated if they are to address system performance.

6.3 THE NEED FOR NEW OR IMPROVED TECHNIQUES

147. Increasingly, modern systems emphasize knowledge-based operator behaviour. Available task analysis techniques cannot deal effectively with that class of behaviour. More work is required to develop effective cognitive task analysis techniques. The growing application of decision aids and knowledge-based systems leads to new operator and maintainer tasks. As these applications increase, so the need for suitable user task-analysis techniques will increase.

148. The growing emphasis on taking a truly integrated approach to project development, including an integrated project data base, argues for finding a common approach to the definition of system functional and performance requirements, in order to include human factors in system performance.

149. The use of rapid prototyping and user interface management systems is growing. Therefore, there is a need to find the most effective way to combine task analysis and rapid prototyping and of using them within a design process that is more iterative than previous ones.

150. Modern system design focuses increasingly on the user. More widespread use of user-centred design approaches and user analysis may require developments or modifications to existing task analysis techniques.

151. The steps recommended for developing systems specifications parallel those for human engineering (as outlined in Chapter 2). The techniques discussed in Chapter 3 and described in Volume 2 are an important means of developing a specification for the human system components.

6.4 THE NEED FOR STANDARDIZATION

152. The review of over fifty standards, specifications, and guidelines for human engineering showed that there are few requirements documents which govern human engineering analytical techniques; most are design criteria specifications. Of the few national or NATO specifications that cover analytical techniques, most usually only identify or list the technique and do not provide additional employment or technical information.

153. Existing handbooks and guides are not tailored to specific users of the information, and none cover information required by all their users, e.g., programme managers, human engineering specialist designers, and operational personnel.

154. Therefore, there is a need for NATO standards, specifications, and guidelines for human engineering analysis techniques which can be used by all member nations. The development of computer software tools for human engineering analyses and of application specific human engineering specifications, and the growing use of commercial specifications for procurements, will require modifications of the current approach to human engineering standardization in NATO.

6.5 RECOMMENDATIONS

155. Panel-8 should support research and development of function allocation and task analysis techniques to deal with cognitive behaviour, as discussed in Chapters 3 and 4.

156. The DRG should collaborate with the NATO agencies responsible for standardization to ensure the application of human engineering in NATO projects through the development of standards, specifications, and guidelines which identify and describe human engineering analysis techniques, the latter based on Volume 2 of this report, as discussed in Chapter 5.

157. The DRG should collaborate with the NAGs to explore how current technological developments can be used to integrate the human, software, and hardware aspects of project development in such a way that human engineering becomes an inseparable part of the design/development process based on the use of computer software, as discussed in Chapter 3.

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ANNEX I: GLOSSARY OF TERMS AND ACRONYMS

allocation of functions – see function allocation.

analysis – the resolution of anything complex into its simple elements.

ANEP – Allied Naval Engineering Publication.

CAD – Computer Aided Design.

CALS – Computer aided Acquisition and Logistics Support. A US DoD and industry initiative to transfer the design process from one based on paper to one based on computer data by developing data exchange standards and data bases for design, reliability, and maintenance information.

CASE – Computer Aided Software Engineering.

CNAD – Council of NATO Armaments Directors.

cognitive behaviour – All aspects of knowledge, including perceiving, remembering, imagining, conceiving, judging, and reasoning.

cohesion – A term used in structured analysis/design approaches to software development referring to the extent to which a software module deals with a single, well–defined activity.

contractor – An organization, usually in industry, which contracts to perform engineering activities to develop and build a system or equipment.

coupling – A term used in structured analysis/design approaches to software development referring to the extent to which the software modules are related to one another.

CORE – Controlled Requirements Expression. A proprietary technique for identifying system requirements through structured decomposition.

critical task – A task which, if not accomplished in accordance with system requirements, will have adverse effects on cost, system reliability, efficiency, effectiveness, or safety (after US MIL-H-46855B).

demonstrator – Equipment built to illustrate future trends and possibilities in design. Demonstrators may resemble the real-life counterpart dynamically. Operationally, a demonstrator may range from a functioning laboratory set-up to a complete system.

designer – One who designs or plans or makes patterns for manufacture.

Design and Development – The phase of an equipment programme which calls for design engineering work aimed at full validation of the technical approach and ensures complete system integration to the point where production contract action can be taken (NATO PAPS).

DoD – U.S. Department of Defense.

DRG – The NATO Defence Research Group.

duty – A set of operationally related tasks within a job, e.g, communicating, navigating, system monitoring (NATO STANAG 3994/1). Duties may be divided into primary and secondary duties.

equipment – All non-expendable items needed to outfit/equip an individual or organization (NATO Glossary).

ergonomics – The systematic study of the relation between the human, machine, tools, and environment, and the application of anatomical, physiological, and psychological knowledge to the problems arising therefrom. Synonymous with Human Factors.

feasibility study – A study carried out by industry or government agencies or a combination of both, with the object of providing a technical appraisal of the feasibility of developing and producing an equipment with the performance required by the NATO Staff Target (NATO PAPS).

front end analysis – Analyses conducted at the earliest stages of system design and concerned with a system's personnel, training and logistics requirements (U.K. DEF STAN 00-25).

function – A broad category of activity performed by a system, usually expressed as a verb + noun phrase, e.g., "control air-vehicle," "update way-point" (NATO STANAG3994/1). A function is a logical unit of behaviour of a system.

function allocation – The process of deciding how system functions shall be implemented – by human, by equipment, or by both – and assigning them accordingly.

functional analysis – An analysis of system functions describing broad activities which may be implemented by personnel, and/or hardware and/or software.

FFD – Function Flow Diagram: a block diagram representation of the functions required of a system.

Gantt charts – Charts used for project planning and control which show the necessary project activities listed in a column against horizontal lines showing the dates and duration of each activity.

HARDMAN – A U.S. Navy programme for the integration of issues of manpower, personnel and training with the weapon system acquisition process.

human engineering (HE) – The area of human factors which applies scientific knowledge to the design of items to achieve effective human-machine integration (after US MIL-H-46855B). Human engineering includes developmental test and evaluation activities.

human factors (HF) – A body of scientific facts about human capabilities and limitations. It includes principles and applications of human engineering, personnel selection, training, life support, job performance aids, and human performance evaluation. Synonymous with Ergonomics.

human-machine interface – An imaginary surface across which information and energy are exchanged between the human and machine components of a system. The interface is defined by the displays and controls used by the operator/maintainer to control, monitor or otherwise interact with the system.

human-machine system – A composite of equipment, related facilities, material, software and personnel required for an intended operational role.

human systems integration (HSI) – The technical process of integrating the human operator with a materiel system to ensure safe, effective operability and supportability.

Ishikawa diagram – A diagram, widely used in total quality management, showing the hierarchy of causes of problems as a "fish bone" or tree.

job – The combination of all human performance required for operation and maintenance of one personnel position in a system, e.g., navigator (NATO STANAG 3994/1).

IDEA – Integrated Decision Engineering Aid. A proprietary software program which provides an integrated set of tools and data files to keep track of front-end human engineering analyses within the framework of the US Army's MANPRINT approach.

IDEF – (ICAM [Integrated Computer Aided Manufacturing Office] DEFinition.) A US Air Force developed tool for building descriptive models of system functions and data, commercialized as SADT™.

ILS – Integrated Logistics Support. A method of assuring that a system can be supported effectively and economically, so as to conform to specified operational requirements, within the resources of available personnel sub-system logistic support and maintenance, for its programmed life cycle. It considers jointly all resources needed, namely supplies, maintenance, humans and equipment, transportation, facilities and cost (CAN DND-ENG STD-3).

IMPACTS – A U.S. Air Force programme for the integration of manpower, personnel, and training issues with the weapon system acquisition process.

interval scale – A scale of measurement which has the characteristics of an ordinal scale, and, in addition, uses equal intervals without reference to a true zero value, e.g. the Centigrade scale of temperature, which does not refer to absolute zero.

ISO – International Standards Organization.

link analysis – A technique for representing and attempting to optimize the interactions between an operator or operators and equipment or between multiple operators.

liveware – A U.S. term for the human component of systems (operators and maintainers) which complements the system hardware and software.

maintainer – An individual responsible for retaining a defence system in, or restoring it to, a specified condition.

manpower – The demand for human resources in terms of numbers and organization.

manpower, personnel, training and safety (MPTS) – The human dimension of the complete weapon system. The term MPTS also encompasses the disciplines of human engineering and health hazard prevention.

MANPRINT – The US Army Manpower and Personnel Integration programme for the integration of manpower, personnel, training, systems safety, health hazards analysis, and human factors engineering into the systems acquisition process.

methodology – The study of method, usually taken to mean an integrated set of methods and rules applicable to some goal.

mission – What a human-machine system is supposed to accomplish, in response to a stated operational requirement (NATO STANAG 3994/1).

mission analysis – A process to determine the operational capabilities of military forces that are required to carry out assigned missions, roles, and tasks in the face of the existing and/or postulated threat with an acceptable degree of risk (NATO PAPS).

mission need document – In NATO, a statement based on a mission analysis, identifying in broad outline a quantitative or qualitative operational deficiency that cannot be solved satisfactorily with existing or planned forces and/or equipment (NATO PAPS).

mock-up – A model, built to scale, of a machine, apparatus, or weapon, used in studying the construction of, and in testing a new development, or in teaching personnel how to operate the actual machine, apparatus or weapon (NATO Glossary of Terms). A three-dimensional, full-scale replica of the physical characteristics of a system or sub-system (U.K. DEF STAN 00-25).

moding analysis – The analysis of the different modes of operation of multi-function systems. For example, a multi-function radar can be operated using different search patterns, track-while-scan or other modes. These modes are usually selected through a "tree" of control options, which includes "modes."

MoD PE – U.K. Ministry of Defence Procurement Executive.

MOE – Measures of Effectiveness: measures which are relevant to the effectiveness of a weapon system.

Monte Carlo simulation – A method used in mathematics, statistics, and operations research to resolve problems by the use of random sampling. The behaviour of a system is simulated by feeding in values of the system variables, and repeating the operation over different sets of values so as to explore the system under a variety of conditions.

NAG – NATO Armaments Group.

nominal scale – A scale of measurement which distinguishes only characteristics without regard to order, e.g. the membership of sets.

operator – An individual primarily responsible for using a system, or enabling a system to function, as designed.

OSD – Operational Sequence Diagram: a graphical approach to task analysis which emphasizes information handling activities.

ordinal scale – A scale of measurement which implies some ordering of the values, e.g. more/less relationships. Most subjective ratings are ordinal scale.

PAPS – Phased Armaments Programming System. A systematic and coherent set of procedures and milestones for promoting co-operative armaments programmes in NATO.

Pareto effect – The observation that many naturally occurring phenomena have an inverse linear relationship between the logarithm of their size and their rank according to size.

PC – Personal Computer.

performance analysis – The analysis of the performance to be expected from the operators and maintainers of a system. Performance analysis includes the prediction of operator workload, task times, probability of completion of tasks, and error analysis.

personnel – The definition of manpower in terms of trade, skill, experience levels, and physical attributes.

QA – Quality Assurance.

ratio scale – A scale of measurement which has the characteristics of an interval scale, and in addition has a true zero point as its origin, e.g. length, mass, the Kelvin temperature scale.

RDD – Requirements Driven Development. A proprietary technique for deriving the requirements for complex systems through the systematic decomposition descriptions of system functional relationships.

reliability – The probability that an item will perform its intended function for a specified interval under stated conditions (CAN DND ENG-STD-3).

RSG – Research Study Group. A group sponsored by one of the NATO Defence Research Group Panels to carry out research on a specific topic.

SADT – Structured Analysis and Design Technique™. A proprietary means of identifying system requirements through a structured decomposition.

safety – Freedom from those conditions that can cause death or injury to personnel, damage to or loss of equipment or property, or damage to the environment.

SAINT – Systems Analysis by Integrated Networks of Tasks. Software which supports network simulation and Monte-Carlo modelling of systems.

SAT diagrams – Sequence and timing diagrams. A variety of function flow diagram showing the sequence of functions performance by sub-systems.

SIMWAM – SIMulation for Workload Assessment and Modelling: a proprietary software package for simulating the tasks and workload of system personnel.

specification – The document which prescribes in detail the requirements to which ... supplies or services must conform. NOTE: It may refer to drawings, patterns, or other relevant documents and may indicate the means and criteria whereby conformance can be checked (AGARD Multilingual Dictionary).

– A document intended primarily for use in procurements which clearly and accurately describes the essential and technical requirements for items, materials, or services, including procedures by which it can be determined that the requirements have been met (CAN A-LP-005-000/AG-006).

staff requirement – A detailed statement of the required design parameters and operational performance of the equipment or weapon system. This document represents the specification of the system upon which project definition is based (NATO PAPS).

staff target – A broad outline of the function and desired performance of new equipment or weapon system(s), before the feasibility or the method of meeting the requirement, or other implications have been fully assessed (NATO PAPS).

statement of requirement (SOR) – A statement of the capability required of a new system, to meet an existing or postulated threat. synonymous with NATO Staff Target. In the U.K. it ...cludes estimated costs and technical factors.

STANAG – A NATO standardization agreement.

standard – An exact value, a physical entity, or an abstract concept, established and defined by authority, custom, or common consent to serve as a reference, model, or rule in measuring quantities, establishing practices or procedures, or evaluating results. A fixed quantity or quality (NATO Glossary of Terms and Definitions).

– A document that establishes engineering and technical limitations and applications for items, materials, processes, methods, designs, and engineering practices (CAN A-LP-005-000/AG-006).

STD – State Transition Diagram: a diagram showing system states and the related transitions from one state to another.

span of control – A term used in structured analysis/design approaches to software development referring to the number of lower-level modules which are called, or controlled, by one module.

sub-task – Activities (perceptions, decisions, and responses) which fulfill a portion of the immediate purpose within a task, e.g., "key in latitude."

SWAT – Subjective Workload Assessment Technique: a technique for measuring the workload experienced by an operator performing a task.

system – In general a set or arrangement of things so related or connected as to form a unity or organic whole (Webster's New World Dictionary of the American Language, 2nd College Edition, 1970. The Publishing Company.)

system design – The preparation of an assembly of methods, procedures, and techniques united by regulated iterations to form an an organized whole (NATO Glossary of Terms).

system effectiveness – The probability that the system will provide, in terms of resources required, and as specified, either:

(a) the maximum operational performance within the total cost prescribed, or
(b) the required value at lowest cost. (CAN DND-ENG-STD-3).

system(s) engineering – A basic tool for systematically defining the equipment, personnel, facilities and procedural data required to meet system objectives (US MIL-H-46855B).

system requirements analysis – An analysis of what is required of a system to identify those characteristics which the system (both personnel and equipment) must have to satisfy the purposes of the system (after U.K. DEF STAN 00-25).

task – A composite of related operator or maintainer activities (perceptions, decisions, and responses) performed for an immediate purpose, e.g., "insert aircraft position" (after NATO STANAG 3994/1).

task analysis – A time oriented description of personnel-equipment-software interactions brought about by an operator, controller or maintainer in accomplishing a unit of work with a system or item of equipment. It shows the sequential and simultaneous manual and intellectual activities of personnel operating, maintaining, or controlling equipment (US MIL-H-46855B).

task description – A listing of tasks, usually in tabular form, arising from the results of a system description/analysis (U.K. DEF STAN 00-25).

task element – The smallest logically and reasonably defined unit of behaviour required in completing a task or sub-task, e.g., "key in digits."

task synthesis – The process of creating or putting together the tasks which compose a system function (after U.K. DEF STAN 00-25).

technique – A mechanical, or formal, approach to doing something.

Test and Evaluation (T&E) – A comprehensive programme of test activities, conducted throughout the system hierarchy and over the system life cycle, to:

(a) assess system performance
(b) verify conformance to system requirements
(c) determine system acceptability

time line – A representation of actions, activities or tasks in the temporal domain using a horizontal line or bar.

TQM – Total Quality Management: an approach to product improvement through continual efforts to improve the production process and reduce losses of any sort.

training – The process by which trainees acquire or enhance specific skills, knowledge, and attitudes required to accomplish military tasks.

UIMS – User Interface Management System.

weapon system – A combination of one or more weapons with all related equipment, materials, services, personnel and means of delivery and deployment (if applicable) required for self-sufficiency (NATO Glossary of Terms).

work breakdown structure (WBS) – A matrix of sub-systems and design/development team activities used for project management.

workload – The level of activity or effort required of an operator to meet performance requirements or criteria (Glossary of Ergonomics).

workplace – The complete working environment within which all the operators and equipment are arranged to function as a unit (U.K. DEF STAN 00-25).

workspace – The geometrical space required to perform a job, duties, or task, including the details of display and control location, the physical relationship between different displays and controls, and the standing/seating arrangement of the operators/maintainers.

WSAP – Weapon system acquisition process.

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AC/243(Panel 8)TR/7
VOLUME 2

ANALYSIS TECHNIQUES FOR MAN-MACHINE SYSTEMS DESIGN

Panel 8 on the Defence Applications of Human and Bio-Medical Sciences

RSG. 14 on Analysis Techniques for Man-Machine Systems Design

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TECHNICAL REPORT
AC/243(Panel 8)TR/7
Volume 2

DEFENCE RESEARCH GROUP

PANEL 8 ON THE DEFENCE APPLICATIONS OF HUMAN AND BIO-MEDICAL SCIENCES

Technical Report on Analysis Techniques for Man-Machine System Design

This is Volume 2 of the technical report on Analysis Techniques for Man-Machine System Design. The report was prepared by RSG.14. The Executive Summary of this report ("Yellow Pages") was also distributed under reference AC/243-N/359 dated 24 July 1992.

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14. Abstract:

Human engineering (known in some countries as human factors in design or ergonomics) is a discipline by which data on human capabilities and limitations are taken into account during the engineering design and development process. NATO AC/243(Panel 8/RSG.14) completed a study of analysis techniques used for human engineering. The RSG collected information on the of kinown human engineering analysis techniques, compiled descriptions of thirty-one existing techniques, reviewed them to identify the need for new and improved techiques, reviewed the current state of standardization of such techniques, and compiled examples of functional decompositions of typical manned systems. The two volumes of this report review the state-of-the-art of human engineering analysis and its relationship to systems engineering.

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VOLUME 2 PART 1

AVAILABLE HUMAN ENGINEERING ANALYSIS TECHNIQUES

INTRODUCTION: OVERVIEW OF HUMAN ENGINEERING ANALYSIS TECHNIQUES

This Volume consists of two parts and three appendices. In this, Part 1, thirty-one analysis techniques which have been used by human engineering specialists are reviewed to a standard format; in Part 2, examples are given of different functional analyses of systems. Part 1 is divided into six sections which correspond to the classes of human engineering analysis techniques :

(1) system missions
(2) system functions
(3) system operator and maintainer functions
(4) system operator and maintainer tasks
(5) workload and possible errors of the system personnel
(6) requirements for displays, controls, workspace and inter-personnel communication

as discussed in Volume 1. Most of the techniques reviewed permit the designers and developers of equipment and systems to define, structure and decompose relevant information: they are not algorithms which transform input data. Thus they require some learning or experience. Each stage of analysis produces information for subsequent analyses (Figure 0.1).

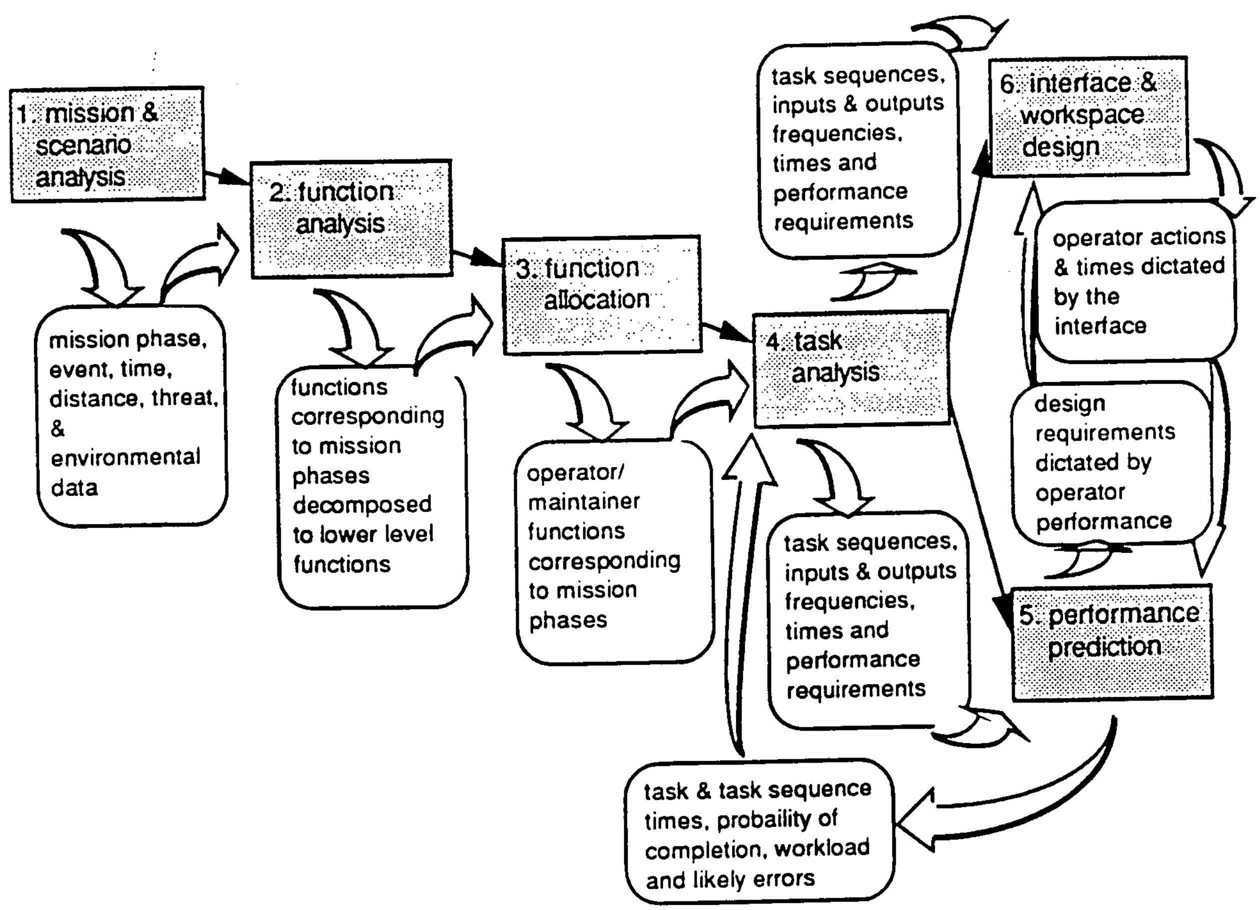
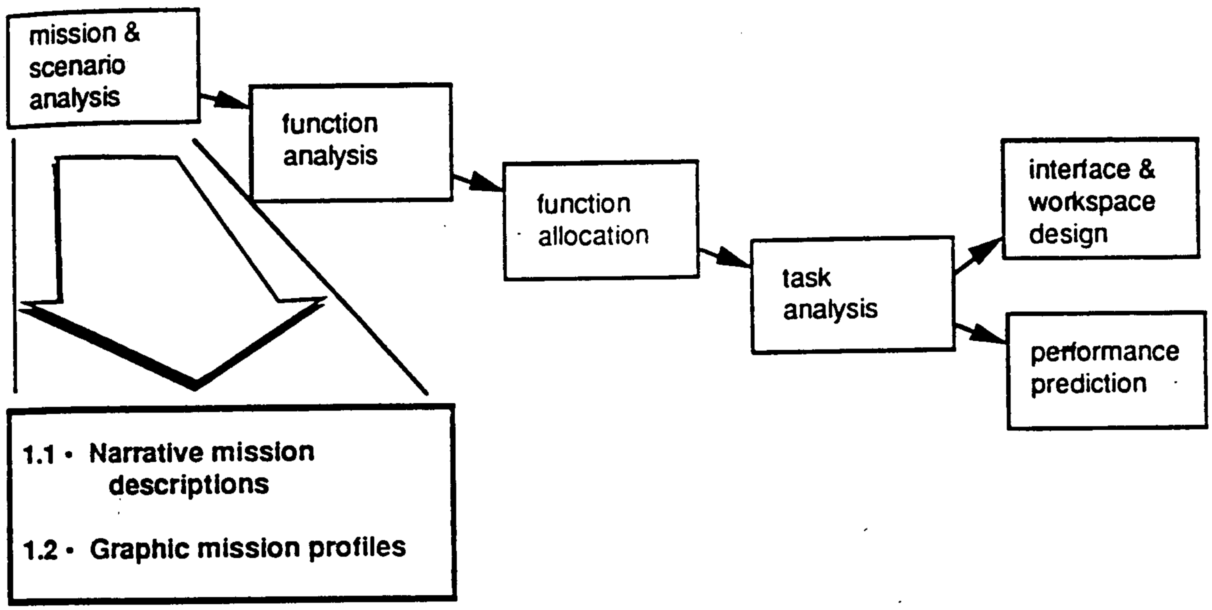


Figure 0.1: Information flow in the sequence of human engineering analyses

1 MISSION AND SCENARIO ANALYSIS



What the techniques do

These analyses define the overall requirements of the system under development, in terms which provide information for subsequent human engineering analyses. They are used to define what the system must do (the operational requirement) and the circumstances and environment in which it must be done[1].

Background

Ideally, the basis for the development of mission and scenario analysis should be the operational analysis conducted to establish the requirements for a new system (NATO Mission Need Document). In practice, however, the operational analyses are seldom available to the project personnel responsible for design and development. The operational

[1] The terms most frequently used for these activities are *mission analysis*, *mission profiles*, and *scenarios*. The user should be aware of possible problems with these terms. Generally, a *scenario* is a "sketch or plot of a play, giving particulars of the scenes, situations etc." (Oxford English Dictionary), and a *mission* is "a clear, concise statement of the task of the command and its purpose" (NATO Glossary of Terms and Definitions). Thus a "scenario" is often taken as the higher, overall level from which the analysis starts, and the "mission" is taken as a lower, more specific level of analysis.

In the USA, however, the term *mission analysis* is taken as "the first step in the system development, required for the establishment of human factors design criteria" (DoD-HDBK-763), and "scenarios are developed from the threat/concept and the mission profiles, and they must fully describe the events implied by the profile." In practice these differences in terminology can lead to confusion, particularly in discussions between the procuring agency and the performing agency (whether government or contractor).

analyses are often conducted well before the project is initiated, by a separate agency, and the results may not be disseminated to either the project management or the performing agency, due to their security classification.

Analyses conducted for other systems engineering studies can provide much of the information required for mission and scenario analysis. Recommended approaches to systems engineering (US Defense Systems Management College, 1990, US Department of the Army, 1979) stress the need to conduct mission analyses to derive the system requirements and define the operational environment and the constraints on the system. These mission analyses provide a link between the human factors/human engineering analyses and other system engineering activities.

For example, on a recent project to study crew workload in a tactical helicopter it was discovered that detailed operational missions had been prepared and evaluated to identify the loading on the helicopter rotor system. It was comparatively easy to take those analyses and revise them to show operator activity, since changes in rotor loading implied pilot input and tactical decisions. The resulting human engineering analyses were an excellent starting point for the crew workload studies.

Types of analysis available

There are two basic types of analysis in this category. Narrative mission descriptions provide a written or point form description of a mission, and graphic mission profiles provide the mission information in graphic form.

Table 1.1: Applicability of mission and scenario analysis techniques to different projects

Technique	Simple system (e.g. rifle, hand-held radio)	Medium complexity system (e.g., 1-man radar console)	High complexity system (e.g., 1-place attack aircraft)	Complex multi-man system (e.g., ship combat centre)
1.1 Narrative mission description	high	high	high	medium
1.2 Graphic mission profiles	not recommended	not recommended	high	high

References and Bibliography

1. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
2. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
3. US Department of the Army (1979). System engineering. Washington D.C.: Headquarters, Dept. of the Army. FM 770-78.
4. US Defense Systems Management College (1990). System engineering management guide. Washington D.C.: U.S. Government Printing Office

1.1 NARRATIVE MISSION DESCRIPTIONS

What the technique does

Narrative mission descriptions (sometimes called "Mission Scenarios") describe the events of a mission in detail. The description should be sufficiently detailed to permit identification of the major mission phases, the major system functions, the time-scale of activities, and the "external" events which dictate the activities of the system. Where multiple missions are to be performed by a system, each should be described or a "composite" mission description should be developed which identifies all of the unique mission activities, avoiding repetition of common activities. Examples of the technique have been published by Döring (1976), Lindquist, Jones & Wingert (1971), and Linton, Jahns & Chatelier (1977).

Inputs to the technique

Information is required from the operational analyses used to identify the operational requirement (Mission Need Document, in NATO). Required information includes the system missions, required capability, operational environment, and system dynamics and constraints. The analysis should draw on any Monte Carlo simulations that may have been run to develop mission time lines. Input from subject matter experts with experience of similar missions or similar equipment is essential.

Outputs of the technique

The descriptions document the characteristics, sequences and times of mission events, mission constraints and environmental conditions. A description may be in a highly structured, point-by-point form, or a free-flowing narrative. It may describe several missions, or mission segments, or one composite mission. The outputs of the technique should be sufficiently detailed to identify the upper level functions performed by the system (see Section.2 Function Analysis).

When to use

The technique should be used at the outset of the human engineering analyses conducted during the concept development phase. The work may be re-iterated in greater detail at the start of the preliminary design phase. The analysis is a necessary precursor to all human engineering analyses, unless the information is available from the analysis of identical systems.

Related techniques

Narrative mission descriptions are related to the mission descriptions and early performance parameter studies carried out to establish Mission Need Documents, or as part of the system engineering activities.

Resources required

The advice of experts with operational experience of similar missions and systems is essential to the preparation of the analysis. Access to documentation on similar systems and to the system requirements analysis is extremely useful. No significant technical resources are required.

Example of Mission Analysis

A mission analysis starts with the identification of mission phases, for example, the phases for a close air support mission. Each phase is then expanded by a narrative description, as shown below.

CLOSE AIR SUPPORT - MISSION PHASES

1.0 PRE-FLIGHT
2.0 LAUNCH
3.0 CLIMB TO ALTITUDE
4.0 RENDEZVOUS
5.0 OUTBOUND CRUISE
6.0 DESCEND
7.0 LOITER
8.0 PRE-ATTACK
9.0 ATTACK
10.0 ESCAPE
11.0 CLIMB TO ALTITUDE
12.0 INBOUND CRUISE
13.0 RENDEZVOUS
14.0 RECOVER
15.0 POST FLIGHT

5.0 OUTBOUND CRUISE: At dawn the ground feature checkpoint is detected and confirmed electro-optically by the LLTV (Low Light Level Television). Flight leader raises Forward Air Controller (FAC) Alpha on the preassigned secure communication channel and receives his specific mission assignment and a more complete briefing. FAC(A) informs Flight that an advance enemy force has moved up during the night and will soon be within striking distance of a strategic friendly position.
6.0 DESCEND: FAC(A) provides an updated vector from the coastal checkpoint and assigns Flight loiter position. Flight leader provides an estimated time of arrival, and as he crosses the coastline, he performs a navigation update, reduces power, and drops to a terrain-following altitude. The penetration route has been chosen to minimize detection. No known enemy radar sites are along the route. No missiles are indicated by the threat detection and warning set.
7.0 LOITER: Flight leader reviews his ordnance load via a tabular display on one of his multi-purpose CRT's (Cathode Ray Tube). (after Linton et al., 1977)

Figure 1.1: Example of decomposition of a narrative mission analysis

Advantages

Users report the technique to be highly cost-effective. It is comparatively easy to use, and is generally a low cost activity. It requires few resources, and serves as a very useful means of reaching consensus on *what* and *how* the system is to fulfil its objectives.

Disadvantages

Users report that the analyses can be too subjective, if a limited amount of data is available. Analysts and potential operators can become too enthusiastic about detail, prolonging the analysis time at the outset of the development process. Some users report difficulties in coordinating their analyses with other systems engineering analyses. For example, the human engineering analyses will highlight operations which are manpower critical, whereas avionics specialists will focus on analyses which load the avionics, not the human operators.

The typical sequential description of system activities and events is not suited to systems which control a process, such as C^3I or a machinery control monitoring system. In such cases it is better to analyse "events" which cause changes in the system state and require operator intervention (see Kincade & Anderson, 1984).

Relative contribution

Users rated the technique extremely effective. It is seen as an essential building block to human engineering programmes within a system development project.

Applications

The technique has been widely used for many years, and has been employed for land-, sea-, and air-borne systems. The references provide some examples of the technique. Woodson (1981) provides an example of a non-military mission description.

Quality assurance considerations

Analysts should take precautions to avoid representing a limited view of the system operations. Because it is the starting point for subsequent analyses, it is important that the mission description reflects all operational requirements. The description of the use of sub-systems must reflect any functional requirements that have been developed. In a recent project the mission analyses omitted the use of tactical data links, despite the fact that such communications were an obvious operational necessity. As a result the subsequent human factors analyses did not include the operation of the data link, until a progress review identified the deficiency.

Thus it is important that the mission description be checked for consistency, completeness, and compatibility with any statement of operational requirements, both wartime and peacetime. Check that the analysis includes:

- system description (including its general capabilities)
- mission requirements (the types of mission), performance requirements (e.g., ranges, speeds, times, and accuracies)
- system constraints (logistics, transportability, manning limitations, cost)
- environment (weather, temperature, threats, and support - the latter is too often ignored)
- mission segments (times and activities showing specific system capabilities).

Relationship to system performance requirements

The analysis is derived from system performance requirements. Descriptions of mission events define what the system must accomplish to complete a mission.

References and Bibliography

1. Döring, B. (1976). Application of system human engineering. In: K.F. Kraiss, J. Moraal, (Eds.), Introduction to human engineering. Köln: Verlag TÜV Rheinland GmbH.
2. Kincade, R.G., & Anderson, J. (1984). Human factors guide for nuclear power plant control room development. San Diego, CA: Essex Corporation for Electric Power Research Institute. EPRI NP-3659.
3. Lindquist, O.H., Jones, A.L., & Wingert, J.W. (1971). An investigation of airborne displays and controls for search and rescue (SAR): volume II. Minneapolis: Honeywell Inc. JANAIR Report No. 701220.
4. Linton, P.M., Jahns, D.W., & Chatelier, Cdr. P.R. (1977). Operator workload assessment model: an evaluation of a VF/VA-V/STOL system. In: Methods to assess workload, (pp A12-9 – A12-11). Neuilly sur Seine, France: AGARD CP-216.
5. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
6. Woodson, W.E. (1981). Human factors design handbook, (pp. 910-933). New York: McGraw-Hill Book Co.

1.2 GRAPHIC MISSION PROFILES

What the technique does

Graphic mission profiles are used to analyse system missions or operations. For the system of interest, they show relevant system activities and significant mission events plotted against time, and/or space. System variables which are represented include system state, geographical position, tracks, altitude or depth, and speed. Significant mission functions are noted on the plot. Most published examples of mission profiles are for aircraft (Linton et al., 1978, Meister, 1985; Stringer, 1978). They show the flight profile during the mission, and the major events which will dictate the system functions. Another example shows the system variable, speed, plotted against the independent variable of time (see Döring, 1992).

Inputs to the technique

The analyst requires information on the mission objectives and operational requirements. From that information he/she must select the appropriate system variables for representation.

Outputs of the technique

The completed profiles show a sequence of operational events or situations that will determine the function and performance requirements of the system. Implicit in those requirements is the overall performance of the operator(s).

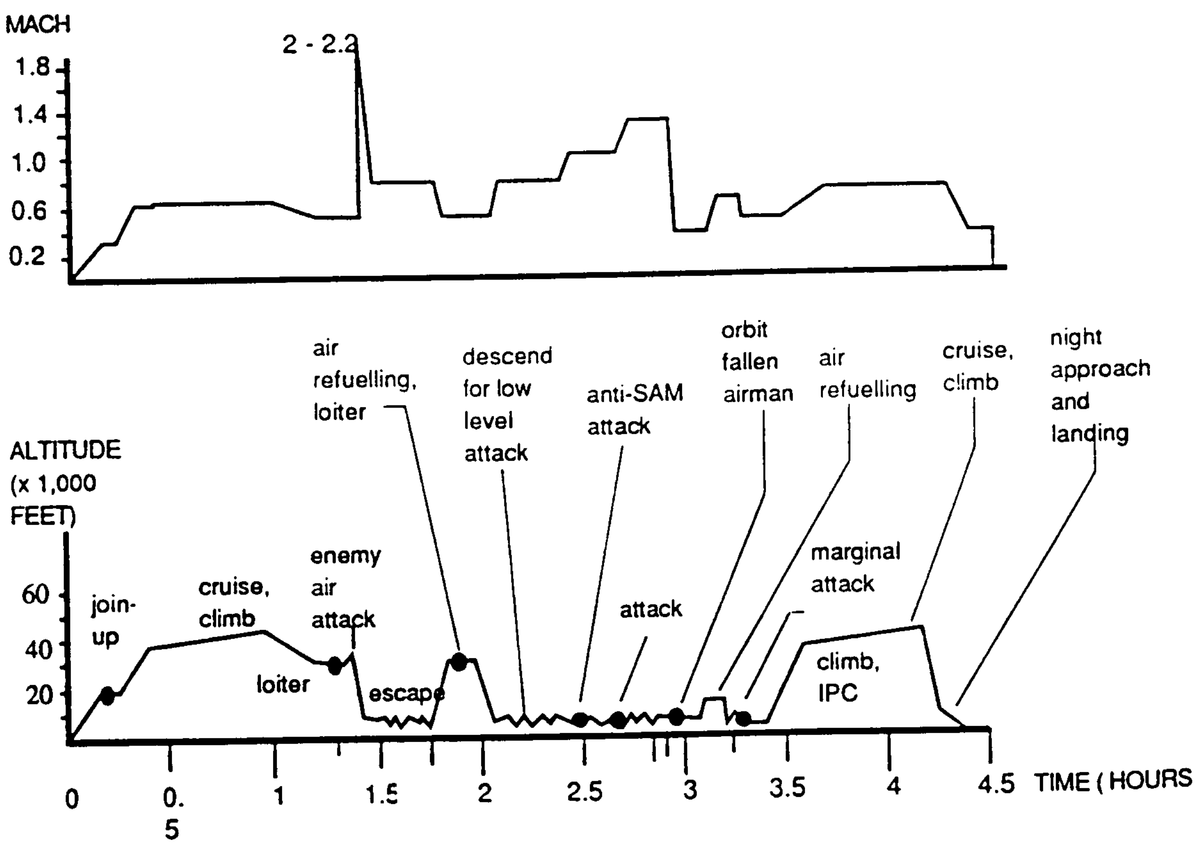


Figure 1.2: Example of an attack aircraft mission profile (after Zipoy et al. 1970)

When to use

Mission profiles are developed at the outset of a human factors project. Some users argue that, because the procuring agency has the best understanding of the mission requirements, the latter should prepare the mission profiles. If the profiles are not prepared by the procuring agency, then they should be prepared during the concept development or system definition phases. They are frequently prepared in conjunction with narrative mission descriptions (Section 1.1). Mission profiles precede the function analysis of a system.

Other systems engineering studies also may require the preparation of mission profiles. Thus there is the possibility of using those systems engineering studies, or of collaborating in the compilation of the data.

Related techniques

Graphic mission profiles are usually prepared for and used in conjunction with narrative mission descriptions.

Resources required

The technique requires the support of engineering and operational analysis groups and of operational personnel with experience of similar systems or operations. Human factors information on the operation of similar or previous systems is also of use. Although computer-aided graphic tools are of use in preparing the analyses, simple sketches are often sufficient.

Advantages

Graphic mission profiles are an effective way of communicating the overall operational requirements of a system. They are simple to construct, and require a minimum of time to develop. Compared to other techniques, they have low cost and high effectiveness, particularly for communicating with other project personnel.

Disadvantages

If numerous events are included in the analysis, the diagrams can become complex and difficult to understand. The profiles show "top-level" events better than more detailed events. Some users report that the development of the profiles can be too subjective, and that the personnel developing them can become too involved with detail, resulting in a long and costly development.

Relative contribution

The technique can make a useful contribution, provided it is used as a precursor to subsequent analyses. It does not have high utility on its own.

Applications

The most frequently published examples of the technique are for the development of air-borne systems, which lend themselves to a comparatively simple mission time-scale. Hollister (1986) provides examples of five different aircraft missions. The technique has also been used successfully for ship-board systems, and for land-based systems such as an air-defence system.

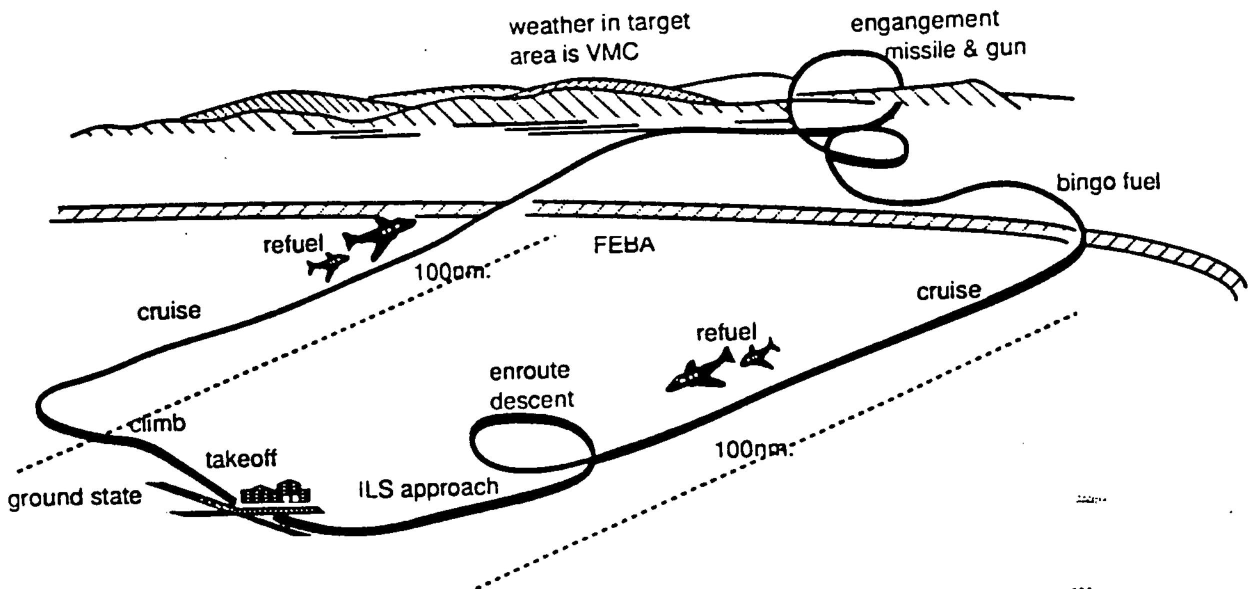
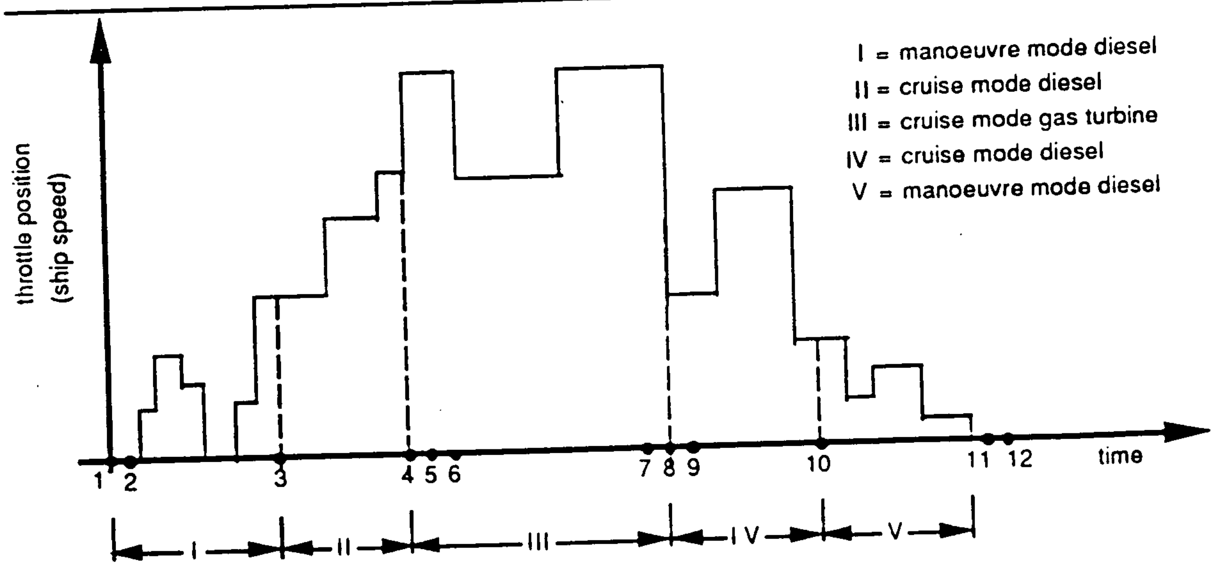


Figure 1.3: Example of alternative style of aircraft mission profile (after Linton et al., 1978)



Requests of Bridge Personnel:

1. Start diesel
2. Fill hydraulic clutch
3. Change mode
4. Start gas turbine
   Shift to gas turbine
5. Empty hydraulic clutch
6. Stop diesel
7. Start diesel
8. Fill hydraulic clutch
   Shift to diesel
9. Stop gas turbine
10. Change mode
11. Empty hydraulic clutch
12. Stop diesel

Figure 1.4: Example of mission profile for ship's machinery propulsion control (after Döring, 1992)

Quality assurance considerations

Because the analysis is the starting point for subsequent human factors analyses (in conjunction with narrative mission descriptions), it is important that the information is correct. Users caution against the use of subjective estimates of time in the development of the time-scale. One user recommends that the profile be checked against the performance requirements stated in the contract or statement of requirement. The analysts and those setting the operational requirements must agree on the times and events.

Relationship to system performance requirements

The analysis derives directly from the system performance requirements. It should relate directly to the requirements which describe times, events, etc.

References and Bibliography

1. Döring, B. (1992) Determining human-machine interface requirements for a highly automated ship engine control center. In: H. Kragt, (Ed.) Case studies in ergonomics. London: Taylor & Francis.
2. Hollister, W.M. (1986). Improved guidance and control automation at the man-machine interface. Neuilly sur Seine, France: AGARD AR-228.
3. Linton, P.M., Jahns, D.W., & Chatelier, Cdr. P.R. (1978). Operator workload assessment model: an evaluation of a VF/VA-V/STOL system. In: Methods to assess workload. Neuilly sur Seine, France: AGARD-CP-216.
4. Meister, D. (1985). Behavioral analysis and measurement methods. New York: John Wiley & Sons.
5. Stringer, F.S. (Ed.). (1978). Optimisation of pilot capability and avionic system design. Section 3. Mission Analysis. Neuilly sur Seine, France: AGARD-AR-118.
6. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
7. Zipoy, D.R., Premselaar, S.J., Gargett, R.E., Belyea, I.L., & Hall, H.J. (1970). Integrated information presentation and control system study. Volume 1: system development concepts. Ohio: Wright Patterson Air Force Base. Technical Report AFDL-TR-70-79.

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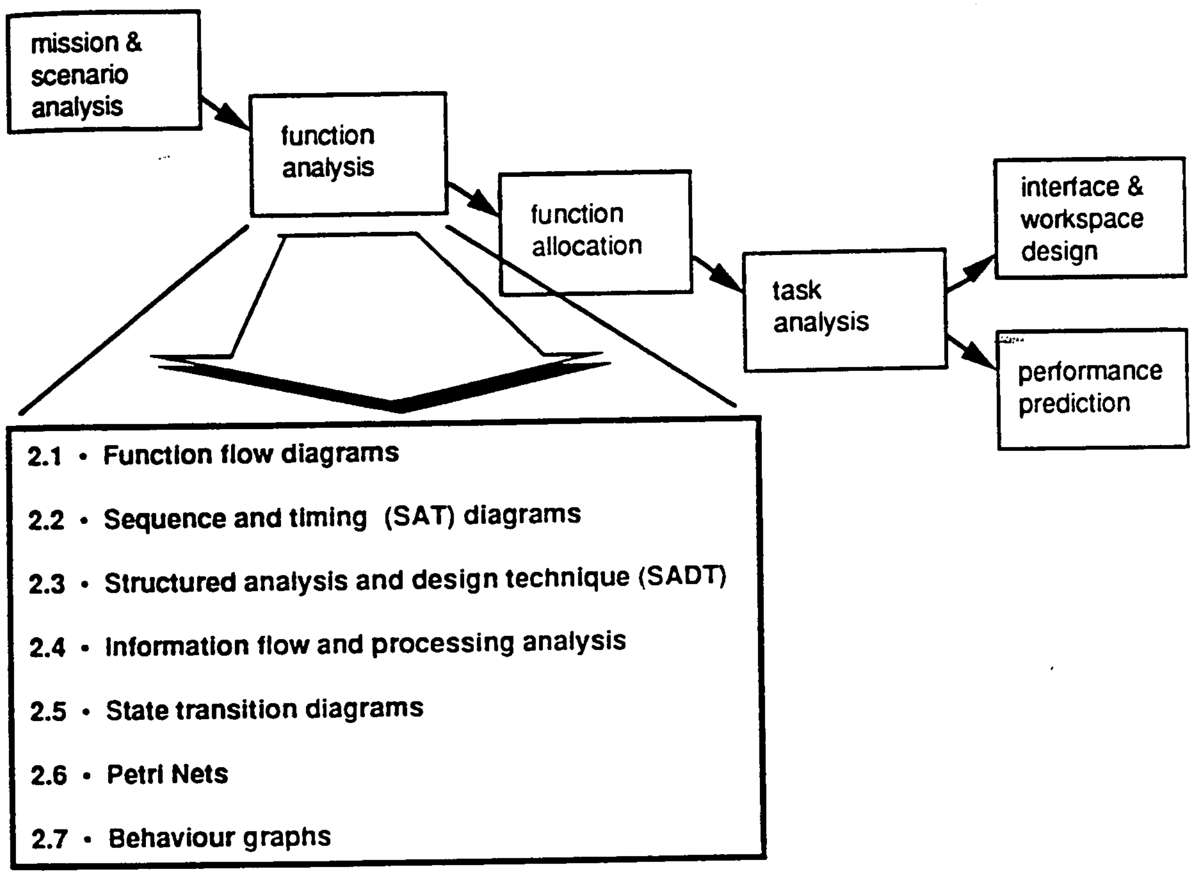
2 FUNCTION ANALYSIS



What the techniques do

A function is a logical unit of behaviour of a system. Function analysis is a necessary step in systems engineering, leading to systems synthesis, trade-off studies, and a system description (US Army, 1979; US Defense Systems Management College, 1990; NATO, 1989). It consists of analysing the system in terms of the functions which must be performed, rather than in terms of a set of specific sub-systems. Function analysis is hierarchical in nature, and proceeds in a top-down fashion. Each phase in the analysis is the basis for the analysis in subsequent phases. Higher level functions tend to be identical for similar systems. In general, at the higher levels of analysis, no distinction should be made between operator, equipment, or software implementation of the functions. This is in order to permit unbiased trade-off studies, through the subsequent allocation of functions process. Older function analysis techniques describe the system in static terms. More recently developed techniques such as SADT, state transition diagrams, Petri nets and Requirement Driven Developments (RDD) permit the functional description of the system to be checked for logical consistency and used as a basis for computer simulation.

Background

Function analysis has become increasingly necessary as the software component of systems has increased. As Tooze

(1989) has noted "complex modern systems are high on functionality but low on in-place objects." For such systems, function analysis is a valuable tool for coordinating the activities of system engineers and engineering specialists (Lurcott, 1977).

Like mission analysis, function analysis is the responsibility of, and should be conducted by, the systems engineering effort in a project. Although this may happen, the analyses may not be conducted in a way which is directly usable by human engineering specialists, and may need revision (Beevis, 1987). Thus, the human engineering specialist may have to exploit system engineering analyses produced for other disciplines, particularly for software design. For this reason, there is a growing interest in the use of software engineering analysis tools for human engineering analyses. Several of the techniques reviewed here permit such use, in particular SADT™(2.3), State Transition Diagrams (2.5), Petri Nets (2.6), and Behaviour Graphs (2.7). Data Flow Diagrams have also been used, as the basis for human engineering analyses (Sutcliffe & McDermot, 1991) as well as the Jackson System Development (JSD) method (Lim, Long & Silcock, 1990), but the group responsible for this review has no direct experience with those techniques.

Human engineering emphasizes the need to conduct function analyses of systems because of the importance of defining and allocating to the human operator those functions which are best suited to human capabilities and limitations (Meister, 1985). Function analyses were reported to be the most frequently used technique in a survey of human engineering analyses in 33 projects. Function analyses decompose systems into either their functions, or their structure; some techniques include both approaches. Mission functions are the principal components of analysis. At the uppermost level, system functions are neutral, and reflect the phases of the mission analysis ("navigate the ship"). These are decomposed into more specific functions ("steer the ship" and "check heading"). Only at these lower levels do performance requirements become apparent. Other types of components are constraint functions, including structural or technical limitations such as vehicle size, crew number and environmental conditions. The different types of function analysis, and examples of function analyses of difference systems, are reviewed in Volume 2, Part 2.

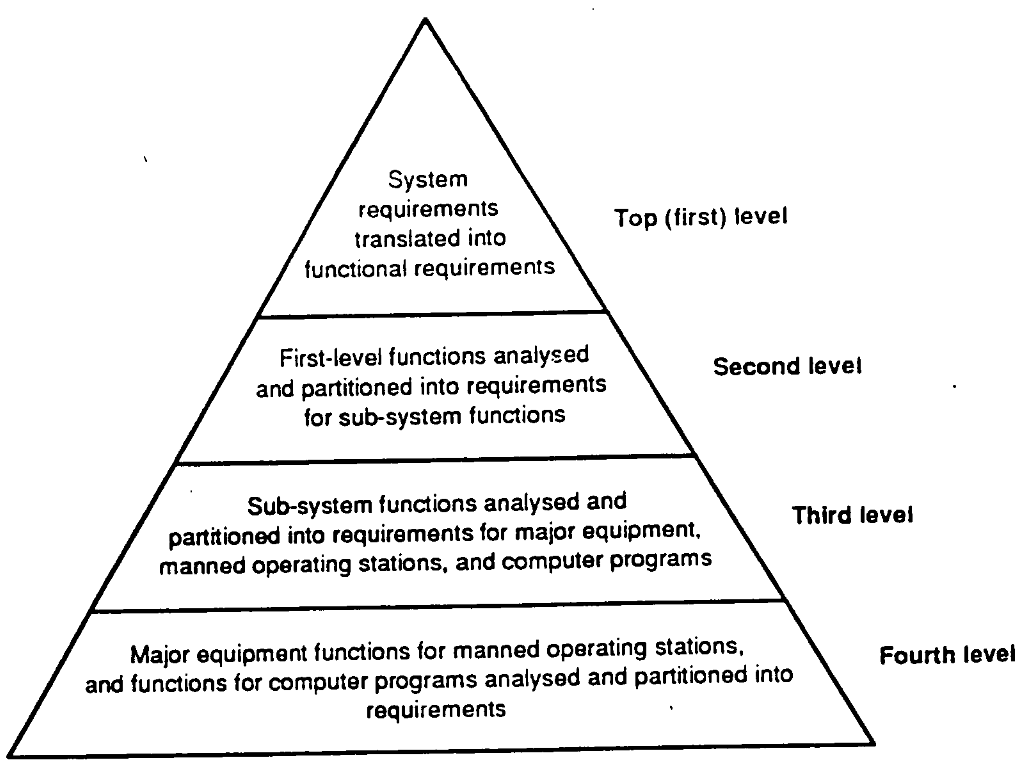


Figure 2.1: Hierarchical approach to systems development (after Lurcott, 1977)

Henry (1968) reviewed a family of function decomposition techniques, starting with Function Sequence Diagrams, through System Sequence Diagrams, to Personnel Sequence Diagrams. That approach anticipated the work of Rasmussen (1986) who observed that the design process moves from "abstraction" to "concretization" through a series of analyses which evolve from abstract considerations to increasingly more physical detail. A similar approach is recommended to systems engineering (US Defense Systems Management College, 1990). Lurcott (1977) reviewed the application of function analysis to systems design, and described an hierarchical approach, similar to that of Rasmussen, which evolves from the definition of system requirements to the design of major operator stations and the definition of software requirements. More recently, the disciplines of computer science and software engineering have emphasized the importance of analysing the functional requirements of systems as a necessary first step in development.

Top level (mission) functions can be derived directly from the mission and scenario analyses previously described. For example, each of the mission phases listed in the example of Narrative Mission Descriptions (1.1) (climb, rendezvous, cruise, descend, loiter, attack etc.) can form the top-level functions of the function analysis. Roe (1982) provides an example of a function analysis derived from a graphic mission profile. Replicating the mission sequence at the top level of function analysis has the advantage that concurrent functions are shown together; this makes it easier to conduct task analyses or create network simulations in later stages of analysis. At each level, functions are analysed to identify those at lower levels. For most projects, three levels of function analyses are usually sufficient to identify functions which can be allocated to humans (liveware), hardware, or software.

Types of technique available

The main types of function analyses used in human engineering are described in this section. The techniques differ in their applicability to different sizes and types of project, as shown in Table 2.1. The various approaches, discussed in detail in Part 2 of this volume, differ in their use of graphic symbols, as well as in their content. Some use different rules of composition. Some techniques permit the documentation of data flow, others of control flow, and some permit the combination of data and control flow information. Few techniques represent time accurately, due to their use of loops, recursion, etc. Most techniques support the systematic description of systems by formalisms such as Yourdon's Structured Design (Yourdon, 1989).

Table 2.1: Applicability of function analysis techniques to different projects

Technique	Simple system (e.g. rifle, hand-held radio)	Medium complexity system (e.g., 1-man radar console)	High complexity system (e.g., 1-place attack aircraft)	Complex multi-man system (e.g., ship combat centre)
2.1 Function Flow Diagrams - FFDs	low	medium	high	high
2.2 SAT	not relevant	low	medium	high
2.3 SADT™	not relevant	low	medium	high
2.4 Information Flow & Processing Analysis	not relevant	low	low	low
2.5 State Transition Diagrams	not relevant	low	medium	medium
2.6 Petri Nets	not relevant	not relevant	medium	medium
2.7 Behaviour Graphs	not relevant	medium	high	high

The scope of the work associated with function analysis should not be underestimated. A typical function decomposition has about ten functions at the top level. Each function decomposes to some ten more, so that in three levels of analysis 1000 functions can be identified. Once the functions have been defined, they can be used as the basis for establishing *function performance criteria* (Meister, 1985), to analyse the ability of the system to meet its performance requirements.

References and Bibliography

1. Beevis, D. (1987). Experience in the integration of human engineering effort with avionics systems development. In The Design, Development and Testing of Complex Avionics Systems. AGARD-CP-417. Neuilly sur Seine, France: Advisory Groups for Aerospace Research and Development.
2. Henry, O.W. (1968). Human factors in ship control: human engineering techniques and guidelines applicable to merchant marine bridge design. Groton, Connecticut: General Dynamics Inc. Volume II
3. Lim, K.Y., Long, J.B., & Silcock, N. (1990). Integrating human factors with structured analysis and design methods: An enhanced conception of the extended Jackson System Development method. In: D. Diaper, (Ed.) Human-Computer Interaction - INTERACT '90. North-Holland: Elsevier Science Publishers B.V.
4. Lurcott, E. (1977). F2D2 (functional flow diagram and descriptions), a system management tool. Defense Systems Management Review, (1) 19-28.
5. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
6. Ministere de la defense (1988). Guide de mise en oeuvre de l'analyse fonctionnelle. DEN/CMQ No. 88610. Paris-Armees: Délégation Générale pour l'Armament. Direction des Engins.
7. NATO (1989). Handbook on the phased armaments programming systems (PAPS). Volume I &II. NATO AAP-20.Brussels: NATO CNAD.
8. Rasmussen, J. (1986). Information processing and human-machine interaction.New York: North Holland.
9. Roe, G. (1982). The heap up hands back control concept. In Advanced avionics and the military aircraft man/machine interface. AGARD-CP-329. Neuilly sur Seine, France: Advisory Groups for Aerospace Research and Development.
10. Sutcliffe, A.G., & McDermott, M. (1991). Integrating methods of human-computer interface design with structured systems development. Int. J. Man-Machine Studies, 34, 631-655.
11. Tooze, M.J. (1989). Avionic system design methodology. In: Systems engineering: AGARD Lecture Series No. 164. Neuilly sur Seine, France: AGARD LS-164.
12. US Department of the Army (1979). System engineering. Washington D.C.: Headquarters, Dept. of the Army. FM 770-78.
13. US Defense Systems Management College (1990). System engineering management guide. Washington D.C.: U.S. Government Printing Office.
14. Yourdon, E. (1989). Modern structured analysis. Englewood Cliffs, New Jersey: Prentice-Hall Inc.

2.1 FUNCTION FLOW DIAGRAMS

What the technique does

A function flow diagram identifies the sequential relationships of the functions required to perform the mission and operations defined in the operational requirement and analysed in the mission analysis. Starting with the system or mission objectives and the mission analyses, function flows are developed at increasing levels of detail, down to the level where specific tasks can be identified for performance by hardware, software, or human operators. Typically the analysis proceeds by successive decompositions of the individual functions. Examples are provided in sections 3.1.2 and 3.2.3 of Volume 2, Part 2. These graphical representations are the starting point for the determination of detailed system requirements.

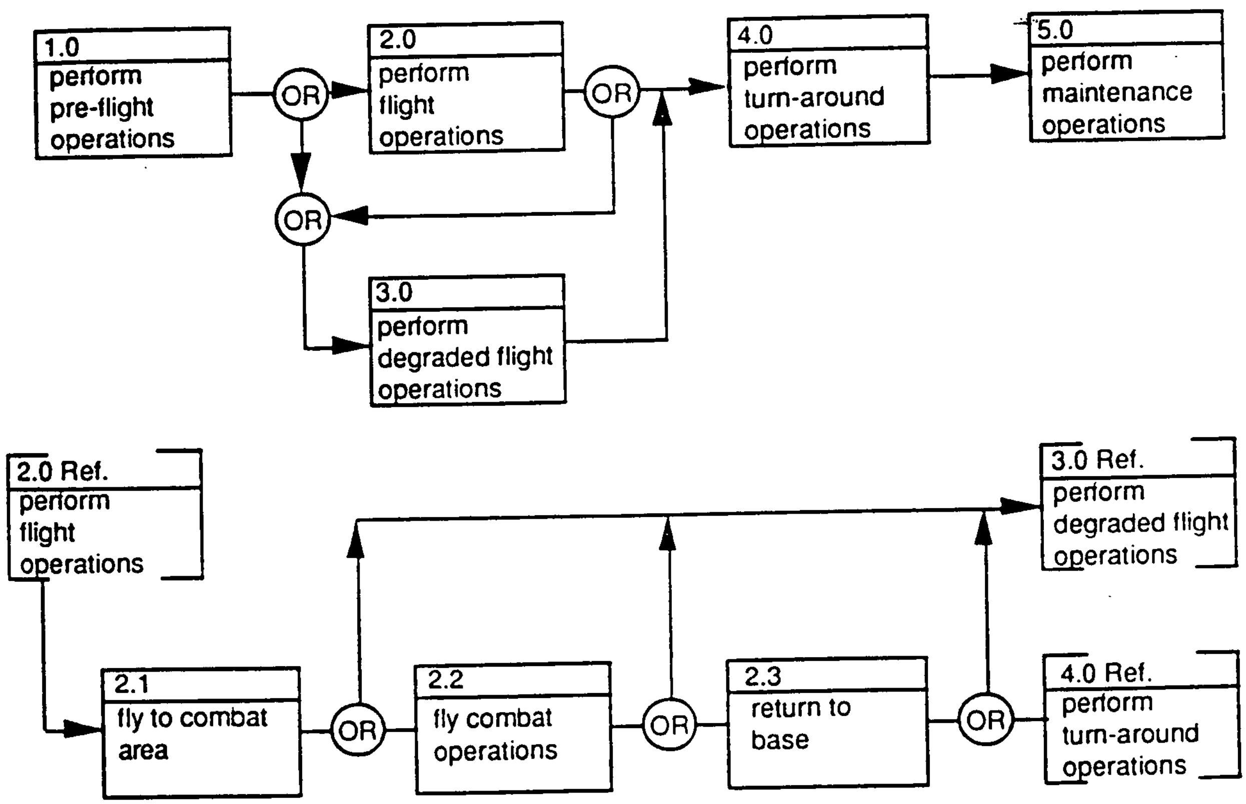


Figure 2.2: First and second level function flow diagrams for a tactical fighter aircraft

Function Flow Diagrams (FFDs) are sometimes called Function Flow Block Diagrams. The term is confusing, because Function Block Diagrams are static representations of system functions grouped into organizational areas; Function Flow Diagrams indicate the sequential relationships of all the functions needed to accomplish the system performance requirements (US Defense Systems Management College, 1990). FFDs are constructed by arranging in sequence all of the functions that are believed necessary to perform the mission, or to fulfil the system performance requirements. The sequence is arranged to reflect the order in which the functions are performed. The flows are constructed using "AND/OR" logic, to distinguish between functions conducted in series or parallel. Flow connections normally enter a function box from the left, and exit from the right. "No go" connections can exit from the bottom of a function box. The individual functions are numbered using a system which indicates the order of the functions, and the level of the analysis. Each diagram should include a reference block showing the next higher level of analysis.

Inputs to the technique

The analyst needs information on the mission sequence, derived from a mission analysis, or equivalent data on the sequence of events and operational requirements. The analyst also needs knowledge of previous, similar systems and similar operational requirements.

Outputs of the technique

Function flow diagrams provide a comprehensive inventory of system functions that must be considered in assuring the ability to perform a mission. As more detailed function flows are produced, specific system requirements begin to emerge. The diagrams provide a view of how the system will operate, in logical terms.

When to use

The analysis should be conducted early in concept definition and design definition. The analysis should follow from the mission analyses; it precedes Function Allocation (3.3). Some texts treat FFDs as preceding the use of Requirements Allocation Sheets (US Defense Systems Management College, 1990; USAF, 1971.b).

Related techniques

The technique is related to the function analyses conducted as part of the system engineering effort (Lurcott, 1977). There is little reason why a common analysis is not conducted to serve all systems engineering analyses. Usually, however, the analyses conducted for other systems engineering specialities do not make the functions performed by the system operators and maintainers explicit at the lower levels of analysis. The technique is strongly related to systems engineering techniques such as Sequence and Timing (SAT) diagrams (2.2) and to software requirements development methods such as SADT™/IDEF® (2.3).

Resources Required

Because of the need to reference functions across and between levels, and because of the iterative nature of their development, it is desirable to have a computer system available that can create the function flow diagrams and keep track of the function names and reference numbers.

Relative contribution

Users' reports vary from "medium" to "excellent". This technique is generally seen to make an important contribution to the identification of the functions that human operators will perform.

Applications

The technique has been widely used (see Laughery & Laughery, 1987; Nice, 1984), and has been employed in a wide variety of systems development projects. It has been used to analyse aircraft (both fixed and rotary wing), ship-board systems (combat systems, helicopter landing control systems, re-supply at sea systems), and land-based systems, including major command and control systems.

Advantages

Block diagrams are widely used to communicate ideas about the structure and logic of systems. Users report that the technique is very effective for communicating system function requirements to potential users. The diagrams are also useful for communicating with other members of the design team. The technique is generally found to be a highly effective way of identifying system requirements, at the outset of design. It is simple to learn, and is not labour intensive, unless all diagrams are prepared by hand.

The systematic decomposition of the system functions, coupled with the reference numbering system provides rationalized traceability from lower to higher level functions, and between functions at the same level. The function analysis can be used to study reversionary-mode operations, by examining the impact of removing specific functions.

Disadvantages

The technique requires a good understanding of typical system functions. Although the technique is easy to learn, it is is beneficial to have available function decompositions from similar systems. Thus there is a "start-up" cost if the user has no previous experience.

The diagrams show only the logical or chronological sequence of functions. They do not contain the inputs and outputs of system functions, or show the input-output flow. They do not show the information pertaining to decisions or time and time-critical activities.

Function flow diagrams are not an end in themselves: they are not suitable for inputs to detailed system requirements which involve human operators, but must be used as a basis for further analyses.

Quality assurance considerations

Novice users have shown some difficulty in keeping each level of analysis consistent. Because the number of functions increases exponentially with the level of detail, it is easy for inconsistencies to occur at the lower levels. A computer data-base is recommended for maintaining consistency of terms, numbering, and application of the individual functions.Woodson (1981) cautions that what purports to be function analysis is often the description of a concept. Thus terms such as "data entry unit" or "drum storage" are used, instead of descriptions of what has to be done. Guidance for the preparation of FFDs is contained in a US Air Force Data Item Description (USAF, 1971.a): although not widely referenced, it still may be written into contracts.

Relationship to system performance requirements

FFDs are indirectly related to system performance requirements They can be related to the system performance requirements via the mission analyses. The functions define what the system must do to perform the mission.

References and Bibliography

1. Laughery, K.R. Snr., Laughery, K.R. Jr. (1987). Analytic techniques for function analysis. In: G. Salvendy (Ed.), Handbook of human factors. New York: John Wiley & Sons.
2. Lurcott, E. (1977). F2D2 (Functional flow diagram and descriptions), a system management tool. Defense Systems Management Review (1), 19-28.
3. Nice, J.A. (1984).. A system designer's view and use of human factors. In: Workshop on applications of systems ergonomics to weapons system development. Volume 1: Technical Papers. Brussels: NATO. DS/A/DR(84)408.
4. USAF (1971.a) Data Item Description -Functional flow diagrams. DI-S-3604/S-126-1. Washington D.C.: U.S. Air Force Systems Command.
5. USAF (1971.b). Data Item Description - Requirements Allocation Sheets. DI-S-3605/S-127-1. Washington D.C.

US Air Force Systems Command.
6. US Defense Systems Management College (1990). System engineering management guide. Washington D.C.: US Government Printing Office.
7. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
8. Woodson, W. (1981). Human factors design handbook. (pp. 913-922). New York: McGraw-Hill Book Co.

2.2 SEQUENCE AND TIMING (SAT) DIAGRAMS

What the technique does

Sequence and Timing Diagrams were developed for systems engineering purposes. They show the sequence of activation of the sub-systems as necessary system functions are performed.

Inputs to the technique

To generate the diagrams, the analyst requires information on the sub-systems (see Part 2 of this volume for examples of system hierarchies), and on the sequence of functions to be performed by the sub-systems.

Outputs of the technique

The diagrams show the flow of "activations" through sub-systems, as system functions are performed.

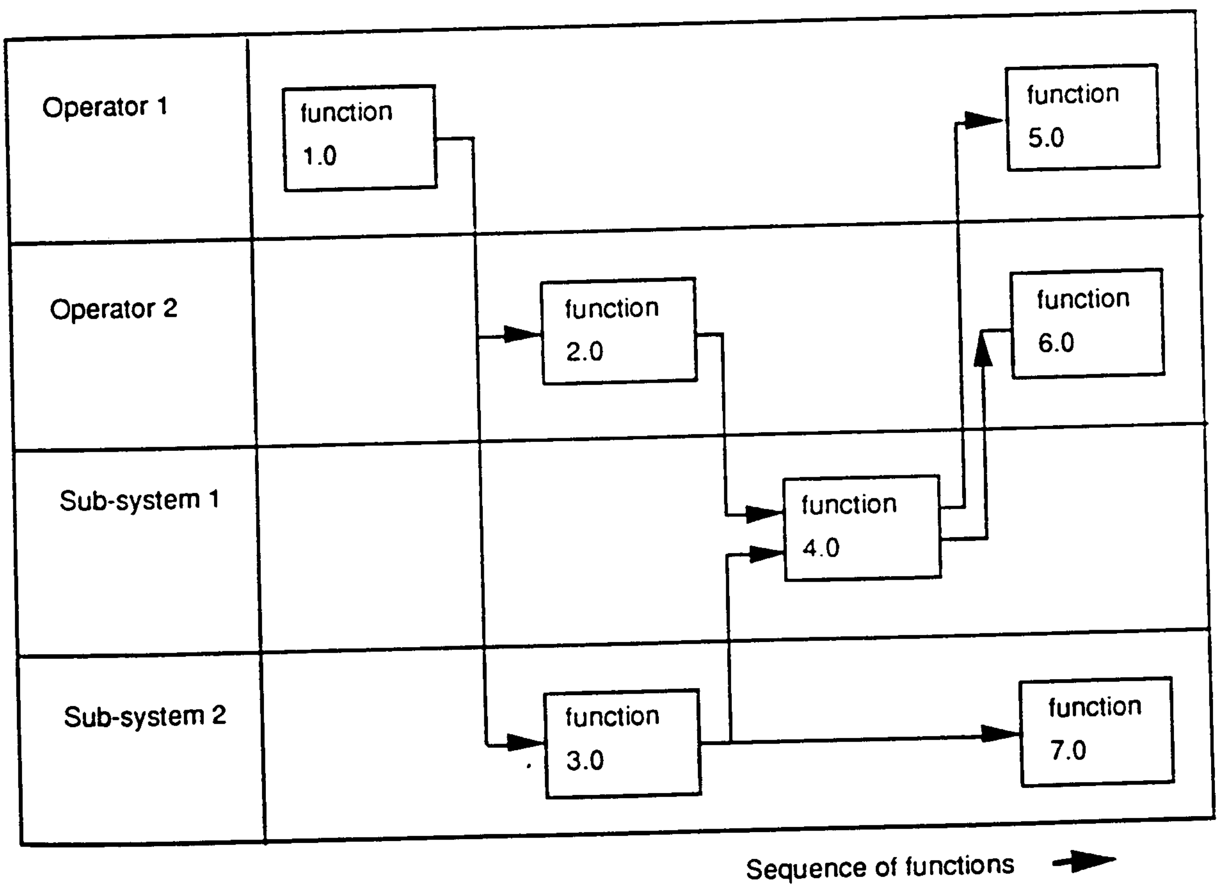


Figure 2.3: Sequence and timing diagram

When to use

The diagrams can be produced during concept development, once decisions have been made about the allocation of functions to sub-systems. For this reason they are sometimes known as "Task Allocation Charts" (MoD-PE, 1988), "Job Process Charts," or "User/Computer Work Allocation Charts" (Lurcott, 1977). The charts also lend themselves to the description of an existing system, prior to a change in the level of automation.

Advantages

The charts show clearly the sequence of events, and related sub-systems, and facilitate a review of the allocation of functions to sub-systems. They combine the information on system structure, with information on the sequential relationships of system functions.

Disadvantages

As with similar graphic techniques, the charts can describe only a limited part of a system's operation on each page. Thus they do not provide a good overview of the functioning of a complex system.

Relative contribution

No data available.

Applications

The technique was used for the development of the US Navy's AEGIS system (Lurcott, 1977), and was used in the initial stages of analysis of the NATO Anti-Air Warfare System (NAAWS).

Quality assurance considerations

Because the diagrams cannot be related directly to system performance requirements, quality control must be exercised by checking for consistency and completeness in the function flows.

Relationship to system performance requirements

The output of the analysis cannot be related directly to system performance requirements. Such requirements are implicit in the sequence of functions, but are not addressed directly.

References and Bibliography

1. Lurcott, E. (1977). F2D2 (Functional flow diagrams and descriptions), a system management tool. Defense Systems Management Review, (1), 19-28.

2. MoD-PE/DTI (1988). Human factors guidelines for the design of computer-based systems, Vol. 2, (pp. 66-72). London: Controller, HMSO.

2.3 STRUCTURED ANALYSIS AND DESIGN TECHNIQUE (SADT™)

What the technique does

SADT™, and its military equivalent IDEF®, were developed to describe complex systems and control the development of complex software through a systematic approach to requirements definition (Ross & Schoman, 1977). One of the aims was to develop a process which includes definition of human roles and interpersonal procedures as part of the technique. SADT™ (or IDEF) approaches requirements definition through a series of steps which determine *why* the system is needed, *what* the system features will serve, and *how* the system is to be constructed. The requirements are defined by identifying the necessary functions, and developing an implementation that meets the requirements by performing the functions (see Marca & McGrowan, 1987, for example).

The technique has been adopted to describe complex systems which may include any combination of hardware, software, and people. It is also being used to describe systems for computer simulation, or modelling. A SADT™ description of a system consists of diagrams, text, and a glossary, cross-referenced to each other. The description is organized into a hierarchy of interconnected diagrams. The top level of the hierarchy contains the most general description of the system: the bottom level contains the most detailed description.

Diagrams are the principal means of representation. All system functions (activities, actions, processes, operations) are represented as boxes, and interfaces are represented by arrows. The positions at which an arrow enters a box conveys the role of the interface. Conditions which govern the function (controls) enter the top of the box. Materials, or information acted on, enter the left side of the box. The mechanism (person or equipment) which performs the function enters the bottom of the box. The output of the function leaves the right side of the box.

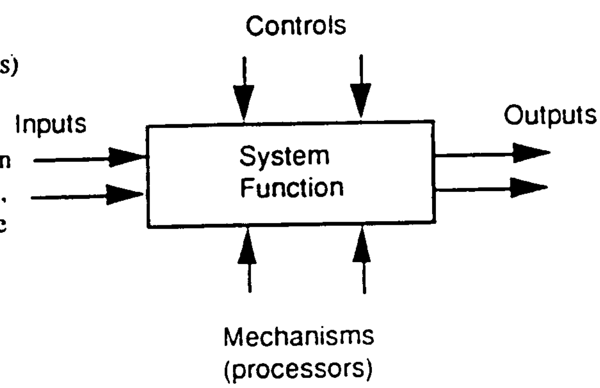


Figure 2.4: Basic SADT Diagram

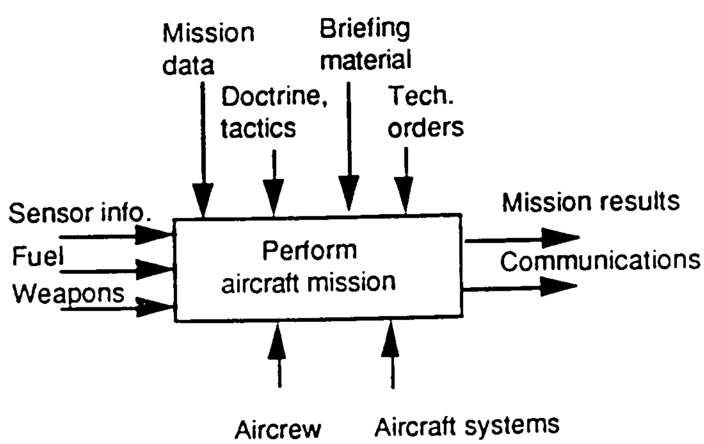


Figure 2.5: Top level SADT function for an aircraft mission

The analysis introduces increasing levels of detail by breaking each function into its component parts. Starting with a single unit (box) showing the interfaces to functions and resources outside the system, the decomposition proceeds by identifying the sub-modules, each represented as a box with interfaces. SADT™ uses rules for these decompositions. It is recommended that a module be divided always into no fewer than three, and no more than six sub-modules. Functions are described by an active verb written inside the box. Arrows that connect to a box represent objects, resources, information, etc. and are labelled by a noun. SADT™ includes procedures for critiquing the analyses by a larger group of people. The creation of a SADT™ definition is a dynamic process, which is seen as requiring the participation of more than one person. Throughout the project, designated "authors" create initial diagrams which are distributed to project members for review and comment. Supporting procedures such as librarian rules and procedures are also included.

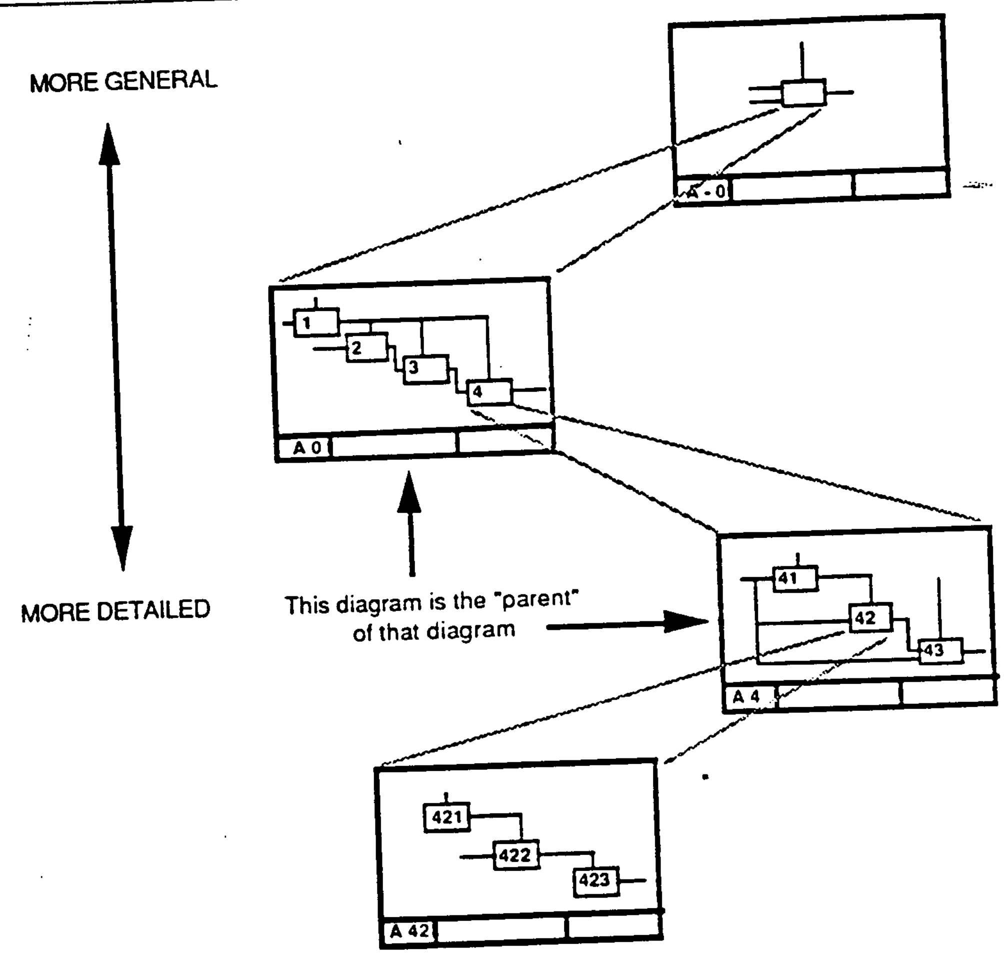


Figure 2.6: SADT model structure

Inputs to the technique

Information on system context (why the system is required) is needed to initiate the analysis. The analysts must obtain information on system functions, inputs, controls, outputs, and design and operating constraints, as they proceed through the analysis.

Outputs of the technique

The output of the technique is a system requirements specification, including SADT™ diagrams, which show the system functions, the function inputs, controls, resources, and outputs, and the logical flow of information and material between them. The specification thus identifies the mechanisms needed for the system concept.

When to use

By definition, the technique is most suitable for the requirements definition phase of a project, (the preliminary system studies phase and concept formulation). This can include the requirements definition for a computer simulation such as SAINT (5.2) or other networking models, which can occur later during system development. The technique can also be used to document an existing system prior to upgrade.

For human engineering purposes the technique could follow a mission analysis, or be derived directly from the statement of requirements. It should precede detailed tasks analyses and workload analyses. If SADT™ is being used for system software development, then it may be possible to use it as the basis for human engineering studies.

Advantages

SADT™ supports the systematic definition of requirements. It provides a management and accounting tool, and is an effective way of obtaining consensus about the requirements for a project. Wallace, Stockenburg and Charette (1987) argue that SADT™ is the first of three essential steps in a unified method for developing systems.

The technique permits the specification of system requirements with the minimum of redundancy. It represents the allocation of resources within a system, and provides an effective basis for trade-off decisions, to study future system capabilities and improvements, and to identify system tasks and task dependencies. The documentation of function resources also facilitates the study of reversionary-mode operation, because the impact of the "failure" of a specific resource can be studied easily.

Disadvantages

SADT™ diagrams show only the input and output flow between functions. They do not show sequential function flows or times. Thus SADT™ does not provide all of the information required to produce a network model of operator tasks (see Floyd, 1986). Additional analysis is necessary.

The recommended limit of not more than six boxes per level can limit the scope of the representation, so that, at lower levels, concurrent functions may not be represented on the same diagram.

One user cautions that the "viewpoints" used to develop the requirements are not unique. Thus the analysis reflects a specific viewpoint, and could be biased.

Related techniques

SADT™ is a development of the basic form of function analysis. The Controlled Requirements Expression (CORE) technique developed and used in the UK is closely related (System Designers, 1986). Also related are the Structured Design approach of Yourdon (1989), Structured Analysis of De Marco (1979), Essential System Analysis of McMenamin & Palmer (1989), and Information Systems Work and Analysis of Change (ISAC) developed by Stockholm University (Lundeberg, Goldkuhl, & Nilson, 1981).

Resources required

The analysts must be experienced in the use of the technique and must have some understanding of the functioning of similar systems. They also must have access to "commentators," "readers" and "experts" on requirements and constraints.
Programmes are available to run on personal and mainframe computers, to facilitate the generation of SADT™ analyses.

Relative contribution

Users report the technique (or its U.S. DoD variant IDEF®) to be very effective for forcing the analyst to consider the complete system, and to be a good tool for communicating ideas, concepts, and problem areas.

Applications

Ross & Schoman (1977) report the use of SADT™ in wide variety of developments, from real-time communications to process control. SADT™ has been used by the USAF in a number of major projects, and is a major tool in the GENSAW project being undertaken at USAF AAMRL, to develop tools for the computer simulation of operator tasks (Mills, 1988).

Quality assurance considerations

Quality assurance considerations include the need to check the analysis for the inclusion of all requirements and constraints. This is done through the recommended review and editing process, using other experts to comment on the work of the authors.

Relationship to system performance requirements

The technique can be related to functional requirements, but not to those involving timing or sequences.

References and Bibliography

1 De Marco, T. (1979) Structured analysis and system specification. New York: Yourdon Inc.
2. Floyd, C. (1986). A comparative evaluation of system development methods. In: T.W. Olle, H.G. Soland, A.A. Verijn-Stuart (Eds.), Information systems design methods. Amsterdam: Elsevier-Science Publishers B.V.
3. Lundeberg, M., Goldkuhl, G. & Nilson, A. (1981). Information systems development: A systems approach. Englewood Cliffs, N.J.: Prentice Hall Inc.
4. Marca, D.A., McGrowan, C.L. (1987). SADT™ - Structured analysis and design technique. New York: McGraw-Hill Book Co.
5. McMenamin, S.J., & Palmer, J.F. (1989). Essential systems analysis. New York: Yourdon Press.
6 Mills, R. (1988). The user-assisted GENeric Systems Analyst Workstation (GENSAW): Summary. Presentation to NATO AC/243 Panel-8/RSG.9, Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory.
7. Price, C.P., & Forsyth, D.Y. (1982). Practical considerations in the introduction of requirements analysis

techniques. In: Software for avionics. Neuilly sur Seine, France: AGARD CP-330.

8. Ross, D.T. & Schoman, K.E. Jr. (January 1977). Structured analysis for requirements definition. IEEE Transactions in Software Engineering, SE-3 (1), pp. 6-15.
9. SoftTech Inc. (1981). Integrated computer aided manufacturing (ICAM) architecture. Part II Vol. I-X. Ohio: Wright Patterson Air Force Base, Wright Aeronautics Laboratories, Air Force System Command. AFWAL-TR-81-4023.
10. Systems Designers plc. (1986). CORE: COntrolled Requirements Expression. Fleet, Hants, U.K.
11. Wallace, R.H., Stockenberg, J.E. & Charette, R.N. (1987). A unified methodology for developing systems. New York: McGraw-Hill Intertext Publications Inc.
12. Yourdon, E. (1989). Modern structured analysis. Englewood Cliffs, New Jersey: Prentice-Hall Inc.

2.4 INFORMATION FLOW AND PROCESSING ANALYSIS
(INFORMATION/ DECISION/ ACTION DIAGRAMS)

What the technique does

The term "information flow and processing analysis" is used in some documents regulating the application of human engineering to systems development (US Department of Defense, 1979). It covers "analyses performed to determine basic information flow and processing required to accomplish the system objective and include decisions and operations without reference to any specific machine or level of human involvement." There is no one technique which is used for such analyses, although it is generally taken to refer to the Information/Decision/Action diagrams developed by Dunlap & Associates in the 1950s. Woodson (1981) reviews several techniques which are basically flow charts, or block diagrams, showing the flow of information through a system. Meister (1985) calls the charts "decision/action" (D/A) diagrams.

The analysis identifies the chronological sequence of functions, and the logic relating them in the form of "yes/no" decisions, information input sources (functions), information channels (links between functions, and functions which modify the information), and information receivers (functions which use the information). Decision/Action Diagrams are one way of documenting the output of the analysis. They show a sequence of decisions and operations without reference to any specific machine implementation. The technique has much in common with Function Flow Diagrams (2.1) and SADT™ diagrams (2.3). It can be considered to be a function flow diagram incorporating a separate classification for 'decision' functions, together with AND/OR logic.

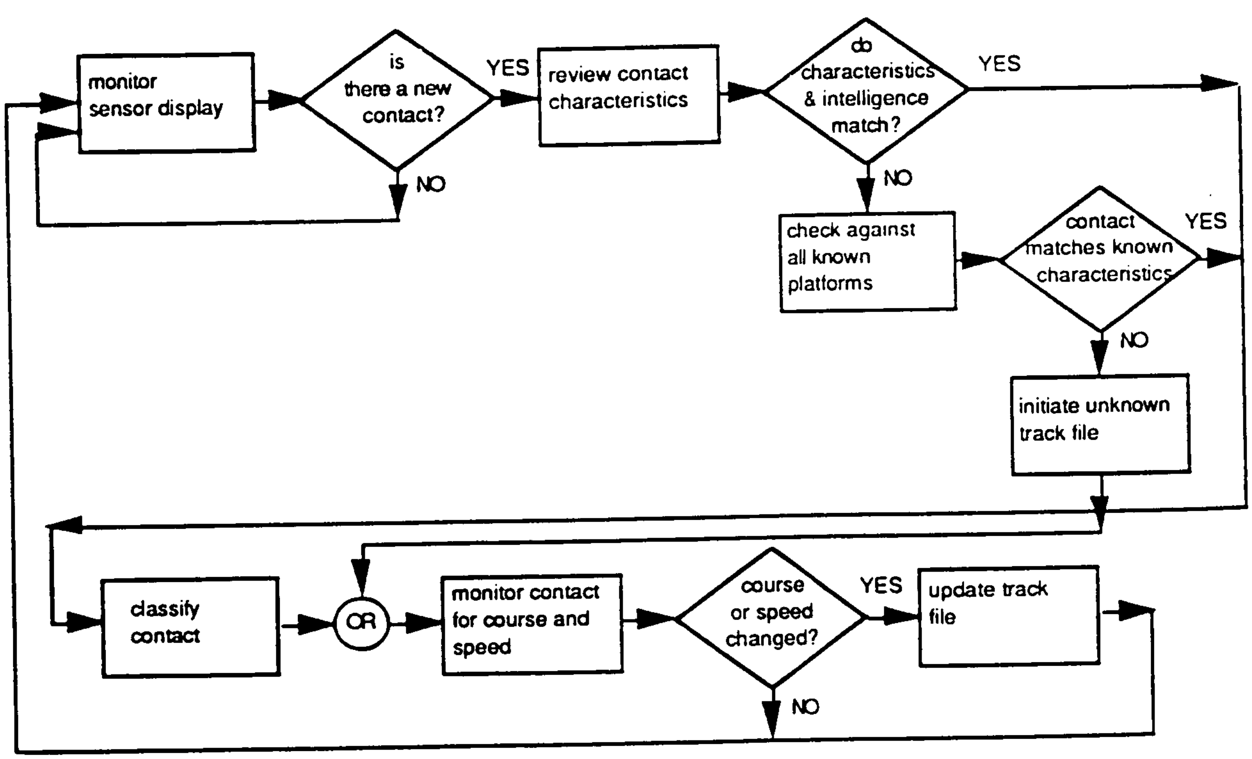


Figure 2.7: Information/decision/action diagram for a sonar system concept

Inputs to the technique

Information on the major system functions, the information flow, and those functions which modify information. Detailed mission analyses might be sufficient to start the analysis.

Outputs of the technique

Charts showing the information flow, and identifying the critical decision points and information modifiers. Decision/Action diagrams use only two symbols, one for decisions, and one for other activities.

When to use

The technique should be used during concept definition and preliminary design. It should be used for the functional analysis of systems where there may be important dichotomous decisions. It is useful for identifying the critical decisions made by human operators, and could be a useful input to a cognitive task analysis.

Related techniques

The technique is strongly related to function analysis, to SADT™/IDEF®, and to flow charts produced for computer programming. There is a high level of redundancy between information flow and processing analyses and function flow diagrams (2.1). It is recommended that only one of the techniques be used on the same project. Meister (1985) recommends that the analyses should be followed by time line analysis (4.1) to investigate the effect of time on system performance.

Resources required

The analyst must have information on the system functions, particularly those which modify information. No technical resources are required, but a computer aided production system is desirable.

Advantages

Users report the technique highly effective and easy to use. It has been found very effective for analysing the option trees and identifying the "modes" of operation of multi-function controls and menu systems ("moding analysis").

Disadvantages

Users find the technique time consuming. It is difficult to define many human operator decisions clearly, because humans are included as system components to deal with unanticipated events. The Decision/Action Diagram itself is a cumbersome way to analyse information flows, because it forces decisions into a "Yes/No" dichotomy, thereby creating a large number of decisions.

Relative contribution

Users report the technique to make a good contribution to detailed analyses, such as the moding analysis mentioned above.

Applications

The technique was developed for use on the U.S. Navy's ballistic missile submarine programme. Henry (1968) reported its use in the development of the concept for a ship's bridge system. More recently, it was used in the development of the Panavia Tornado aircraft, a mine-sweeper, and a missile range communications system.

Quality assurance considerations

As with all function analyses, the application must be comprehensive. The decisions can be checked against the system functions, if a function analysis is available.

Relationship to system performance requirements

The analysis can be used to identify key decisions, where error or delay might be critical to system effectiveness. It can be related to the system mission segment analyses at a gross level.

References and Bibliography

1. Henry, O.W. (1968). Human factors in ship control: human engineering techniques and guidelines applicable to merchant marine bridge design, Volume II. Groton, Connecticut: General Dynamics Inc.
2. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
3. US Department of Defense. (1979). Human engineering requirements for military systems, equipment, and facilities, MIL-H-46855B. Washington D.C.: US Army Missile R&D Command.
4. US Department of Defense. (1987). Human engineering procedures guide. DoD-HDBK-763. Washington D.C.
5. Woodson, W. (1981). Human factors design handbook, (pp. 932-934.) New York: McGraw-Hill Book Co.

2.5 STATE TRANSITION DIAGRAMS

What the technique does

State Transition Diagrams are extensions of data-flow analysis techniques used for the development of real-time software systems. They are based on finite automata theory, and describe sequential machines which are defined as finite state machines whose outputs are determined by both their current inputs and actual state; i.e., the machines have memory. The memory is represented in the form of states: a sequential machine is always in one of its specified states. State Transition Diagrams show the relationship between system "states" and "events" which change the system state. They can be used to identify operator actions needed to change the system state, and to show the effects of human operator actions which change the system state.

System states are shown as circles (Pressman, 1987) or rectangles (Yourdon, 1989) with the state name inside, connected by arcs, which represent the transitions. The arcs can show transitions between states: they can be annotated to show the events which cause the transition, and/or the actions associated with the transition. Two different types of finite state machines have been defined: one has the output uniquely determined by the states (Moore machine); one has the output determined by both the state and the input (Mealy machine).

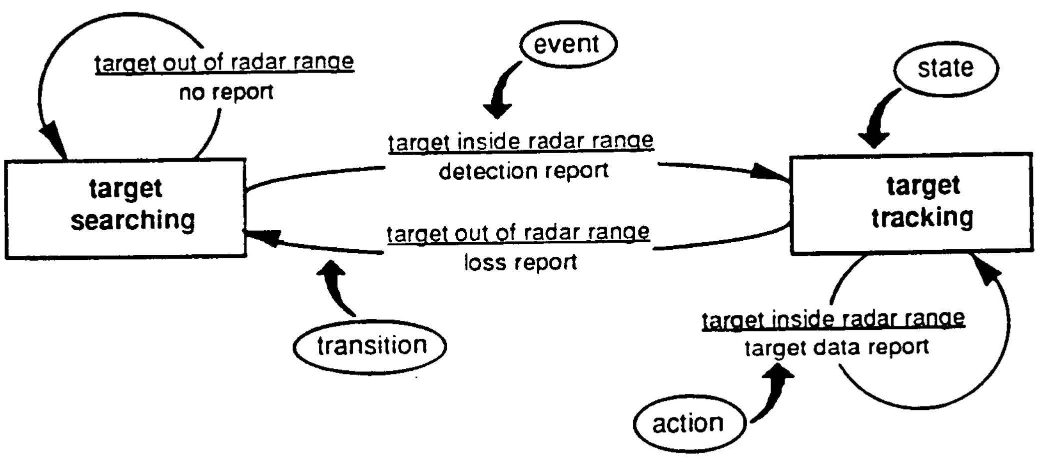


Figure 2.8: States and transitions of a radar system

Another form of visual notation for a finite state machine is the state transition matrix. The tables and diagrams are formally equivalent, in terms of describing the system logic.

Table 2.2: State table for the radar system

State	Event	Action	Next State
target searching	target inside radar range	detection report	target tracking
	target out of radar range	no report	target searching
target tracking	target out of radar range	loss report	target searching
	target inside radar range	target data report	target tracking

State transition matrices may be plotted as state-state tables, or as state-event tables. Shown below are two versions of the same transition matrix. The state-state table shows that, to change from state '01' to '02' requires event 'p' and produces output "q." The state-event table shows the same logic: given event "p," the machine will change from state "01" to state "02" with output "q."

Table 2.3: State-State Table **and** **State-Event Table**

FROM STATE \ TO STATE	State 01	State 02
State 01	x	p
	y	q
State 02		x
		z

EVENT \ STATE	State 01	State 02
x	y	
	State 01	
p	q	
	State 02	
x		z
		State 02

Inputs to the technique

The analyst must have information on the various possible system states, the inputs (events) which initiate a state, and outputs (actions) which are associated with that system state or state transition.

Outputs of the technique

The technique produces diagrams of the states and state transitions, showing the structure and relationships between initiating events, system states, and system outputs. The information can be shown in tabular form.

When to use the technique

The technique can be used during the development of system software, following the definition of software system "tasks." It is used to define processing requirements by specifying a set of inputs and outputs, a set of states, and a function that maps inputs plus current state onto outputs plus updated states.

In human engineering analyses, state transition diagrams can be used as a task description technique, to identify the control actions required of an operator, and the resultant system states and associated classes of information. Finite state machines have been used to specify user interfaces: the input alphabet is the input from the user, and the output alphabet is the system response.

Related techniques

A related technique, the signal flow graph, shows system variables instead of states, and causal dependencies instead of "events." Signal flow graphs have been used to analyse operator tasks in process control (Beishon, 1967). The technique is closely related to several other software development techniques, particularly to Data Flow Diagrams and Finite State Machine algebra. The state machine model underlies several more advanced techniques (Davis, 1988). A Petri net model (2.6) can be considered as an alternative to a state machine model, and is specially suited to modelling concurrent systems (Peterson, 1981). In an "extended" finite state machine, attributes are associated with the input. Behaviour graphs used in the RDD approach (2.7) can be reduced to an extended finite state machine. In fact, this is a necessary step in order to generate simulation models and prototypes directly from the specification.

Advantages

The technique is used and understood by software developers (Wirstad, 1989). The diagrams are good for communicating the required operator input information for tasks and possible sequences of operator actions, particularly when multiple options must be analysed, e.g., when developing menus. Transition tables permit a rapid, complete, analysis of individual operator control actions and avoid some of the limitations of the diagrams by introducing the possibility of combining states using AND/OR logic to create a hierarchy. It has been suggested that the diagrams would be very useful for providing a framework for the analysis of data on operator actions captured by on-line monitoring of keystrokes and other control movements (Maguire & Sweeney, 1989).

Disadvantages

The technique does not describe clearly complex human-machine interfaces where multiple control actions (e.g., several key-strokes) may be required to initiate a change of state. Normally, the diagrams do not show the outcome of incorrect operator actions: (transition tables can be checked for completeness, however, thereby identifying possibly undesirable operator actions). They are inherently sequential in nature, and small extensions of a system can give rise to an exponential increase in the number of states that have to be considered (Harel et al. 1988). The flat structure of a state transition diagram does not describe well the "state explosion" that occurs when concurrent activities and large systems are described.

Relative contribution

No data available.

Applications

The technique was used for the development of an integrated, digital-data-bus based ship-board communication system for the Canadian Forces. It has been used for the development of training requirements for a ship-board system in the Royal Navy (UK), and a howitzer, an air-defence system, training system and human performance model, in the USA.

Quality assurance considerations

The technique must be checked for consistency and completeness. The diagram appears best suited to checking for consistency, the transition table best suited for checking completeness. The analyst should check that all states have been defined and that each can be entered and exited.

Relationship to system performance requirements

The output of the technique cannot be related directly to system performance requirements. System performance is expressed only as a series of system states, and the logic by which those states are initiated.

References and Bibliography

1 Beishon, R.J. (1967). Problems of task description in process control. Ergonomics 10 (2), 177-186.

2. Davis, A. (1988). A comparison of techniques for the specification of external systems behaviour. Communications of the ACM 31 (9)

3. Harel, D., Iachover, H., Naamad, A., Pnueli, A., Sherman, R. & Shtul-Tauringet, A. (1988). STATEMATE: A working environment for the development of complex reactive systems. In: Proceedings of the Tenth IEEE International Conference on Software Engineering. New York: IEEE Press.

4. Hatley, D.J. & Pirbhai, I.A. (1978). Strategies for real-time system specification. New York: Dorset House Publishing Inc.

5. Maguire, M., & Sweeney, M. (1989). System monitoring: garbage generator or basis for comprehensive evaluation system? In A. Sutcliffe, L. Macaulay (Eds.), People and Computers V. Proceedings of the fifth conference of the British Computer Society Human-Computer Interaction Specialist group. Cambridge: Cambridge University Press.

6. Peterson, J.L. (1981). Petri net theory and the modeling of systems. New York: Prentice-Hall.

7. Pressman, R. (1987). Software engineering: A practitioners approach. New York: McGraw-Hill.

8. Wirstad, J. (1989). The state diagram – a technique for better communication between operators and designers. Paper to Meeting of Human Factors Society – European Chapter Meeting. Newsletter HFS - EC.

9. Yourdon, E. (1989). Modern structured analysis. Englewood Cliffs, New Jersey: Prentice-Hall Inc.

2.6 PETRI NETS

What the technique does

A Petri net is a graphical and mathematical modelling tool for describing and studying information processing systems in which concurrent, asynchronous, distributed, non-deterministic and/or stochastic processes can occur (see Murata, 1989 and Peterson, 1981). Recently, there has been a growing interest in applying them during the requirement development phase (Davis, 1990).

Petri nets are graphs where two types of nodes – *places* (circles) and *transitions* (bars) – are interconnected by *directed arcs*. For each transition, the directed arcs connect *input places* to transitions, and transitions to *output places*. An example of a Petri net is shown in Figure 2.9.

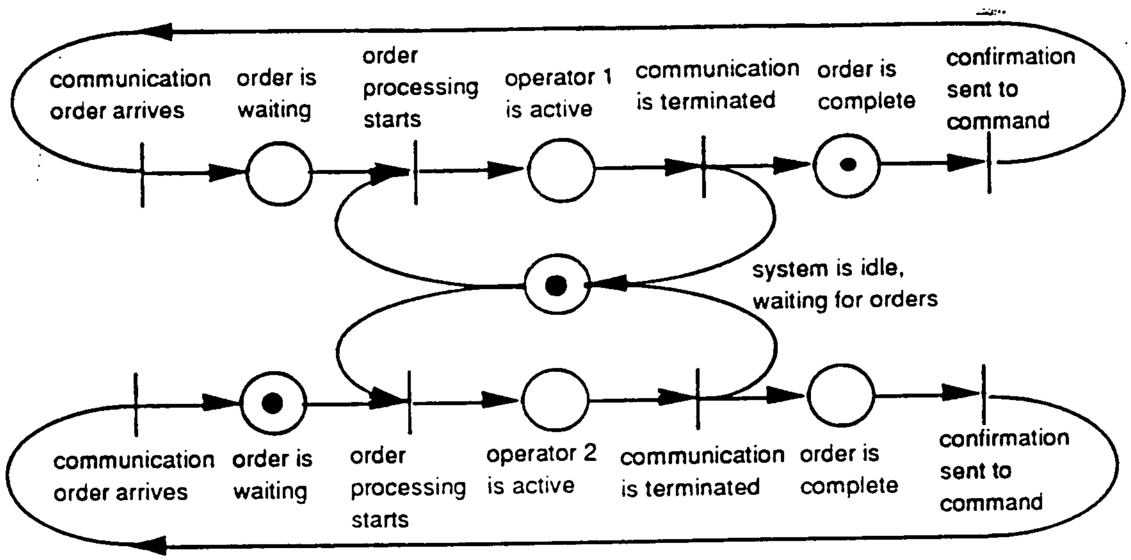


Figure 2.9: A Petri net model of a communication system: initial condition

The simple Petri net view of a system concentrates on two primitive concepts (Peterson,1981):

- Events: these are the results of actions which take place in the system. Their occurrence is controlled by the state of the system which can be described as a set of conditions. Events are modelled as *transitions* (bars).
- Conditions: certain (pre)conditions must hold for an event to occur, and the occurrence of an event may cause one or more new (post)conditions. Conditions are modeled as *places* (circles).

An event in the example (Figure 2.9) is "order processing starts." The relevant preconditions are "an order is waiting" and "system is idle." The post-condition would be that "operator 2 is active" and "system is not idle." (Other interpretations of transitions and places are given in Table 2.4 (Murata, 1989)). In the given example, there can be a conflict between the two operators. In fact, only one operator can use the communication system at a time.

A place can contain *tokens* (illustrated as dots within the circle). A Petri net is executed by defining a distribution of *tokens* to the *places* of the net (a *marking*) and then firing the *transitions*. When a Petri net model is executed the distribution of tokens among the places is changed as illustrated in Figure 2.10. A token is transferred through a transition if all the connected places contain one or more tokens. Timed Petri nets are possible. In that case an event duration time is associated with each transition. The values can be constant, or computed as functions of the values of tokens at the input places, or sampled from distributions.

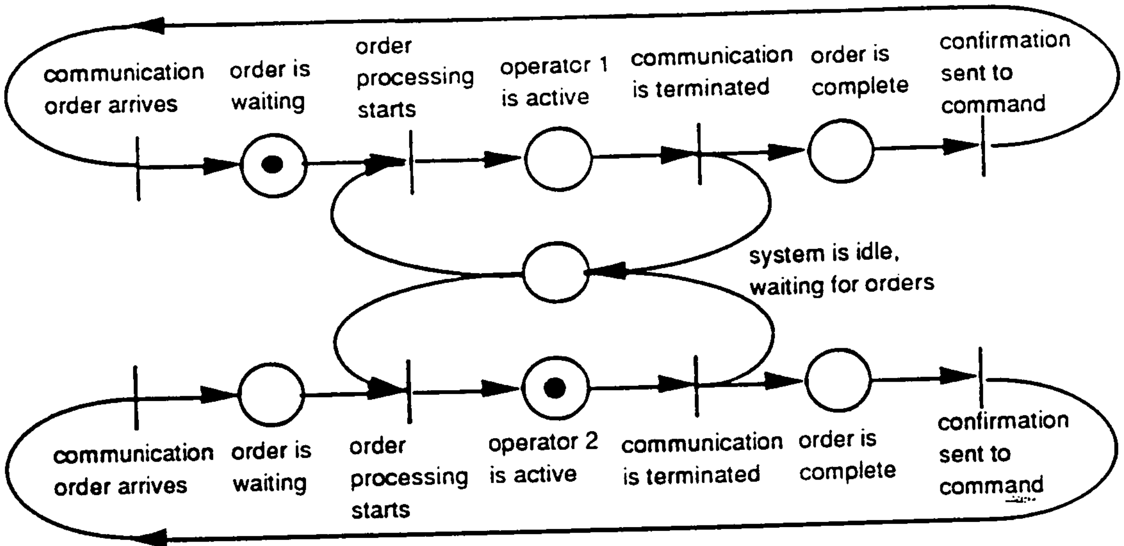


Figure 2.10: A Petri net model of a communication system in a conflict situation

Table 2.4: Some typical interpretations of Transitions and Places (Murata, 1989)

Input places	Transition	Output places
Preconditions	Event	Post-conditions
Input data	Computation step	Output data
Input signals	Signal processor	Output signals
Resources needed	Task or job	Resources released
Conditions	Clause in logic	Conclusions
Buffers	Processor	Buffers

Inputs to the technique

The events and the conditions of a system must be described and modelled. The sequencing between the events must be available, as well as their priorities and duration times.

Outputs of the technique

The execution of the Petri net results in a sequence of discrete events that can be analysed. Further, several techniques have been developed for analyzing Petri nets without execution of the net. Some typical questions that can be addressed by this type of model are:

1. Reachability of certain markings, i.e., unsafe system states.
2. Resource administration and allocation, i.e., overflow and conflict situations, and deadlock problems and "starvation" of the system.

When to use

Petri nets can be used in the latter stages of design definition, or when other systems engineering specialities have made them available.

Related techniques

Petri nets are related to Function Flow Diagrams (2.1), SADT™/IDEF (2.3), Finite State Machines (see 2.5), Data Flow Diagrams, and Behaviour Graphs (2.7)

Resources required

The analyst must obtain information concerning the expected behaviour of the system. A user-defined scenario is a typical starting point. A CASE tool is mandatory in order to record different relationships systematically (e.g., between functions and items, between functions and requirements) and to handle the iterative development of the description effectively.

Advantages

A Petri net model can be considered as an alternative to a state machine model and is specially suited to modelling a-synchronous concurrent systems. Petri nets can be used for the hierarchical decomposition of systems and for developing models for SAINT simulation (5.2). Petri net models can used by practitioners and analysed formally by theoreticians. The modeling power of a Petri net can be extended in several ways (Christensen, 1991).

Disadvantages

Petri nets tends to become too large for analysis of even modest systems. In applying Petri nets it is often necessary to add special modifications or restrictions suited to the particular application (Murata, 1989).

Relative contribution

No data available.

Applications

Petri nets can be used to describe behaviour where ambiguity cannot be tolerated (e.g., a life-critical application) or where precise process synchrony is important. Petri nets have been used for specifying man-machine dialogues which involve asynchronous events and interleaving (mixed command sequences) (Biljon, 1988). They have been applied to decision making (Perdu & Levis, 1989) and to command and control systems (Wohl, 1987; Wohl & Tenney, 1987). Petri nets have also been proposed as a means of evaluating operator workload (Madni & Lyman, 1983) by defining human operator tasks as *places*, and internal or external forcing events as *transitions*.

Quality assurance considerations

Petri nets check for consistency, completeness, and potential conflicts in concurrent operations. Dynamic consistency can be checked using simulation techniques.

Relationship to system performance requirements

Performance requirements are specified as an integral part of the model. It is possible to associate deterministic or stochastic time delays with transitions and/or places in the net model. Additionally, by establishing item arrival times and/or duration times for the functions, time performance requirements can be established by executing the model. Performance evaluation and scheduling problems of dynamic systems can thus be performed.

References and Bibliography

1. Biljon, van W.R. (1988). Extending Petri nets for specifying man-machine dialogues. Int. J. Man-Machine Studies, 28, 437-355.
2. Christensen, S. (1991). Modelling and simulation using hierarchical coloured Petri nets. Aarhus University, Denmark.
3. Davis, A.M. (1990). Software requirements: Analysis and specifications. New York: Prentice Hall.
4. Madni, A.H. & Lyman, J. (1983). Model-based estimation and prediction of task-imposed workload. Proceedings of the Human Factors Society – 27th Annual Meeting. Santa Monica, CA: Human Factors Society.
5. Murata, T. (1989). Petri nets: Properties, analysis and applications. In Proceedings of the IEEE, Vol. 77, (4).
6. Perdu, D.M., & Levis, A.H. (1989). Analysis and evaluation of decision aids in organizations. In: Preprints of the 4th IFAC/IFIP/IFORS/IEA Conference on Man-Machine Systems Analysis, Design, and Evaluation, (pp. 50-56). Sept. 12- 14. XI'AN JIAOTONG University, XI'AN, China.
7. Peterson, J.L. (1981). Petri net theory and the modeling of systems. New York: Prentice-hall.
8. Weingaertner, S.T., & Levis, A.H. (1989) Analysis of decision aiding in submarine emergency decision making. Automatica, 25 (3), pp. 349-358.
9. Wohl, J.G. (1987). Representing the organizational dimension in Petri-net form. Burlington, MA: ALPHATECH Inc.
10. Wohl, J.G., & Tenney, R.R. (1987). Integrated analysis techniques for command, control, and communications systems. Wright-Patterson AFB, OH: Armstrong Aerospace Medical Research Laboratory, AAMRL-TR-87-040.

2.7 BEHAVIOUR GRAPHS

What the technique does

Behaviour graphs are combined control and information flow graphs for describing system behaviour within the Requirements Driven Development (RDD) systems engineering methodology (Alford, 1985b; Kloster & Tischer, 1987; Lenorovitz & Phillips, 1987). The graphs show system behaviour explicitly as a function of time. The data flow is shown on the horizontal axis, and time on the vertical axis. The graphs are used for function analysis at the system level, and for scenario modelling.

The basic language element of behaviour graphs is the *discrete function*. A discrete function inputs one (out of several possible) discrete items, and outputs one (or several) discrete items. The transformation is triggered by the arrival of the discrete item. The transformation can also be based on state information. The discrete function may have several exit paths. One exit path is selected, based on conditions from the transformation. The transformation of the discrete function includes both a mapping between the input and output items (interpreted as symbols) and a transformation of their contents. The transformation has specified performance indices. The formal description of this transformation is regarded as a software engineering responsibility, and is not described here.

In its graphical representation, the discrete function is visualized as a shaded rectangle, discrete items as ovals, and states as shaded ovals.

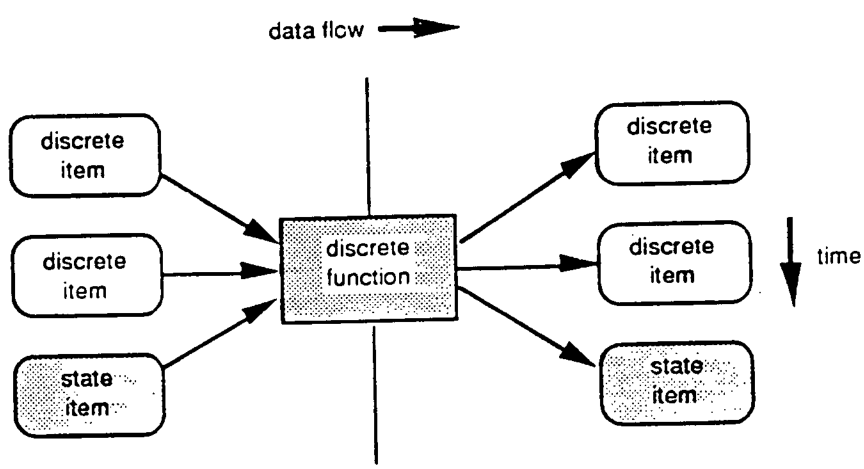


Figure 2.11: Graphical representation of a discrete function

Sequences and "concurrencies" of discrete functions are described by control constructs. The control constructs are selection, loop, iteration, GOTO, concurrency, and replication (copies of functions that are performed concurrently). A graph of discrete functions (called an F-net) can be aggregated into a *time function*. Time functions are also used for modelling of continuous transformations. A *time function* is visualized as a rectangle. The top level system behaviour consists of one single time function. This function is then refined (decomposed) into a graph of new time functions and/or discrete functions. This process is repeated until every time function has been decomposed into discrete functions.

Sequences and concurrencies of discrete items are described by the same control constructs as used for the functions, except for loop and GOTO. A graph (I-net) of discrete items can be aggregated into a *time-item*.

Inputs to the technique

Behaviour graphs model the communication and coordination between components and operators in a system. Thus details of the system architecture must be available. The input and output item sequences between the system and its environment must also be available.

Outputs of the technique

A complete behavioural model is established by performing the analysis.

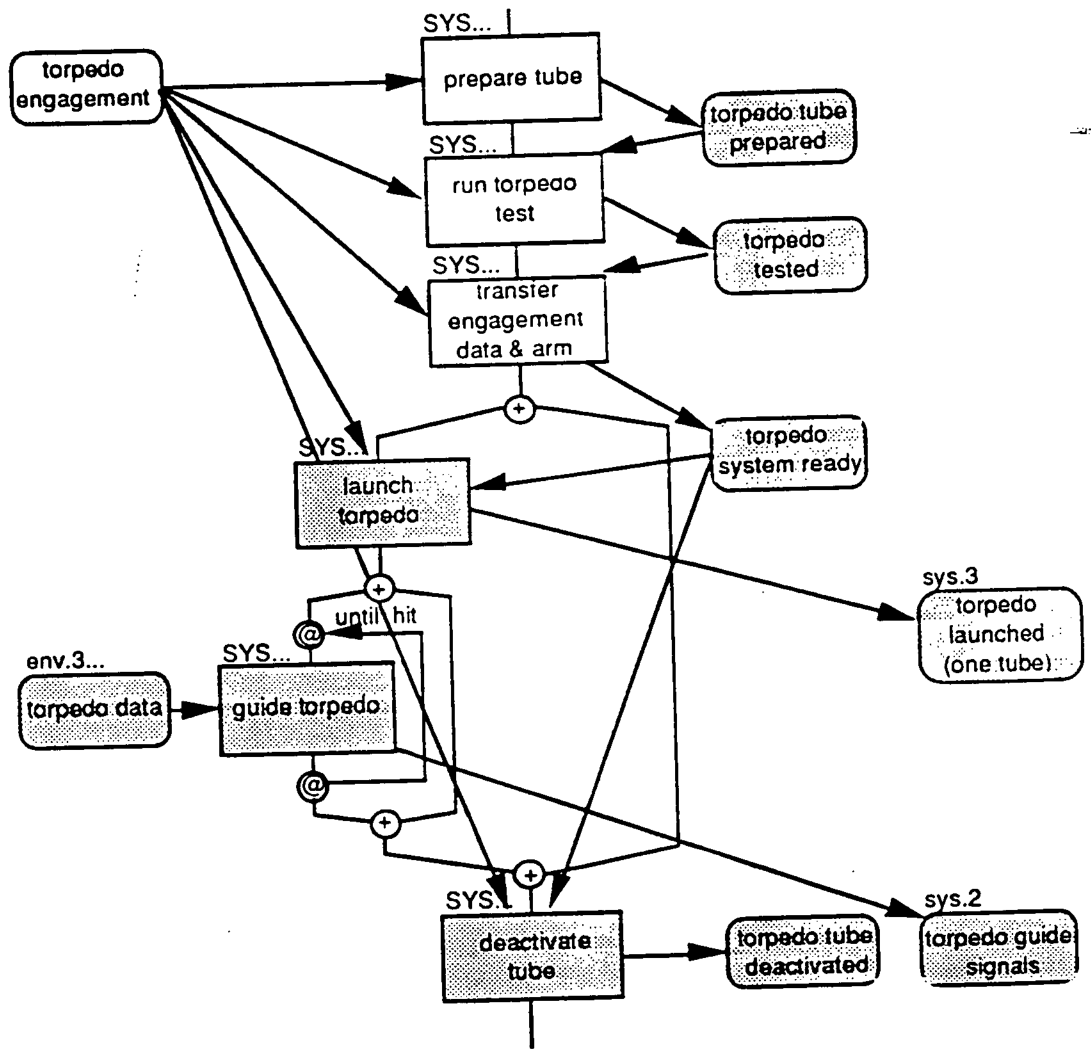


Figure 2.12: Behaviour graph for a torpedo engagement

When to use

Behaviour graphs are used for function analysis at the system level and for scenario modelling. Discrete functions can be further decomposed into *stimulus-response* nets, which are used for specification and analysis at the component level (e.g., software requirements analysis).

Related techniques

Several well known system analysis modelling languages are projections of behaviour graphs, e.g., Finite State Machines, Petri Nets (2.6), Function Flow Diagrams (2.1), Data Flow Diagrams, and SADT™/IDEF® (2.3).

Resources required

The analyst requires information concerning the behaviour expected of the system. User-defined scenarios are a typical starting point (Alford, 1989). A CASE tool is essential, in order to record the different relationships (e.g., between functions and items, and functions and requirements) systematically, and to handle the iterative development of the description effectively. Called RDD 100, this tool includes a graphical editor for creation and modification of behaviour graphs, consistency checks and a simulator for executing the graphs.

Advantages

The behaviour graphs provide an explicit model of sequences and concurrencies which are key issues with regard to user oriented system analysis. The graphs inform the reader of the main control flow, without need for further explanations. Information flow is shown as an integral part of the graph.

Behaviour graphs are an integral part of the RDD system engineering method. Tools for creating, editing, validating, and executing behaviour graphs and some of the systems engineering tasks are available.

Disadvantages

The complexity of the integrated graphs, which show information flow and explicit control-flow information, reduces their comprehensibility. Methods that use implicit control flow in their graphs, e.g. SADT™, can be more compact and much easier to edit. RDD models and behaviour graphs lack state information structuring and interrupt mechanisms as described by Harel (1987).

Relative contribution

No data available.

Applications

Behaviour graphs have been used for the development of the Advanced Automation System (AAS) air-traffic control system (Phillips et al., 1987). RDD, which incorporates the graphs, is currently being used in a number of projects, including Strategic Defense Initiative (SDI) and the Norwegian fast patrol boat project (Veum & Kramarics, 1990).

Quality assurance considerations

Computer-aided tools check for consistency and completeness. Dynamic consistency can be validated by executing (simulating) the graphs.

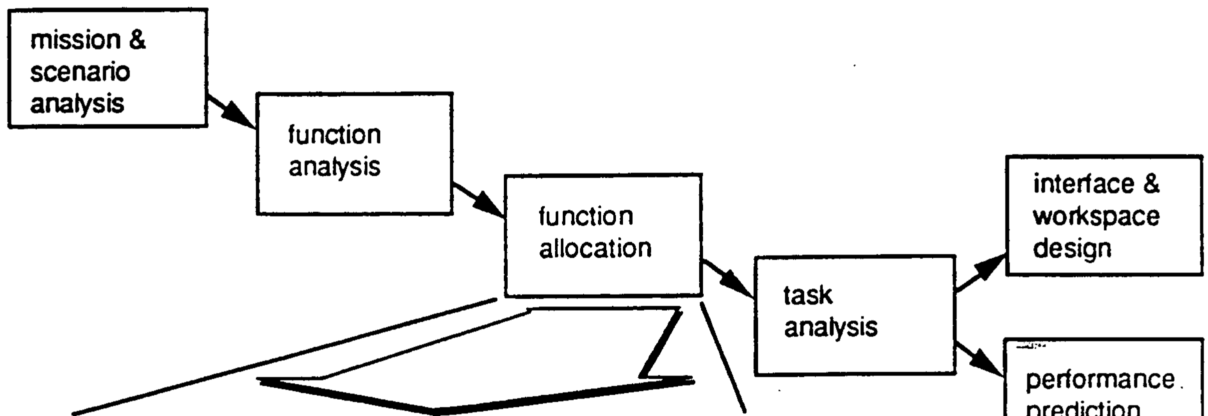
Relationship to system performance requirements

Performance requirements are specified as an integral part of the model. Additionally, by establishing item arrival times and/or duration times for the functions, time performance requirements can be identified by executing the model.

References and Bibliography

1. Alford, M.W. (1985a). SREM at the age of eight: The distributed design system. IEEE Computer, 18, 36-46.
2. Alford, M.W. (1985b). A graph model based approach to specification. In: M. Paul & H.J. Siegert (Eds.), Distributed systems: methods and tools for specification. Springer-Verlag.
3. Alford, M.W. (1989). Implementing scenario definition techniques using RDD-100. Proceedings of the IEEE real-time system symposium. IEEE Press.
4. Davis, A.M. (1990). Software requirements: analysis and specifications. New York: Prentice Hall.
5. Harel, D. (1987). Statecharts: a visual formalism for complex systems. Science of Computer Programing, 8 (3), 231-274.
6. Koster, G.V. & Tischer, K. (1987). Engineering the man-machine interface for air traffic control. IEEE Computer, 20 (2), 47-62.
7. Lenorovitz, D.R., & Phillips, M.D. (1987). Human factors requirements for air traffic control systems. In: G. Salvendy (Ed.), Handbook of human factors.(pp. 1771 - 1789). New York: John Wiley & Sons.
8. Phillips, M.D., Bashinski, H.S., Ammerman, H.L., & Fligg, C.M. (1987). A task analytical approach to dialogue design. In: E. Helander (Ed.), Handbook of human-computer interaction. New York: North-Holland.
9. Veum, K.A., & Kramarics, A.M.S. (1990). Requirement driven development: a system engineering method. In: Proceedings of the Norwegian Informatics Conference (NIK '90), (pp. 81-91). Tapir.

3 FUNCTION ALLOCATION



3.1 • Ad hoc function allocation

3.2 • Fitts' list

3.3 • Review of potential operator capabilities

3.4 • Function allocation evaluation matrix

3.5 • Requirements Allocation Sheets

What the techniques do

Typically, decisions about the functions performed by system operators and maintainers are made implicitly in the design process or through the selection of equipment and software. Although this approach does have a certain logic to it (Chapanis, 1970), such decisions may be made without systematic consideration of their impact on the roles, functions, and tasks of the human components of the system. This is particularly true of applications of computers to tasks which were formally performed manually. A rational allocation of functions to people (liveware), hardware, or software is necessary for optimal system design. Function allocation analyses provide the basis for subsequent efforts relating to crew or operator task analysis and description, operator performance analysis, display and control selection or design (including communication systems design), and crew-station design, development, and evaluation. In particular, decisions on the allocation of functions affect crew or operator workload and have a significant influence on manning, selection, and training requirements (US Department of Defense, 1987). In the systems engineering process, function allocation is conducted formally through Requirements Allocation (US Defense Systems Management College, 1990). The techniques reviewed herein can contribute to the Requirements Allocation process.

Because the analyses are based on the functions which are required to meet system requirements, they seldom reflect the functions which emerge once decisions have been made about system manning. Typically, crew functions such as supervision, monitoring, direction, consultation and training are not included in functional analyses or in the allocation of functions, because they can be identified only once function allocation decisions have been made. None of five functional analyses of major military systems reviewed at random included these human crew functions (see the examples in Part 2). Yet the performance of such functions can have a major influence on the design of manned systems (Beevis, 1987). Analyses must reiterate their function allocation decisions to include human crew functions.

Background

Historically, a variety of approaches have been taken to allocation of functions (Singleton, 1974) from the original comparative assessment of human and machine performance using qualitative indices (the Fitts' list) through cost-value considerations, integrated operator task concerns, the provision of different levels of task to match the capabilities of different operators, and the use of hardware to supplement human functions which correspond to basic system functions, to the flexible delegation of operator responsibility. Allocation of function is not a simple dichotomous choice between human and machine (Sheridan, Vámos, & Aida, 1983): different levels of automation are possible. As they suggest, it is possible for system hardware and/or software to provide any of the options shown below, ANDed or ORed as noted.

1. Offer no assistance to the operator.
2. Offer a complete set of alternatives to the operator, AND
3. Narrow the set of alternatives to a restricted set, OR
4. Suggest one of the alternatives, AND
5. Execute the suggestion if the human approves, OR
6. Allow the human to veto the suggestion before automatic execution, OR
7. Inform the human after execution, OR
8. Inform the human after execution, if asked, OR
9. Inform him after execution, it decides to.
10. The hardware and/or software decides everything without communication to the human.

Types of analysis available

Typically, three basic approaches to function allocation are described in human engineering texts. The first, referred to here as "ad hoc" (3.1) assumes that the function allocations implicit in predecessor systems ("up to this time") are satisfactory, and that only minor changes are required to increase the level of automation. The function allocation decisions are based on the economically available level of automation, and the decisions are made almost entirely on criteria such as cost, availability, reliability, and compatibility of hardware and software. In military systems, however, humans are no longer low-cost items, nor are they in plentiful supply. In addition, because automation usually addresses simple, repetitive tasks, increasing levels of automation require highly trained and skilled operators and maintainers. Thus, the ad hoc approach is no longer effective for complex systems. The alternative to the ad hoc approach has been called the "formal approach" (Kantowitz & Sorkin, 1987). This approach concentrates on formally allocating each system function to hardware, software, or liveware, using a rational decision making technique.

Neither the "ad-hoc" nor the "formal" approaches are followed entirely in practice: what usually happens is a more "balanced" approach (Kantowitz & Sorkin, 1987). This approach is based on the fact that there are political, managerial, and performance constraints on the allocation of functions. Some functions must be assigned to humans for political or managerial reasons (e.g., the release of certain types of weapon). Some function allocations are dictated by performance requirements, such as the need to respond to a threat reliably, in a limited time (see Eggleston, 1988, for example), the need to maintain operator skills, or the space and weight constraints associated with accommodating human operators. Such political, financial, managerial, and performance constraints can account for a very large number of the function allocations, leaving a much smaller set which require formal analysis. Meister (1985) outlines the balanced approach as five stages, as shown in Figure 3.1.

The "balanced" approach is a more realistic reflection of how functions are assigned on major projects than either the "ad hoc" or the "formal" approaches (see Schuffel, 1989, for an example). Several formal techniques are available for function allocation, corresponding to the third step or third and fourth steps in Meister's process. Fitts' list (3.2), which has been widely published (e.g., US Department of Defense, 1987), is based on a simple comparison of human and machine capabilities. Price (1985) recommends an approach to function allocation which avoids the simple dichotomy of the Fitts' list (Fig. 3.2).

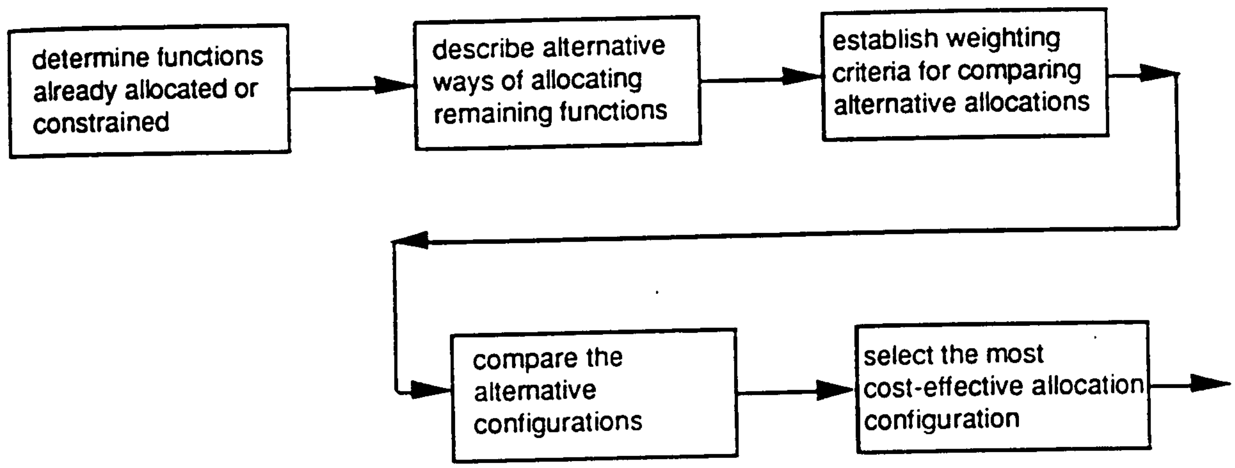


Figure 3.1: Five stage approach to function allocation (after Meister, 1985)

The approach recognizes six different cases of human and machine capability.

- In region 1 there is little difference in the relative capabilities of human and machine, and function allocation decisions can be made on the basis of criteria other than relative performance.
- In area 2, human performance exceeds machine performance.
- In area 3, machine performance exceeds human.
- In area 4, machine performance is so poor that the functions should definitely be allocated to humans.
- In area 5, human performance is so poor that the functions should be allocated to machine.
- In area 6 the functions are performed unacceptably by both human and machine, arguing for a different design approach.

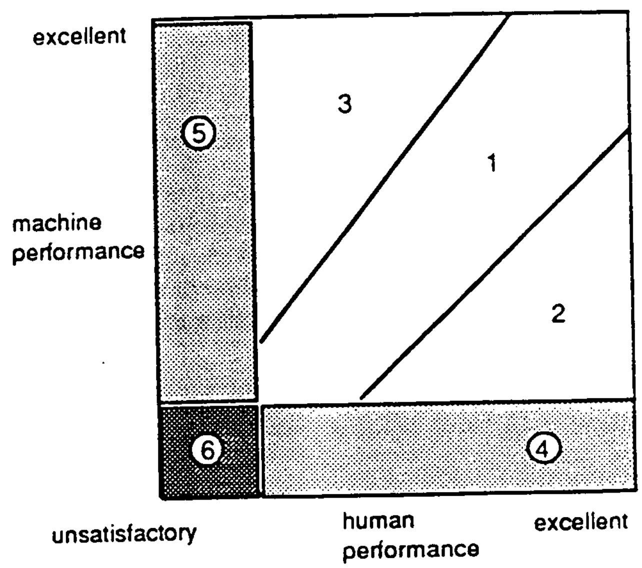


Figure 3.2: Criteria for allocating functions to human or machine (after Price, 1985)

Price suggests three different criteria for function allocation: "balance of value," "utilitarian and cost-based allocation," and "allocation for affective or cognitive support."

The Review of Potential Operator Capabilities (3.3) could be based on Price's approach. It is not well defined, however, and human engineering texts do not describe it. The weighted comparison of human capabilities and machine capabilities (Function Allocation Evaluation Matrix, 3.4) has been documented widely: Meister (1985) describes two methods.

As noted in Volume 1, Chapter 3, the majority of techniques used for function analysis cannot be related directly to system performance requirements, because they use interval or ratio scale measures such as "better/worse" criteria. This suggests that the function allocation techniques are not as mature as those used for other classes of analysis. Current developments in software engineering may contribute to improving this class of analysis. Guidelines are used in structured analysis/design to determine which modules (basic software components), and which interactions between them, will best implement the functional requirements. The more important guidelines which are relevant to human engineering are the principles of *cohesion* , *coupling*, and *span of control* (Yourdon, 1989).

As noted above, function allocation is an implicit part of the engineering design process (Price, 1985) and may be conducted formally through Requirements Allocation (3.5). Analysts must find ways of conducting whatever formal analyses are necessary within the general approach being taken to design. The specific approach taken to function allocation will depend on factors such as the complexity of the project, extent of innovation involved, etc.

Table 3.1: Applicability of function allocation techniques to different projects

Technique	Simple system (e.g. rifle,hand-held radio)	Medium complexity system (1 man radar console)	High complexity system (e.g. 1 place attack aircraft)	Complex multi-man system (e.g. ship combat centre)
3.1 Ad hoc	not relevant	low	low	low
3.2 Fitts' list	not relevant	low	low	not relevant
3.3 Review of potential operator capabilities	not relevant	low	medium	medium
3.4 Function allocation evaluation matrix	not relevant	low	medium	medium
3.5 Requirements Allocation Sheets	not-relevant	low	medium	medium

Analysts should remember that the state of the art in function allocation is not fully mature, and that advances in software are changing the concept of what functions should be allocated to the human system components. In complex systems, humans are increasingly responsible for cognitive functions, which have been studied little until recently. If major changes are being made to the level of automation in a system concept, then the human engineering analyses should be supplemented by experimentation and simulation.

References and Bibliography

1. Beevis, D. (1987). Experience in the integration of human engineering effort with avionics systems development. In: The design, development and testing of complex avionics systems. AGARD CP 417, (pp. 27-1 – 27-9). Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
2. Chapanis, A. (1970). Human factors in systems engineering. In: K.B. De Greene (Ed.), Systems Psychology (pp. 51-78). New York: McGraw-Hill Series in Management.
3. Eggleston, Maj. R. (Ed.) (1988). Impact of future developments in electronic technology on cockpit engineering. AGARD-R-757. Neuilly sur Seine, France: Advisory Group for Aeronautical Research and Development.
4. Kantowitz, B.R., & Sorkin, R.D. (1987). Allocation of functions. In: G. Salvendy (Ed.). Handbook of human factors. (pp. 356-369). New York: John Wiley & Sons.
5. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
6. Price, H.E. (1985). The allocation of functions in systems. Human Factors, 27 (1) 33-45.
7. Price, H.E. (1990). Conceptual system design and the human role. In: H. Booher (Ed.). MANPRINT: An approach to systems integration. New York: Van Nostrand Reinhold.
8. Schuffel, H. (1989). The ship's wheelhouse of the nineties: The navigation performance and mental workload of the watchofficer. Journal of Navigation.
9. Sheridan, T.B., Vámos, T., & Aida, S. (1983). Adapting automation to man, culture and society. Automatica 19, 6. 605-612.

10. Singleton, W.T. (1974). Man-machine systems. Harmondsworth, Middlesex, England: Penguin Education.
11. US Department of Defense (1987). Human engineering procedures guide. DoD-HDBK-763. Washington D.C.
12. US Defense Systems Management College (1990). System engineering management guide. Washington D.C.: U.S. Government Printing Office.
13. Yourdon, E. (1989). Modern structured analysis. Englewood Cliffs, N.J.: Yourdon Press.

3.1 AD HOC FUNCTION ALLOCATION

What the technique does

The technique allocates the functions required for a system to hardware, software, and human system components, based on predecessor systems, and on information about what additional automation is possible.

Inputs to the technique

The functions required of the system should have been identified through a function decomposition. In many cases, however, systems are developed from predecessors without a thorough analysis of all system functions. The minimum information required is the description of those functions which will be changed through changes in the level of automation.

Outputs of the technique

The type and quantity of output depends on system complexity and the extent of the changes being made.The technique should produce a function description of the system.

When to use

Early in the design of systems or equipment of medium complexity, so that the implications of the changes can be analysed.

Related techniques

Simple function analysis.

Resources required

The analysis can be performed with pencil and paper. The analyst needs information on the functions to be performed and the functions of the predecessor system.

Advantages

The approach is simple, and involves minimum effort. Users report it to be low cost. It is well suited to the development of equipment or simple systems which evolve comparatively slowly through several generations, such as guns and land transport vehicles, and some armoured fighting vehicles.

Disadvantages

The approach lacks standardization and traceability. The only evidence that the new system will perform well is that available from the previous system.

The assumption that functions should be allocated on the basis of whatever can be done by machine means that operators perform whatever functions are left, that cannot be done by machine. Generally this results in a reduction in the complexity and interest of the human responsibilities, to the point where the operator's functions are boring. Such tasks are not performed reliably over long periods.

Another potential problem is that the tasks "left over" from the machines may not form a coherent set. In the development of a two-place strike aircraft, the use of this approach resulted in the tasks of the pilot and systems operators being uncoordinated.

Relative contribution

Some users rate this as the best available method for simple systems, or for systems based on available equipment or sub-systems.

Applications

The technique was used for a recent major upgrade of a destroyer, the development of a two-place strike aircraft, and the development of a mine-sweeper.

Quality assurance considerations

The lack of documentation and traceability limits the reliability of the technique. The most effective way of ensuring quality is to validate the function-allocation decisions using additional analyses, such as time lines or workload predictions. This is sometimes referred to as the "trial and error" approach (US Department of Defense, 1987).

Relationship to system performance requirements

In the destroyer upgrade project, the approach was used specifically to meet the contractual requirement that performance be at least as good as that of the predecessor system. Users have related the output to system performance through the modification and update of existing performance specifications.

References and Bibliography

1. Kantowitz, B.H. & Sorkin, R.D. (1987). Allocation of functions. In: G. Salvendy (Ed.), Handbook of human factors, (pp. 335-369). New York: John Wiley & Sons.
2. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.

3.2 FITTS' LIST

What the technique does

The technique compares the capabilities of man and machine in terms of general task abilities, such as "data sensing," and "reacting to unexpected events."

Inputs to the technique

A list with comparative characteristics of man and machine was published by Fitts (1951) and has been developed by others (e.g. NNAG, 1991). The system functions must be expressed in terms which permit the identification of one of the items in the categories of man/machine capabilities contained in the list.

Outputs of the technique

The technique produces lists of system functions annotated by their allocation to man or machine.

When to use

In the early stages of design, following a function analysis.

Table 3.2: Original Fitts List (from Price, 1985; after Fitts, 1951)

Humans appear to surpass present-day machines with respect to the following:

1. Ability to detect small amounts of visual or acoustic energy
2. Ability to perceive patterns of light or sound
3. Ability to improvise and use flexible procedures
4. Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time
5. Ability to reason inductively
6. Ability to exercise judgment

Present day machines appear to surpass humans with respect to the following:

1. Ability to respond quickly to control signals, and to apply great force smoothly and precisely
2. Ability to perform repetitive, routine tasks
3. Ability to store information briefly and then to erase it completely
4. Ability to reason deductively, including computational ability
5. Ability to handle complex operations, i.e. to do many different things at once

Related techniques

The technique is related to simple methods of analysing functions.

Resources required

The technique can be applied using pencil and paper. It requires only the Fitts' List and a compatible list of system functions.

Table 3.3: Common Form of Fitts' List (US Department of Defense, 1987)

MAN EXCELS IN	MACHINES EXCEL IN
Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Ability to store large amounts of information for long periods, and recalling relevant facts at appropriate moments	Storing and recalling large amounts of information in short time periods
Ability to exercise judgment where events cannot be completely predicted	Performing complex and rapid computation with high accuracy
Improvising and adopting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (infrared, radio waves, etc.)
Ability to react to unexpected low-probability events	Doing many different things at one time
Applying originality in solving problems: i.e., alternative solutions	Exerting large amounts of force smoothly and precisely
Ability to profit from experience and alter course of action	Insensitivity to extraneous factors
Ability to perform fine manipulation, especially where misalignment appears unexpectedly	Ability to repeat operations very rapidly, continuously, and precisely the same way over a long period
Ability to continue to perform when overloaded	Operating in environments which are hostile to man or beyond human tolerance
Ability to reason inductively	Deductive processes

Advantages

Fitts' list is simple to use, and requires little training. In practice the list is a convenient framework for considering the allocation of functions. It aids people unfamiliar with human factors to think systematically about the functions assigned to human operators.

Disadvantages

The approach is simplistic and uses qualitative terms only. In practice it is of limited help. The listed functions require interpretation to relate them to system functions. The capabilities of man and machine are not directly comparable; they are complementary. The approach ignores other aspects of the allocation trade-off, such as cost and size/weight/support requirements (Fitts, 1962). In addition, the technique treats the operator's tasks as independent modules, which can be allocated without interaction.

Relative contribution of the technique

There is little evidence available; despite frequent references to it in the literature, Fitts' list is little-used in practice. One user reports that the technique is "not bad," another that it is "useless."

Applications

Despite the frequent references to Fitts' list in the human factors literature, it appears to be little used. It was used in the concept development of an ASW helicopter, an air defence system, a shipboard nuclear weapons safety system, and for a major update of a destroyer.

Quality assurance considerations

The listed functions must be interpreted carefully to relate them to typical system functions.

Relationship to system performance requirements

The output of the technique cannot be related directly to system performance: it requires additional analyses.

References and Bibliography

1. Fitts, P.M. (1951). Human engineering for an effective air navigation and traffic control system. Washington D.C.: National Research Council.
2. Fitts, P.M. (1962). Functions of man in complex systems. Aerospace Engineering. January.
3. Kantowitz, B.H. & Sorkin, R.D. (1987). Allocation of functions. In: G. Salvendy (Ed.), Handbook of human factors. (pp. 335-369). New York: John Wiley & Sons.
4. NNAG (1991). Guidelines for automation implementation. Brussels: NATO Naval Armaments Group, Information Exchange Group 6/Sub-Group 8.
5. Price, H.E. (1985). The allocation of functions in systems. Human Factors, 27 (1) 33-45.
6. US Department of Defense (1987). Human engineering procedures guide. Washington D.C: DoD-HDBK-763.

3.3 REVIEW OF POTENTIAL OPERATOR CAPABILITIES

What the technique does

The review of potential operator capabilities documents those abilities of expected system or equipment users in terms which are relevant to the operation of the system. STANAG 3994 AI (NATO MAS, 1991) requires that "the potential capabilities of human system components shall be reviewed based on the function analysis and on a review of operator tasks in similar systems. Emphasis shall be place on those capabilities which are unique to humans, such as signal detection in noise, adaptive decision making, etc. The results shall be expressed in quantitative terms wherever possible, for example in terms of time, accuracy, or amount of information that can be handled, and shall be reflected in the system and equipment detail design." US MIL-H-46855B requires estimates of potential operator/maintainer processing capabilities.

Inputs to the technique

The analyst requires information on the expected operator and maintainer population, and on their potential roles, duties, and functions. The analyst also requires detailed information on operator capabilities to perform those functions, or similar ones.

Outputs of the technique

There is no standard form of output for this technique. It should produce a review of the material on human operator performance cross-referenced or related to the potential operator functions. Useful formats have included a review of operator workload and capabilities related to a mission description, and generic statements about operator ability to perform specific functions.

When to use

The technique should be used after a functional decomposition as an input to the allocation of functions.

Related techniques

The review of potential operator capabilities is closely related to other function-allocation techniques, particularly extensions of the Fitts' list. It parallels the systems engineering activity of requirements analysis.

Resources required

The analyst requires information on the functions typically performed by operators, and general details of the performance of specific functions or tasks in existing systems. The information should concentrate on those tasks which are done very well, and those with which the operator has difficulty.

Advantages

The review has the potential for contributing to the allocation of functions, and for documenting personnel and training requirements and facilitating the kind of design/selection/training tradeoffs emphasized in MANPRINT and related programmes (Barber, Ching, Jones & Miles, 1990).

Disadvantages

The technique was used in only 2 out of 10 projects reviewed in Canada and in one of those applications the purpose of the analysis was misunderstood by the contractor (Beevis, 1987). The contractor emphasized generic human capabilities, and the effects on them of generic environmental stresses, rather than performance related to anticipated operator functions. Contractors have difficulty distinguishing between the material for the review of potential operator capabilities and the more generic material of the Fitts' List (3.2).

Relative contribution

In a review of 38 projects undertaken in NATO nations, the technique ranked 10th out of 24, in terms of frequency of use compared with others. Users, however, are not positive about its contribution.

Applications

Potential operator capability reviews were conducted for the development of an ASW helicopter, an ASW patrol aircraft, a fighter aircraft, a tank, and for a naval training system.

Quality assurance considerations

The analysis should be consistent with the functions decomposed in the system functional analysis, and with known operator/maintainer capabilities and limitations. The information on operator performance should be system specific rather than generic (e.g. radar detections per hour in a given target density rather than general information processing capacity in terms of bits per second).

Relationship to system performance requirements

System performance requirements are implicit in the review of operator capabilities in terms of speed, accuracy of response etc.

References and Bibliography

1. Barber, J.L., Ching, H.L.F., Jones, R.E. & Miles, J.L. Jr. (1990). MANPRINT Handbook for RFP development, 2nd edition. Army Material Command Pamphlet 602-1. Alexandria, VA: US Army Research Institute.
2. Beevis, D. (1987). Experience in the integration of human engineering effort with avionics systems development. In The Design, Development and Testing of Complex Avionics Systems. AGARD-CP-417. Neuilly sur Seine, France: Advisory Groups for Aerospace Research and Development.
3. NATO MAS (1991). Application of human engineering to advanced aircraft systems. STANAG 3994 AI (Edition 1). Brussels: NATO Military Agency for Standardization.
4. US Department of Defense. (1979). Human engineering requirements for military systems, equipment, and facilities. MIL-H-46855B. Washington D.C.: US Army Missile R&D Command.

3.4 FUNCTION ALLOCATION EVALUATION MATRIX

What the technique does

The technique sums weighted scores of human and machine capabilities to make function allocation decisions. Candidate sub-system functions are listed and compared against the capabilities of hardware, software, and humans. The form used to record these comparisons is called a *function allocation screening worksheet* (see example, Figure 3.3). Such worksheets are constructed by listing each of the several functions to be allocated on the left side of the worksheet. Two sets of evaluation criteria are listed across the sheet, as columns. The first set of columns lists operator capabilities; the second set of columns lists equipment capabilities.

Each of the candidate system functions is compared with inherent capabilities of hardware, software, or humans, using the kind of criteria contained in the Fitts' List, previously described. Numerical weightings are assigned for each criterion, relevant to the system being analysed. These weightings can include additional factors such as cost or availability. The weightings can be derived from subject matter experts (SMEs). Meister (1985) describes the development of such weights using a paired comparison technique. Each factor is compared with each other, in a matrix, and given a tally of 1 (if more important than the other factor) or zero (if less important than the other factor). The tallies are summed for each factor, and factor weightings derived from the sums as a percentage of the total number of tallies.

Once the weightings are established, the functions are reviewed in turn. Whenever an evaluation characteristic is applicable to a specific function, a numerical score is assigned. The score is then multiplied by the weighting factor. The original and weighted scores are entered in the row/column intersection. The evaluation is completed by summing each of the weighted scores for the "operator" and the "machine" allocations. If the weighted score total is much higher for one or other type of sub-system, the function is allocated to either "operator" or "equipment." When one of the weighted score totals is more than 80% of the other, then the allocation is made to "both" operator and machine.

Inputs to the technique

Besides the candidate sub-system functions, the analyst requires information on the limitations of human operators, the state-of-the-art performance of hardware and software, and estimates of the system performance requirements in terms of speed, accuracy, load, and reliability.

Outputs of the technique

The outputs are the functions allocated to operator, hardware, and software. The results of the function allocation trade are used to: a) determine the impact of crew tasks, skills, and information needs; b) appraise related crew task capabilities and limitations; c) identify corresponding display and control concepts; d) trade-off specific sub-system performance capabilities; and e) perform task analysis and workload evaluations.

When to use

The technique should be used during concept development and preliminary design. It can also be used during detailed design, to examine function tradeoffs. The technique should be used following a function analysis, and prior to a task analysis.

Related techniques

The technique is related to systems engineering function trade-off analyses, which are sometimes conducted to allocate functions to specific sub-systems.

KEY: 5x1 — weight (first figure), related score (second figure)

scale 1 - 5: 5 best

Hypothetical Tracking Functions	Inherent Operator Capabilities: Detecting signals in the presence of high noise environment (x 5)	Handling unexpected occurrences or low- probability events (x 4)	Recognising objects under varying conditions of perception (x 4)	Reasoning inductively (x 1)	Profiting from experience (x 2)	Inherent Equipment Capabilities: Responding quickly to signals (x 3)	Performing precise routine repetitive operations (x 2)	Computing and handling large amounts of stored information quickly and accurately (x 4)	Total Score: Operator	Total Score: Machine	Proposed Allocation: Operator	Proposed Allocation: Both	Proposed Allocation: Machine: Equipment	Proposed Allocation: Machine: Software
1. Determine if target tracks in system	5x5	4x2	4x3	1x3	2x3	3x3	2x4	4x1	81	41	X			
2. Actuate sequence	5x1	4x2	4x1	1x1	2x1	3x1	2x1	4x1	20	24		X		
3. Put next target in track list under close control	5x1	4x1	4x1	1x1	2x1	3x3	2x5	4x1	21	43			X	X
4. Advance hook on display to track coordinates	5x1	4x1	4x1	1x1	2x2	3x3	2x5	4x1	21	43			X	X
5. Determine if target video present	5x4	4x2	4x2	1x3	2x2	3x3	2x4	4x1	70	39	X			
6. Determine if hook lines up with present target position	5x4	4x2	4x2	1x3	2x3	3x2	2x4	4x1	73	40	X			
etc.....														

Figure 3.3: Example of function allocation screening worksheet (evaluation matrix)

Resources required

The analysis can be conducted using manual methods. It requires a collaborative effort between sub-system designers and human engineers or human factors specialists to obtain the extensive knowledge of hardware, software, and human capabilities required to make the comparisons.

Advantages

DoD-HDBK-763 notes that, although the technique does not ensure the optimum allocation of functions, it goes a long way beyond the informal, or "gut feel," methods so often used in design.

Disadvantages

The function allocation procedure is of average complexity. It may be used at either a gross or detailed level of analysis, but it is used more often for gross function allocation. The technique does not deal well with function allocation between multiple operators. As with other function allocation techniques which are initiated by a system function decomposition, it does not include human functions such as collaborative decision making, supervision, etc.

Users report difficulty in accessing data on human capabilities and limitations for use in the analysis. Some users report the technique is inaccurate. Technically, the mathematical treatment of subjective ratings (weighting and addition) is inappropriate.

Relative contribution

DoD-HDBK-763 rates function allocation techniques as having medium cost-effectiveness. One user (out of twelve surveyed) sees it as a necessary step to support sub-systems development.

Applications

Although the technique is quite widely published, there are few reports on its use. It was used for the development of a military training system and for an aircraft.

Quality assurance considerations

To be effective the technique must start from a comprehensive and complete list of system functions. The verb-noun phrase used to describe functions is obviously important in the identification of candidate function allocations.

Relationship to system performance requirements

The technique is related to system performance requirements through the list of system functions. The allocation decisions are usually made on the basis of qualitative statements, rather than performance parameters. Thus the output of the analysis cannot be related directly to system performance. Additional analyses such as workload prediction are required.

References and Bibliography

1. US Department of Defense (1987). Human engineering procedures guide. Washington D.C: DoD-HDBK-763.
2. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.

3.5 REQUIREMENTS ALLOCATION SHEETS (RAS)

What the technique does

Requirements allocation sheets are used to translate functions into performance and design requirements. The functional analysis (usually a Function Flow Diagram) is used as a basis for the data entered on the sheets. RAS are normally prepared for each function block. In some cases, closely related functions may be analysed using the same RAS. Design requirements are identified in terms of the purpose of the function, parameters of the design, design constraints, and requirements for reliability, human performance, accuracy, safety, operability, maintainability, and transportability (USAF, 1971; US Defense Systems Management College, 1990). Thus the RAS bridges the systems engineering activities of function analysis and synthesis. The format of an RAS is not fixed: typical entry headings are shown below. Each RAS documents the performance requirements and the design requirements for a specific system function, as follows.

Table 3.4: Requirements allocation sheet

REQUIREMENTS ALLOCATION SHEET		FUNCTIONAL DIAGRAM TITLE & No.	EQUIPMENT IDENTIFICATION		PERSONNEL AND TRAINING EQUIPMENT REQUIREMENTS				PROCEDURAL DATA REQUIREMENTS
	Functional performance and design requirements	Facility requmt.	Nomenclature	Spec.or index master control No.	Tasks	Time requird.	Performance requmt	Trng. & trng. equip. requmt	

Functional Diagram Title & No. - the title and number of the drawing containing the function diagram or analysis.
Function number - the reference for the function from the functional analysis diagram.
Functional performance and design requirements - including: input & output values; requirements which constrain the design solution; engineering speciality requirements such as safety, accessibility criteria etc.
Facility requirements - for the environment, utilities, architecture etc, imposed by the performance requirements.
Equipment identification - the type, name, and specification number of the equipment which performs the function.
Personnel and training related requirements - those which affect the performance of the function, described at a level which permits identification of human engineering requirements; with an alphanumeric reference number derived from the function number.
Time required - the elapsed time required to perform the task.
Performance requirements - for crew coordination, knowledge, skill, decision making, safety procedures, performance under stress, life support etc.
Training and training equipment requirement - the level of training required and whether training equipment is required.
Procedural data requirements - the need for data which govern procedures (test directives, test procedures, equipment operating procedures etc.) for hazardous or complicated functions involving personnel.

Inputs to the technique

Performance requirements identified from the operational requirement and the functional decomposition. Functions from functional analyses (FFDs, SATs, SADT™/ IDEF® etc.), and information from function allocation analyses.

Outputs of the technique

The technique documents the data listed in the description on the previous page.

When to use

The RAS is most useful during concept development and design definition. It must be preceded by a functional analysis and some system design synthesis. It provides the basis of detailed task analyses, performance prediction, and interface and workspace design. It is less useful during the latter stages of design and development.

Related techniques

The Requirements Allocation Sheet is a systems engineering technique related to the Critical Design Requirements analysis (6.2)

Resources required

Although the analysis can be performed using pencil and paper, it is recommended that a computer filing system be used to keep track of all the analyses, and to facilitate expansion of the entries.

Advantages

The RAS combines the steps of function allocation, performance requirements analysis, task analysis and design requirements analysis in one document.
It is a systems engineering technique which can be exploited by human engineering specialists as a means of integrating their work with the larger design/development effort.

Disadvantages

The technique mixes functional requirements and design requirements. By combining the different steps of function allocation, performance requirements analysis, task analysis and design requirements analysis it risks confusion and misunderstanding in the design team.

Relative contribution

No data available.

Applications

No data available. Woodson (1981) provides an example based on two system check-out functions.

Quality assurance considerations

The analysis must be checked exhaustively against the functional analysis and the system performance requirements.

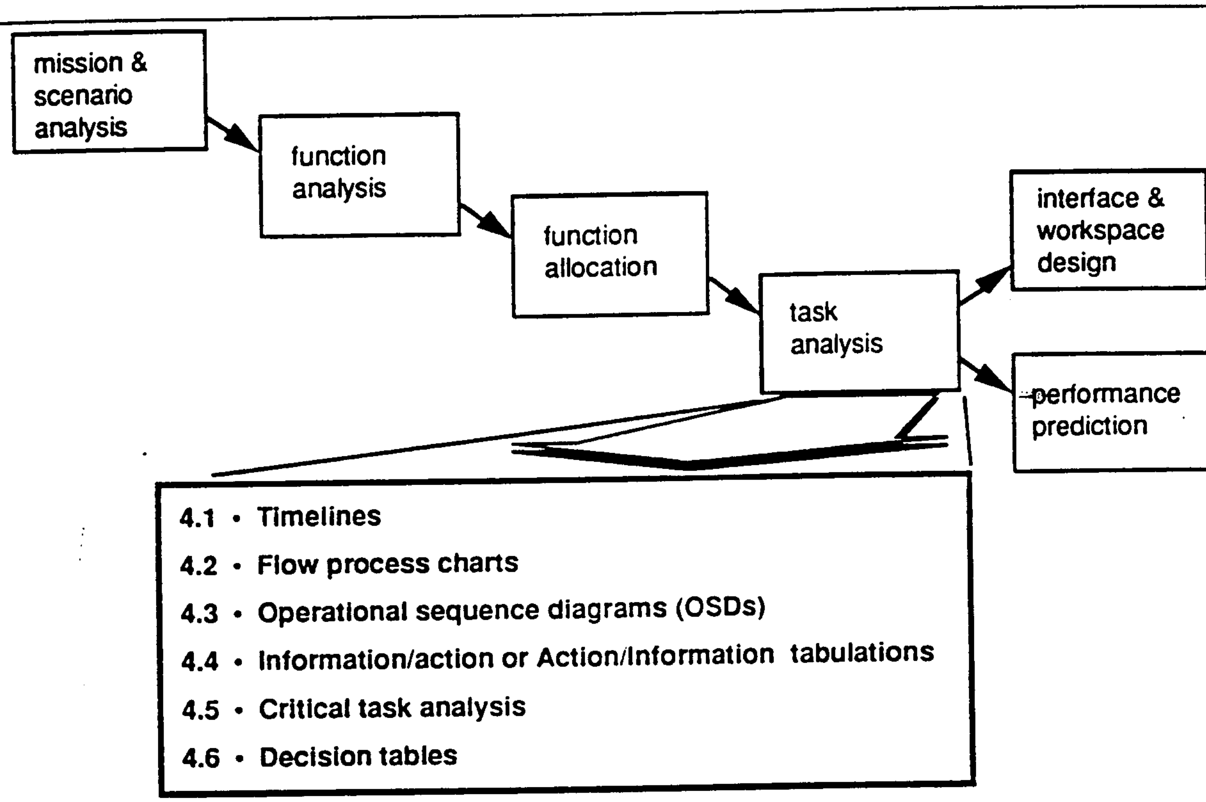
Relationship to system performance requirements

System performance requirements are decomposed into the performance requirements for the individual functions and documented on each RAS. Overall systems performance requirements are implicit in those decompositions, but are not addressed directly.

References and Bibliography

1. USAF (1971). Data Item Description - Requirements Allocation Sheets. DI-S-3605/S-127-1. Washington D.C. U.S. Air Force Systems Command.
2. US Defense Systems Management College (1990). System engineering management guide. Washington D.C.: US Government Printing Office
3. Woodson, W.E. (1981). Human factors design handbook. New York: McGraw-Hill Book Co.

4 TASK ANALYSIS



What the techniques do

Essentially, a task is a system function that has been allocated to a human operator. Meister (1971) defines *task* as an operator activity that includes an immediate purpose, a machine output or consequences of action, and the human inputs, decisions, and outputs needed to accomplish the purpose. Task analysis is one of the most common activities of the human engineering specialist. There are two major goals of task analysis: one is to define what an operator will be required to do[2], to permit the application of relevant knowledge on human performance; the other goal is to define what an operator will do in order to determine how he or she will interact with the rest of the system. A completed task analysis specifies the activities of the operator, in the same way that other analyses specify what it is that the system hardware and software do (see DeGreene, 1970; Drury et al., 1987; Gillies, 1984; Laughery & Laughery, 1987; and Woodson, 1981).

Background

Task analysis is central to the design of the system and the human-machine interface and has been a key tool in

[2] The terms *task synthesis* or *task description* are sometimes used for the analysis of what an operator will be required to do in systems under development, and the term *task analysis* is sometimes reserved for analyses of tasks in existing systems. There is no standardization in the use of such terms, however, and "task analysis" is used here for simplicity.

human engineering since the pioneering work of Miller (1953). Task analysis is the basis for performance prediction through workload prediction (5.1), computer simulation (5.2; 5.3), projective subjective workload prediction (see 5.4), rapid prototyping, or man-in-the-loop simulation, and to the subsequent test and evaluation of the design (a task-analysis based approach is more effective than a static checklist, see Malone & Micicci, 1975). As shown in Figure 4.1, task analysis is also central to the development of job aids, and the development of the training plan. In industrial applications of computer systems, task analyses have been used as part of the system requirements specification.

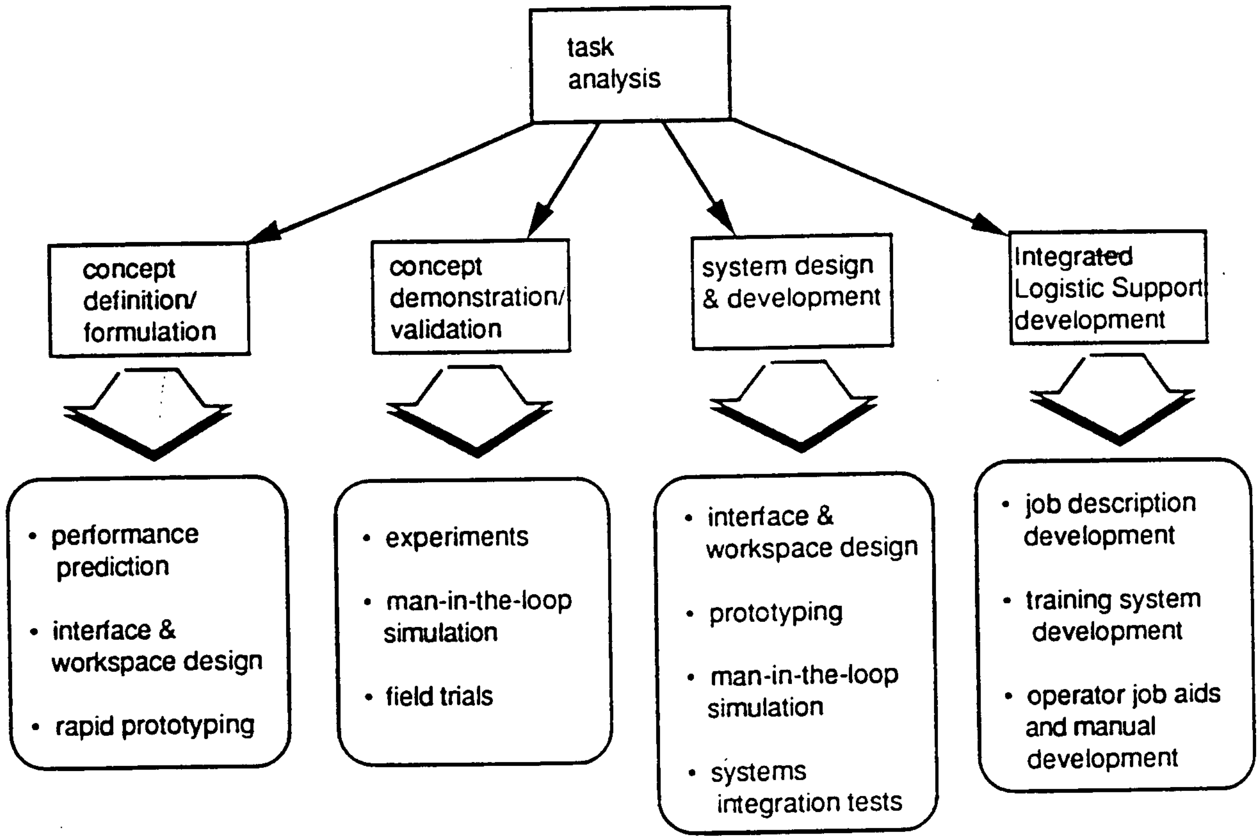


Figure 4.1: Contributions of task analysis to systems development

Meister (1985) provides a set of questions which the task analysis must answer, for each of the uses listed above. The questions cover issues of the mission conditions (emergencies, accuracy etc.), task demands (speed of response, duration, frequency, accuracy, error probability, criticality and concurrency), display design (amount of information to assimilate, difficulty of perceptual or discrimination tasks), control design (accuracy, force, sequencing), and the working environment (temperature, lighting, etc.). Any one task analysis may not provide all that information, however, nor may all that information be needed. The key to an effective analysis is to keep it as simple as possible, commensurate with the information required by subsequent analyses or design activities. For example, Dillon (1991) reports the use of a simple analysis based on the questions what? why? and how? in the development of hypertext-based databases and manuals.

Types of task analysis available

A family of task analysis techniques is available to the analyst. All are based on the decomposition of operator activities to some pre-defined level of detail. Some are based in industrial engineering, or work study approaches to the analysis of operator activity. Several forms of task analysis represent the flow of information or activities. Such approaches include time lines (4.1), flow process charts (4.2), and operational sequence diagrams (4.3). The Critical Path Method (CPM) or PERT formalism has been used as a task analysis technique. It is particularly useful for representing activities involving choice, and team activities. McCrobie (1986) reports the use of a personal computer-based CPM program for task analysis.

The simplest task analysis technique is a tabulation of the tasks that the operator must perform[3], annotated with remarks about the human factors design requirements. This approach can be elaborated by using an hierarchical decomposition of the operator's tasks (Hodgkinson & Crawshaw, 1985). The most common tabular task analysis technique (4.4) is a list of operator activities and the associated inputs (information displays) and outputs (controls). To this basic list can be added additional information such as "triggering event" (stimulus), response, and "feedback." The addition of information such as "skill requirement" can provide the information required for a training analysis. Most tabulations list the operator's tasks in sequence down the page. Tabulations of operator activities are simple to perform, and can be carried out on microcomputers using a spreadsheet programme (Rice, 1988). Shepherd (1989) describes the use of some of the facilities available in Microsoft Word® for the compilation of hierarchical task analyses. Specialized programmes have also been developed to facilitate task analysis using personal computers (see Kearsley, 1987, for example).

Typically, such analyses are completed in an hierarchical format, with the upper level of the hierarchy being the function assigned to the human operator, and lower levels providing increasing detail at the task and sub-task levels. The hierarchical technique of Annett and Duncan (Duncan, 1974, Shepherd, 1989), treats the decomposition as a tree. The most elaborate form of tabular task analysis is the "critical task analysis" (4.5) specified by STANAG 3994 (NATO MAS, 1991) and US MIL-H-46855B. The latter specification requires up to seventeen columns of data, and is seldom implemented completely. (Normally, any reduction in the scope of the task analysis should be agreed to between procuring agency and contractor at the outset of the human engineering work: however, this does not always happen).

With the increasing emphasis placed on human cognitive tasks by modern systems, there is a growing need for analysis techniques for cognitive tasks. Various aspects of cognition include: perceiving, remembering, imagining, conceiving, judging, and reasoning. Although several task analysis approaches have been developed to describe these activities (Johnson, Diaper & Long, 1985; Diaper, 1989, Terranova et al., 1989), no one technique has emerged as the most suitable (Redding, 1989; Grant & Mayes, 1991). In fact several published examples deal with the overt activity associated with cognitive tasks, rather than the tasks themselves. Some approaches have focussed on analysing operator decisions. Decision tables (4.6) provide a means of analysing and documenting the information required to make certain decisions.

Users should have a clear understanding of the intended application of the task analysis technique which they select., and verify that he technique selected will provide information which is compatible with that application. For example, Operational Sequence Diagrams (OSDs - 4.3) are highly suited to developing SAINT or MicroSAINT (5.2) simulations of task networks: they are less well suited to the kind of analysis required to develop a concept of the human-machine interface, or for the development of rapid prototypes. For those purposes an object-oriented, tabular, task analysis which identifies task "objects" (displays and controls) is more effective (St. Denis & Beevis, 1991). Potential users should also determine the level of detail required in the task analysis. For example, the different workload modelling techniques which are available (see McMillan et al., 1989) differ in the level of task detail which they require for implementation.

3 Hollister (1986) provides lists of tasks for five types of aircraft mission.

The human factors and human engineering literature include many references to the development and use of Task Taxonomies. Although Task Taxonomies were the fifth most frequently used technique reported in a survey of human engineering techniques in thirty-three acquisition projects, the conclusion of the Research Study Group was that they are not recommended for generic use. The reason for this conclusion is that no taxonomy which was examined met the requirements that its categories of tasks were exhaustive and exclusive and at the same time were applicable to a wide range of applications. Therefore, no Task Taxonomy has been included in this review.

Table 4.1: Applicability of task analysis techniques to different projects

Technique	Simple system (e.g., rifle, hand-held radio)	Medium-complexity system (e.g., 1-man radar console)	High-complexity system (e.g. ,1-place attack aircraft)	Complex multi-man system (e.g., ship combat centre)
4.1 Time lines	low	medium	medium	high
4.2 Flow process charts	low	not relevant	not relevant	low
4.3 Operational Sequence Diagrams	high	high	high	high
4.4 Information/ action tabulations	high	medium	medium	low
4.5 Critical Task Analysis	low	low	high	high
4.6 Decision tables	not relevant	low	medium	medium

References and Bibliography

1. DeGreene, K.B. (1970). Systems analysis techniques. In: K. DeGreene (Ed.), Systems psychology, (pp. 79-130). New York: McGraw-Hill.
2. Diaper, D. (Ed.) (1989). Task analysis for human-computer interaction. Chichester, U.K.:Ellis Horwood Ltd.
3. Dillon, A. (1991). Requirements for hypertext applications: the why, what and how approach. Applied Ergonomics, 22 (4), 258-262.
4. Drury, C.G., Paramore, B., Van Cott, H.P., Grey, S.M., & Corlett, E.N. (1987). Task analysis. In: G. Salvendy, (Ed.), Handbook of human factors, Chapter 3.4. New York: John Wiley & Sons.
5. Duncan, K.D. (1974). Analytical techniques in training design. In: E. Edwards, F.P. Lees (Eds.), The human operator in process control, London: Taylor and Francis Ltd.
6. Gillies, G.J. (1984). Task analysis and task synthesis. In: S.C. Merriman, F. Muckler, H. Howells, B.R. Olive, & D. Beevis (Eds.), Workshop on applications of systems ergonomics to weapon system development, Volume 1: technical papers, (pp. B-23 – B-40). NATO DS/A/DR(84)408.
7. Grant, A.S., & Mayes, J.T. (1991). Cognitive task analysis? In: G.R.S. Weir , J.L. Alty (Eds.), Human-computer interaction and complex systems, (pp. 147-167). New York: Academic Press Ltd.
8. Hodgkinson, G.P., & Crawshaw, C.M. (1985). Hierarchical task analysis for ergonomics research. Applied Ergonomics, 16 (4). 289-299.
9. Hollister, W.M. (1986). Improved guidance and control automation at the man-machine interface. Neuilly sur Seine, France: AGARD AR-228.

10. Johnson, P., Diaper, D., & Long, J. (1985). Tasks, skills and knowledge: task analysis for knowledge based descriptions. In: B. Shackel (Ed.), Human-computer interaction - INTERACT '84, (pp. 499-503). North Holland: Elsevier Science Publishers B.V.
11. Kearsley, G. (1987). The problem analysis disc: A human factors tool for personal computers. CSTG Bulletin 14 (3), 18-19.
12. Laughery, K.R. Snr., & Laughery, K.R. Jr. (1987). Analytic techniques for function analysis. In: G. Salvendy (Ed.), Handbook of human factors. New York: John Wiley & Sons.
13. Malone, T.B., & Micocci, A.J. (1975). Development and validation of methods of man-machine interface evaluation. Final report. Alexandria, VA: Essex Corp., NASA CR 142824.
14. McCrobie, (1986). Application of MacProject to the task analysis process. Human Factors Society Bulletin 29 (3), p. 5.
15. McMillan, G.R., Beevis, D., Salas, E., Strub, M.H., Sutton, R. & van Breda, L. (Eds). (1989). Applications of human performance models to system design. New York: Plenum. Defense Research Series Vol. 2.
16. Meister, D. (1971). Human factors: Theory and practice, New York: Wiley.
17. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
18. Miller, R.B. (1953). A method for man-machine task analysis. (WADC Technical Report 53-137). Ohio: Wright Air Development Center, Wright-Patterson Air Force Base.
19. NATO MAS (1991). Application of human engineering to advanced aircraft systems. STANAG 3994 AI (Edition 1) Brussels: NATO Military Agency for Standardization.
20. Redding, R.E. (1989). Perspectives on cognitive task-analysis: the state of the state of the state of the art. In: Proceedings of the Human Factors Society 33rd. Annual Meeting. 1348-1352.
21. Rice, J. R. (1988). Excel™ spreadsheet software aids task analysis. Human Factors Society Bulletin. 31 (3) 6-7.
22. Shepherd, A. (1989). Analysis and training in information technology tasks. In: D. Diaper (Ed.), Task analysis for human-computer interaction, Chapter 1, (pp. 15-54). Chichester: Ellis Horwood Ltd.
23. St.Denis, G, & Beevis, D. (1991). Linking rapid prototyping and human factors analyses. In: Proceedings of the 24 Annual Conference of the Human Factors Association of Canada. Toronto: Human Factors Association of Canada.
24. Terranova, M., Snyder, C.E., Seamster, T.L., & Treitler, I.E. (1989). Cognitive task analysis: techniques applied to airborne weapons training. In: Proceedings of the Human Factors Society 33rd. Annual Meeting, (pp. 1358-1362).
25. Woodson, W.E. (1981). Human factors design handbook. New York: McGraw-Hill Book Co.

4.1 TIME LINES

What the technique does

Time lines provide a time chart of activities showing the sequence of operator tasks to provide a basis for time line analysis of workload and resource estimation. The charts show clearly any activities conducted in parallel, as well as those where external events dictate the timing of the operator's response (see Laughery & Laughery, 1987; Meister, 1985; Woodson, 1981). Time lines can be produced for a single operator or for multiple operators, for time increments of seconds or minutes.

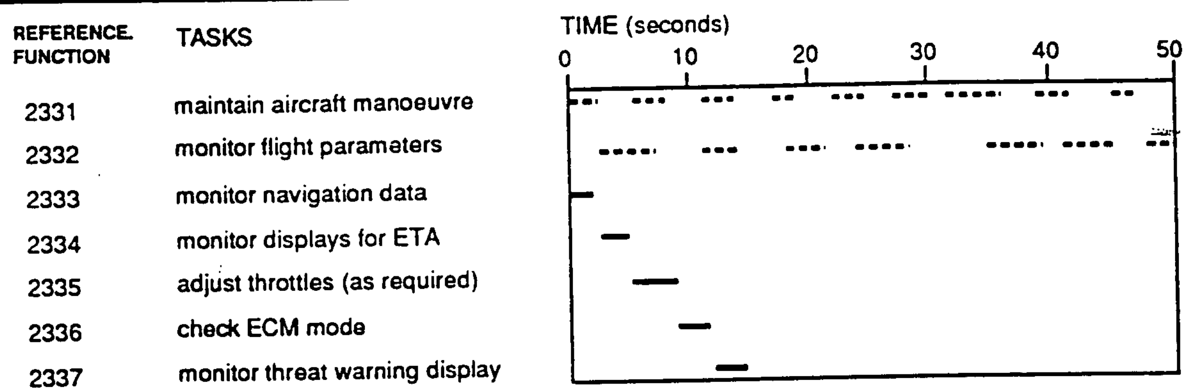


Figure 4.2: Example of a single operator time line analysis (US Dept of Defense, 1987)

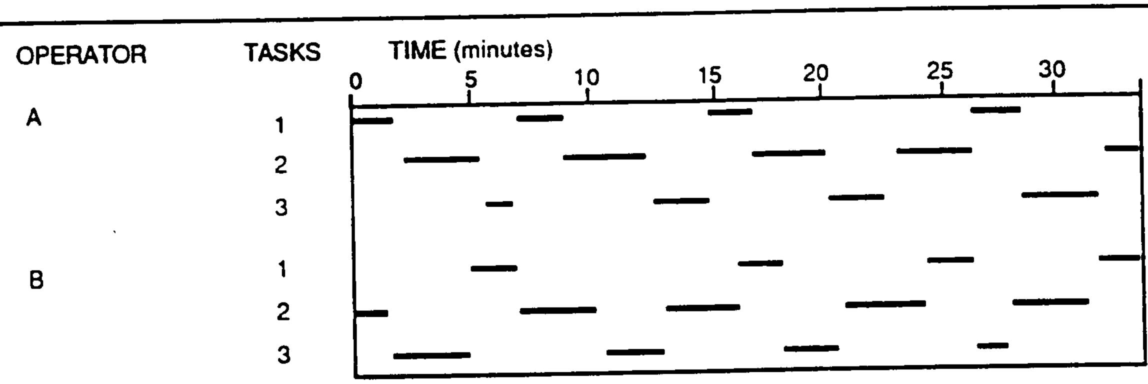


Figure 4.3: Example of a multi-operator time line analysis

Inputs to the technique

Information on the sequence of activities in a system and the time for each activity. SAT diagrams (2.2) may be used as input, or details generated from the mission analyses.

Outputs of the technique

Charts showing the time line of activities for a system are output. These are usually plotted with time as the horizontal axis. The activities are listed along the vertical axis and may include function reference numbers. The duration of an activity is shown by the length of the time line. The time base can be hours, minutes or seconds.

When to use

Time lines can be used in all phases of systems development. They are particularly useful in concept development and during system definition. The technique requires information on the overall time-scale of events (from the mission analysis), the sequences of tasks (from the output of a detailed function flow block diagram or flow process charts), and the length of time required for each task (from a task time data bank or other sources).

Time lines are a useful input to more detailed workload analyses. They can also support other systems engineering analyses of resource allocation.

Related techniques

Time lines are related to flow process charts and other simple task analysis techniques, as well as to engineering tools such as Gantt charts. They are useful for defining network models as used in SAINT simulations (5.2) (van Breda, 1989). They are also an output of SAINT simulations. Time lines are used for some systems engineering analyses (Defense Systems Management College, 1990).

Resources required

The technique requires few resources apart from the input data and some graphics plotting facilities.

Advantages

Time lines are a simple, easy to use, technique which can provide designers with quantitative information on the feasibility of performing required mission functions early in the design/development process. Users report that they can be used easily to study system reversionary mode operation. They are also very useful for test and evaluation.

Disadvantages

Time estimates can be inaccurate, particularly for complex tasks involving simultaneous operator activities. The analyses are deterministic; they are drawn from a specific sequence of mission events. Thus, they do not represent the fluidity that can occur in the performance of highly skilled tasks.

Relative contribution

Users report that the technique is very effective and of low cost. It is particularly useful if used in conjunction with a time-line analysis of operator workload.

Applications

The technique was used during the development of a tank and several aircraft, including fighter, attack, and ASW aircraft. It was used as input to a network analysis of various levels of automation of the snorkelling procedure for a submarine to decide whether the time-budget of operators was sufficient. It was used also to analyse how an operator could manage the organization of a ship's fire-fighting team from a remote control room, using an interactive computer display of damage status (Vermeulen, 1987).

Quality assurance considerations

The technique is heavily dependent on the quality of the task time data.

Relationship to system performance requirements

The technique can be related directly to system performance requirements through comparison of the overall sequence times with times from the mission analysis. This permits calculation of an overall figure of "time required vs. time available."

References and Bibliography

1. Defense Systems Management College (1990). System engineering management guide. Washington D.C.: U.S. Government Printing Office.
2. Laughery, K.R. Snr., Laughery, K.R. Jr. (1987). Analytic techniques for function analysis. In: G. Salvendy (Ed.), Handbook of human factors. New York: John Wiley & Sons.
3. Meister, D. (1985). Behavioral analysis and measurement methods, (pp. 63-65). New York: John Wiley & Sons.
4. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
5. van Breda, L. (1989). Analysis of a procedure for multiple operator task performance on submarines using a network model. In: G.R McMillan, D. Beevis, E. Salas, M.H. Strub, R. Sutton, and L. van Breda (Eds.), Applications of human performance models to system design, (pp. 231-249). New York: Plenum. Defense Research Series Vol. 2.
6. Vermeulen, J. (1987). Analysis of the task of the NBCD operator in the technical centre of M-class frigates. In: Proceedings of the Eighth Ship Control Systems Symposium, (pp. 5-21 – 5-29). The Hague: Ministry of Defence.
7. Woodson, W.E. (1981). Human factors design handbook. New York: McGraw-Hill Book Co.

4.2 FLOW PROCESS CHARTS

What the technique does

The technique is an analysis of task sequences, based on a taxonomy of five basic types of task: operation, transportation, inspection, delay, and storage. A graphic symbol is associated with each type of task, together with a brief written description. Operator and machine activities, or tasks, are plotted sequentially on a vertical axis. Time and/or distance information can be added to the charts if required.

Flow process charts were adopted for charting operator activities by plotting the sequential flow of human operator activities over time (see Henry, 1968; Laughery & Laughery, 1987). The majority of human activities in a system can be represented using these categories, or combinations of them. The charts show a sequence of operator activities, without reference to details of the human-machine interface.

Operation - an operation occurs wnen an object, person, or information is intentionally changed

Transportation - transport occurs when an object, person, or information moves or is moved from one location to another

Inspection - an inspection occurs when an object, person, or information is examined or tested for identification, quality, or quantity

Delay - a delay occurs when an object, person, or information waits for the next planned action

Storage - storage occurs when an object, person, or information is kept under control and authorization is required for removal

Combined operation - inspection is performed within an operation

Combined operation - an operation is performance while a product is in motion

Figure 4.4: Flow process chart task types and symbols

Inputs to the technique

The analyst needs information on the activities the operator is required to perform. The analysis can be conducted from a list of assigned operator functions.

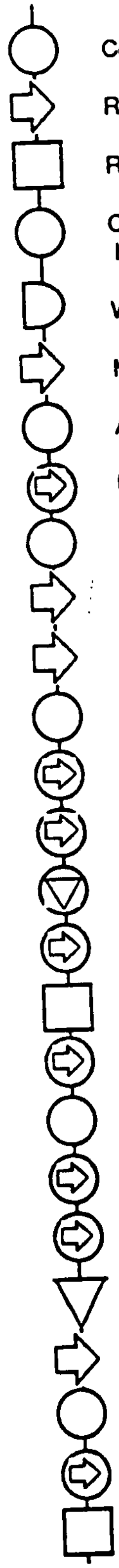
Outputs of the technique

The analysis produces detailed sequences of operator tasks, annotated with the five basic graphic symbols.

When to use

The analysis is relevant to system concept development and can be used up to the test and evaluation phase. It can be completed once some idea of the basic operator tasks is available, i.e., once a function allocation analysis has been completed, or a similar system has been analysed. The analysis is often used as an input to interface design.

Symbol **Description**



Communicate with sensor operator (optional)

Request BIT information

Receive and acknowledge BIT information

Collect tools, Shipboard Replaceable Units (SRUs), equipment, head set, safety harness

Wait for "man aloft" procedures to be applied

Mount mast

Attach safety harness to anchor

Unlatch and open access panel

Plug in communications head set jack

Request control of remote control of scanner

Acknowledge control of scanner

Turn off power to stabilizing platform

Manually rotate scanner to optimum position for azimuth lock

Manually guide scanner into optimum roll and pitch position

Put locking pins in gimbal

Unlatch and open access doors in shroud

Look for LED indicating failed SRU

Unlatch and open access door on cargo cage

Loosen heat sink clamps (2)

Pull out extraction levers (2)

Pull card out of slot

Place card in pocket

Take replacement card from other pocket

Remove protective cover from card

Insert card in slot

Check out system

Summary of 26 operator tasks

Total operations	8
Total operations involving movement	8
Total delays	1
Total storages	1
Total inspections	3
Total transportations	5

Figure 4.5: Flow Process Chart for Maintenance Procedures on Ship's Mast-Mounted Sensor System

Related techniques

As indicated above, flow process charts were originally developed for motion study, for charting the flow of materials around a facility. Subsequently they were adopted for human engineering analyses. They were a precursor to Operational Sequence Diagrams (4.3) and to other variants of task analysis charts.

Resources required

Minimal resources are required. The technique originally was conducted using paper and pencil. A computer data base is an asset, particularly for editing and updating the analyses.

Advantages

Because of its simplicity, the technique can be adapted to a wide variety of uses, from showing the individual hand operations of one operator or the interaction of one man and one machine, to the activities of several operators working in collaboration. It is considerably simpler than many other techniques, and is well suited to a low-cost, low-effort analysis. The charts can be annotated with time and distance information.

Disadvantages

The original emphasis of motion studies was to reduce unnecessary activity such as transportation or delays. The use of the five basic task categories is not always effective for systems where the operator is processing information. For example, in the figure, there is no clear distinction between transporting equipment or information (communication). Thus the technique is most suited to manual tasks where overt operator activity can be charted.

Relative contribution

User opinions vary, depending on whether the technique was applied manually or with computer graphics. When applied manually, its contribution was not seen as high compared to its cost. When computer graphics were used and machine functions were also included in the analysis, it appears to have been quite useful.

Applications

The technique has been widely used in industry for analysing semi-automated processes. It was used in the development of a fighter aircraft and a mine sweeper.

Quality assurance considerations

As with other task analysis techniques, the analysis must be checked for completeness and consistency with system operation.

Relationship to system performance requirements

Plain Flow Process Charts cannot be related directly to system performance requirements. Flow process charts annotated with task times and elapsed time can be related to the mission time line documented in the mission analysis.

References and Bibliography

1. Henry, O.W. (1968). Human factors in ship control: Human engineering technique and guidelines applicable to merchant marine bridge design, Volume II. Groton, Connecticut: General Dynamics Inc.
2. Laughery, K.R. Sr., & Laughery, K.R. Jr. (1987). Analytic techniques for function analysis. In: G. Salvendy (Ed.), Handbook of human factors, (pp. 329-354). New York: John Wiley & Sons.

4.3 OPERATIONAL SEQUENCE DIAGRAMS (OSDs)

What the technique does

Operational Sequence Diagrams are extended forms of Flow Process Chart (4.2) which provide a graphic presentation of the flow of information, decisions, and activities in a system, using a set of five basic graphic symbols and an associated grammar. The technique is tailored for the representation of the flow of information, with symbols for the transmission, receipt, processing, and use of previously stored information. The diagrams show the sequence of tasks or actions in a vertical sequence: they can be annotated with time information or a time line.

The technique is very much an integrative one, pulling together information derived from other analyses. OSDs can be used to represent the task of a single operator or of multiple operators interacting with a system (see Brooks, 1960; DeGreene, 1970; Henry et al., 1968; and Laughery & Laughery, 1987).

Inputs to the technique

Information on the tasks performed by the operators, their sequence, and the processing tasks performed by the system are input. System decompositions and function allocations generally provide sufficient information to start the analysis.

Outputs of the technique

The diagrams show how the operators interact with the system, the sequence of activities, and any branches or loops. The OSD can be used for developing the human-machine interface, for evaluating them, for developing operational procedures and identifying critical conditions with regard to concurrent operations.

When to use

The analysis is a logical successor to function allocation analysis for complex systems. It can be used from preliminary system studies through to design and development. It precedes workload analysis. OSDs also form a good basis for the development of SAINT simulations (5.2).

Related techniques

OSDs are related to Flow Process Charts, and to other industrial and software engineering charting techniques such as the Merise technique (Tardieu, Rochfeld, & Colletti, 1989).
SAINT simulations (5.2) can produce OSDs as output, although the more usual practice is to use OSDs to generate the SAINT network.

Resources required

OSDs can be produced manually. This is not recommended, due to the workload associated with editing changes. A computer-based method is preferable. Very simple computer techniques have been used (Lahey, 1970; Larson & Willis, 1970). Such computer representations should not reduce the OSD to a simple tabular task analysis, thereby losing the advantage of the graphic representation of interactions.

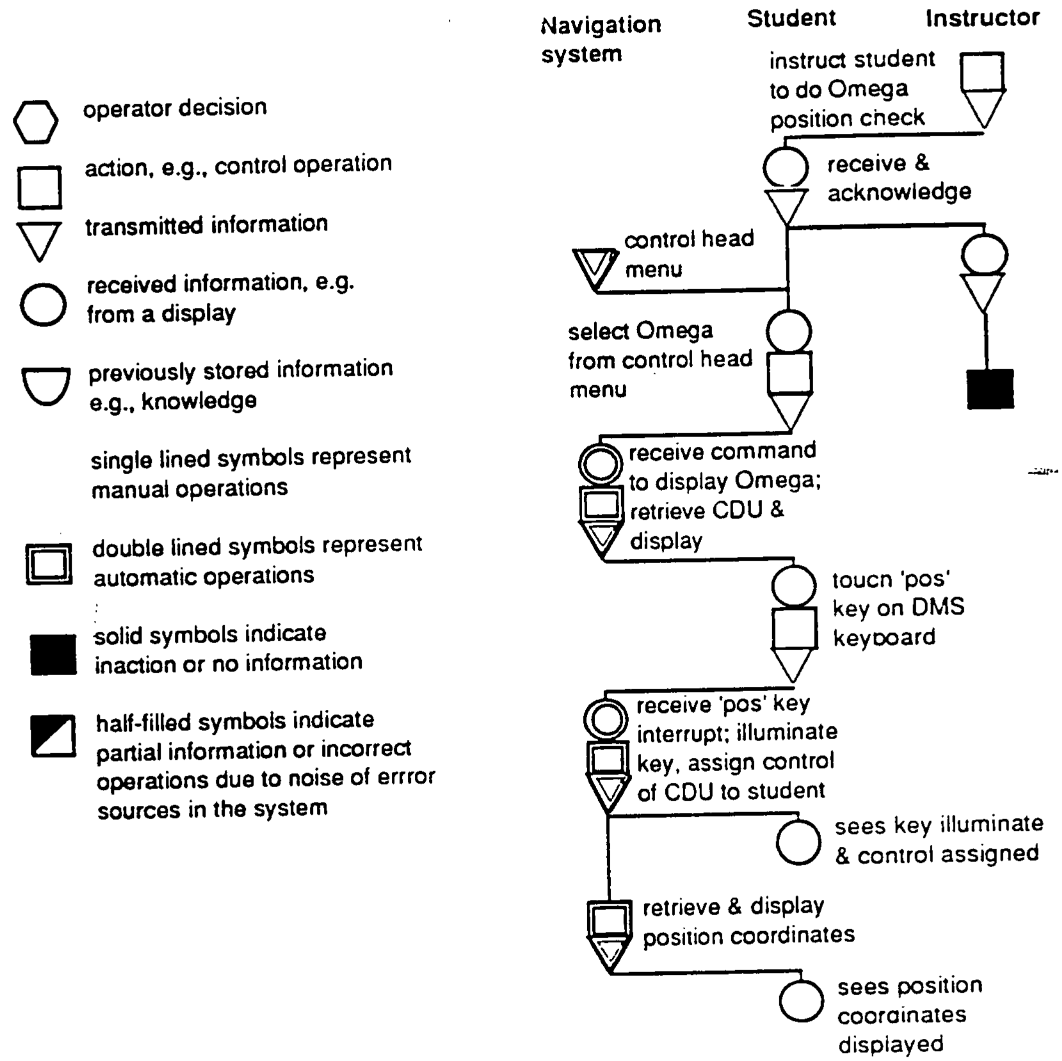


Figure 4.6: OSD symbols & sample of OSD for an airborne navigation trainer

Advantages

The OSD is a very effective method for describing and communicating human-machine interaction and the information flow in a system. It forces the analyst to gather or generate detailed information on the operator's activities. Annotated with a time line, OSDs provide a highly detailed analysis. Malone, Gloss & Eberhard (1967) concluded that the OSD, *combined with a tabular task analysis*, is a very effective tool for system description, analysis, and integration, and serves the function of most other analyses.

Disadvantages

OSDs are extremely labour-intensive to produce, and are hard to edit or modify if not produced on a computer editing system. The descriptions are quite specific to the system, they describe a normative approach to system operation, and do not facilitate more general analyses. The diagrams can become extremely complex, particularly in their branching and in the use of combinations of the standard symbols. The amount of detail and the volume of the analyses makes them hard to read or review. Due to individual interpretations of the symbols and how to represent specific operator tasks there can be quite wide differences between users in the appearance of the diagrams.

Relative contribution

Users generally rate the technique as making a very high contribution to the system development process. However, the application must be timely.

Applications

In a review of human engineering analysis techniques on 33 projects, OSDs were the third most frequently used technique. They were used in the concept development of 9 new systems, and the preliminary design of 11 systems, including aircraft, tanks and ships.

Quality assurance considerations

Because they integrate information made available through other analyses, the OSDs can be checked for consistency with preceding analytical efforts. The level of detail shown in OSDs makes them difficult to check, however. There is no simple way of summarizing the many pages of information contained in a typical OSD analysis, although Link Analysis Charts (6.3) can be used effectively in some circumstances.

Relationship to system performance requirements

The technique cannot be related directly to system performance requirements. As with other task analyses, it is an inventory of the actions required by the operator, and can be checked against specifications at that level. It can be related to workload through the use of time lines or SAINT modelling.

References and Bibliography

1. Brooks, F.A. Jr. (1960). Operational sequence diagrams. IRE Transactions on Human Factors in Electronics, (pp. 33-34).
2. DeGreene, K.B. (1970). Systems analysis techniques, In: K.B. DeGreene (Ed.), Systems Psychology. New York: McGraw-Hill.
3. Henry, W.O., Jones, J.J., & Mara, T.D. (1968). Final Report: Human factors in ship control. Volume II: Human engineering techniques and guidelines applicable to merchant marine bridge design. Report No. U-417-68-001. Groton, Connecticut: General Dynamics Inc.
4. Kurke, M.I. (1961). Operational sequence diagrams in system design. Human Factors 3, 66-73.
5. Lahey, G.F. (1970). Automating the operational sequence diagram (OSD). (Research Memorandum SRM 71-8). San Diego. CA: Naval Personnel and Training Research Laboratory. AD 718842.
6. Larson. O.A., & Willis, J.E. (1970). Human factors methods development and test: Evaluation of the automated operational sequence diagram (OSD). (Research Memorandum SRM 70-17). San Diego, CA: Naval Personnel and Training Research Laboratory.
7. Laughery, K.R. Snr., & Laughery, K.R. Jr. (1987). Analytic techniques for function analysis. In: G. Salvendy, (Ed.) Handbook of human factors. New York: John Wiley & Sons.
8. Malone, T.B., Gloss, D.S., & Eberhard, J.W. (1967). Human factors techniques employed in deriving personnel requirements in weapon system development. Report No. PRR 68-3. Alexandria, VA: The Matrix Corp. for Bureau of Naval Personnel.
9. Tardieu, H., Rochfeld, A. & Colletti, R. (1989). La méthode Merise: principes et outils, démarches et practiques. Paris: Les Editions d'Organisation. Vols 1 & 2.
10. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.

4.4 INFORMATION/ACTION OR ACTION/INFORMATION TABULATIONS

What the technique does

These are comparatively simple techniques for conducting a task analysis which emphasizes the information required by the operator to perform his or her task. Both analyses are hierarchical: they are based on those functions which have been allocated to the operator(s). Each function is analysed in turn to identify the operator's tasks. The information/action analysis starts by analysing the information related to each function in sequence and defining the operator's tasks, and the actions associated with each item of information (see Drury et. al., 1987; Meister, 1985; Woodson, 1981). The action/information analysis is conducted by analysing an operator's tasks and actions in sequence, as a series of discrete steps, to identify the information required for each action.

Inputs to the techniques

The analyst/user requires information on the actions to be taken by the operator, or, conversely, the information which the operator will be given by a specific system state.

Outputs of the techniques

The techniques produce tabulations of the information provided to the operator, the action taken upon receipt of the information, and optionally, the feedback to the operator.

When to use

The techniques are of use in concept development, and particularly, in preliminary design. They may be preceded by one of several types of function analysis: Function Flow Diagrams (2.1), Sequence And Timing (SAT) analysis (2.2), Information Flow and Processing Analysis (2.4). They may be incorporated into Requirements Allocation Sheets (3.5). Information/Action, or Action/Information analyses produce information which can be used either for more detailed task analyses (4.5), for display concept development or analysis of Critical Design Requirements (6.2), for Error Analysis (5.7), or for Link Analysis (6.3).

Related techniques

The techniques are two of several tabular task-analysis techniques all of which analyse the operator's tasks as a series of actions in response to information inputs.

Resources required

The analyst requires the information identified under "inputs." No technical resources are necessary, but a computer system is recommended to keep track of the many details that are created, and to facilitate modification.

Table 4.2: Example of information/action analysis

Mission segment: Aircraft approach to sonar dip position

Function: 5.4.7 Engage /Monitor Automatic Flight Control System (AFCS) for Automatic Approach

Task No. & Task	Initiating stimulus/Information	Action response(s)
5.4.7.1 (a) Engage AFCS for automatic approach	Pre-approach checks completed. Aircraft within automatic approach profile criteria. Required approach profile. AFCS operating status. Procedures	Adjust AFCS for approach to dip. "Approach to dip" mode indication. Actuate AFCS engage. AFCS "Approach to dip enabled" indication.
5.4.7.2 (b) Monitor a/c during automatic approach	AFCS approach to dip. Aircraft flight parameters (transition). AFCS operating status. Aircraft movement relative to desired hover point.	Monitor (visual) aircraft performance.

Table 4.3: Example of action/information requirements analysis

Mission segment: Aircraft approach to base.

Function: 1.0 Initiate pre-approach procedures

Action requirements	Information requirements	Related information, sources, and problems
1.0.1 Review approach information	1.0.1.1 Approach orientation. 1.0.1.2 Approach constraints: Requirements Obstacles Hazards Weather	Position data Approach path data: Course & path data Obstacle locations Terrain characteristics Minimum decision altitudes
1.0.2 Coordinate approach with control	1.0.2.1 Communication: Path designation Limitations & constraints Environmental conditions	Coordination & confirmation of approach clearance. Altimeter setting

Advantages

Users report the techniques to be fast and easy, provided that the level of detail does not become excessive. It has been found useful for deriving test criteria for mockup reviews and for some test & evaluation (T&E) activities.

Disadvantages

The analysis can become time-consuming if the level of detail is not controlled. Standardization of terms for tasks and information is recommended to avoid confusion.

Relative contribution

The techniques can provide a high level of information for the design of the interface and for test and evaluation purposes.

Applications

Action/Information and Information/Action requirements analyses were used during the concept development of an ASW helicopter, and for the development and prototyping of a state-of-the-art combat aircraft. The techniques have also been used to analyse the tasks of operators in a Future Tank Study Operational Demonstrator Programme trial, using tanks with simulated advanced design features (Streets et al., 1987; Scriven, 1991).

Quality assurance considerations

The technique is dependent for accuracy and completeness on the preceding analyses. The task or action lists should be checked against system functions or information flow analyses.

Relationship to system performance requirements

The list of operator actions should reflect the operational requirement, but there is no means of correlating the two directly, due to the differences in level of detail.

References and Bibliography

1. Drury, C.G., Paramore, B., Van Cott, H.P., Grey, S.M., & Corlett, E.N. (1987). Task analysis. In: G. Salvendy (Ed.), Handbook of human factors, Chapter 3.4. New York: John Wiley & Sons.
2. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
3. Scriven, J.G. (1991). Task analysis of main battle tank crew 'In tank' activities. APRE Report 91R024. Farnborough, UK: Army Personnel Research Establishment.
4. Streets, D.F., Wayman, K.M., Scriven, J.G., Marshall, A.A. & Edwards, R.J. (1987). Exercise Endura – Human factors comparison of 3 and 4 man MBT crews during a 12 day operational scenario – Main Trial. APRE Report 87R005. Farnborough, UK: Army Personnel Research Establishment.
5. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
6. Woodson, W.E. (1981). Human factors design handbook. New York: McGraw-Hill Book Co.

4.5 CRITICAL TASK ANALYSIS

What the technique does

This technique analyses "critical" operator tasks in detail according to a specified standard. STANAG 3994 AI (NATO MAS, 1991) defines critical tasks as those which are predicted to have a high workload, or which are critical to system safety or mission success. In US MIL-H-46855B (US Dept. of Defense, 1979), critical tasks are defined as those which "if not accomplished in accordance with system requirements, will most likely have adverse effects on cost, system reliability, efficiency, effectiveness, or safety. ... Critical performance is usually part of a 'single' line of flow in the operation or maintenance cycle of the system."

The standards require such tasks to be decomposed to the sub-task level and subjected to a detailed analysis. The analysis examines operator/maintainer sub-tasks in terms of the information required, perceptual load, decision(s) taken, action taken to implement the decision, feedback provided as a result of the action, communication with others, and any constraints on the interface, workspace, and environment design. The analysis also identifies the performance level required of each sub-task, and the implications for system effectiveness of failure to reach that performance level.

Table 4.4: Requirements for critical task analyses

STANAG 3994 Requirement	US-MIL-H-46855B Requirement
Information required	Information required, including cues for task initiation
Perceptual load	Information available to operator
	Evaluation process
Decision(s)	Decision reached after evaluation
Action	Action taken
	Frequency and tolerance of actions
	Body movements required by action
	Feedback informing operator of adequacy of actions taken
	Time base
Communication	Communications required, including type
	Operator interaction where more than one crewmember involved
Constraints on interface	
Constraints on workspace	Workspace available
	Workspace envelope required by action
Constraints on environment	Location and condition of the work environment
	Special hazards involved
	Tools and equipment required
	Job aids or references required
	Number of personnel required, speciality and experience
	Operational limits of personnel (performance)
	Operational limits of machine & software

Inputs to the technique

The analyst requires information on the sequence and performance criteria for the operator's tasks, and details of the human-machine interface design.

Outputs of the technique

Critical task analyses are usually presented as tabulations of the required information. There is no standard format. Annotated Operational Sequence Diagrams are sometimes used.

When to use

Because of the amount of detail required for the analysis, usually it cannot be prepared prior to the design definition phase of a project. It requires input from other task analyses and from an interface design concept. Some users recommend that a mock-up of the interface be used as a basis for the analysis, which would determine the schedule of the work.

Related techniques

Critical task analyses are characterized more by the level of detail of the analysis, than by the specific technique used. The approach is related to Operational Sequence Diagrams (4.3), and to Information/Action tabulations (4.4).

Resources required

Detailed operator task information and details of the human-machine interface are needed. Use of a computer is recommended, to handle editing and updating.

Advantages

In general, users report the technique to be effective. The analysis is straightforward to conduct, and forces the designers to develop a thorough understanding of what the operators of a system will be required to do.

Disadvantages

The level of detail provided can be overwhelming, so that the reviewer has difficulty understanding the overall pattern of operator activities. Users report that the technique does not deal well with parallel, multi-task situations. It is reported to be of medium difficulty, and quite time-consuming. The time requirement can limit the extent of application of the analysis. Analysts should choose the application carefully.

Relative contribution

Some users find the technique quite effective. One user, however, indicated that it had low effectiveness on their project. It has been found very effective for identifying the tests which are to be run in the test & evaluation phase.

Applications

The technique has been widely called up in system requirements documents, but there are few reports of its use. It was used for the development of a European strike aircraft, for a tank, US helicopter system (Parks, 1987), naval sensor systems, and a naval ship.

Quality assurance considerations

Critical task analyses are very difficult to check for consistency and completeness because of the amount of detail involved. An hierarchical approach, developing the analyses from preceding task analyses, is recommended, together with the use of a computer-based editing system. Customer and contractor should agree clearly on the extent of the work.

Relationship to system performance requirements

The final output can be related directly to operator job aids such as checklists and instruction manuals. The analysis can also be used to identify criteria for test and evaluation.

References and Bibliography

1. NATO MAS, (1991). Application of human engineering to advanced aircraft systems. Brussels: NATO Military Agency for Standardization (MAS) Aircraft Instrument Panel. STANAG 3994 (Edition 1) (Ist Draft).
2. Parks, R.E., (1987). Development and testing of a predictive methodology for optimization of man-machine interface in future avionics systems. In: The design, development and testing of complex avionics systems. (pp. 14-1 – 14-9). AGARD-CP-417.
3. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
4. US Department of Defense (1979) Human engineering requirements for military systems, equipment and facilities. Redstone Arsenal, AL: US Army Missile R & D Command. MIL-H-46855B.

4.6 DECISION TABLES

What the techniques does

Generally, in decision situations, the accomplishment of actions depends on certain conditions. Describing complex decision situations verbally or representing them with flowcharts is often unsatisfactory or insufficient. If the relationships between particular actions and conditions can be specified unambiguously, they can be charted using decision trees (normally used for the analysis of payoffs associated with specific decisions (Edwards, 1987)). Decision tables (DT) are another technique for describing decisions clearly and concisely in terms of the conditions required for a decision, and the action to be taken on a decision.

A DT is simply a tabular display that shows conditions applying to the decision situation and the relationships between the various conditions. The DT describes which action or actions are allowed for each set of conditions as a forward-chaining mechanism, based on the use of IF-THEN logic. The IF area of a table is made up of all conditions or tests that are required to determine the conclusions or actions. The THEN area of the table documents the actions taken when specific conditions are met.

A DT consists of four sections, as shown in Table 4.5. The upper left quadrant documents the conditions. This area should contain all those conditions being examined for a particular problem segment. The lower left quadrant documents the actions. This area should contain, in simple narrative form, all possible actions resulting from the conditions listed above. The upper right quadrant documents the condition entry information. It is here that the questions asked in the condition quadrant are answered with either a "yes" (Y) or a "no" (N) and all possible combinations of entry conditions are developed. If no condition is indicated, it means that the condition was not tested in that particular combination. The lower right quadrant is the action entry portion of the table. The appropriate actions resulting from the various combinations of responses to conditions above are indicated here by means of an X.

The development of DTs is supported by rules that are applied for simplifying and testing the tables for direct redundancies and inconsistencies (McDaniel 1968, 1970).

Table 4.5: Example of a decision table

NAME: Credit	1	2	3	4						
Is credit limit O.K?	Y	N	N	N						
Favourable payment record?		Y	N	N						
Special clearance obtained ?			Y	N						
CONDITION PART					CONDITION ENTRY					
Approve order	X	X	X							
Disapprove order				X						
ACTION PART					ACTION ENTRY					

Inputs to the technique

To describe a decision situation with decision tables, the analyst has to specify the conditions and their possible combinations. The analyst also requires information on the actions that belong to the various combinations.

Outputs of the technique

The technique produces a comprehensive description of a rule-based decision situation.

When to use

The technique can be used at any stage of system development when decisions have to be analysed. The earliest stage at which the decisions are likely to be documented sufficiently well is at the conclusion of a function allocation analysis.

Related techniques

Flowcharts, decision-action diagrams, and decision trees are related.

Resources required

Experienced analysts are required. Computer programmes for developing and checking the Decision Tables are desirable.

Advantages

Rules are available for checking the tables for consistency and redundancy. Thus, the use of DTs ensures a systematic review of possible conditions and condition combinations. DTs can be prepared individually, so the documentation is easily updated. The technique can be learned easily and in a short time.

Disadvantages

Decision Tables do not show the sequence of decisions and actions.

Relative contribution

No data available.

Applications

The technique has been used in projects to develop complex data-processing systems.

Quality assurance considerations

The technique is dependent on an exhaustive list of conditions.

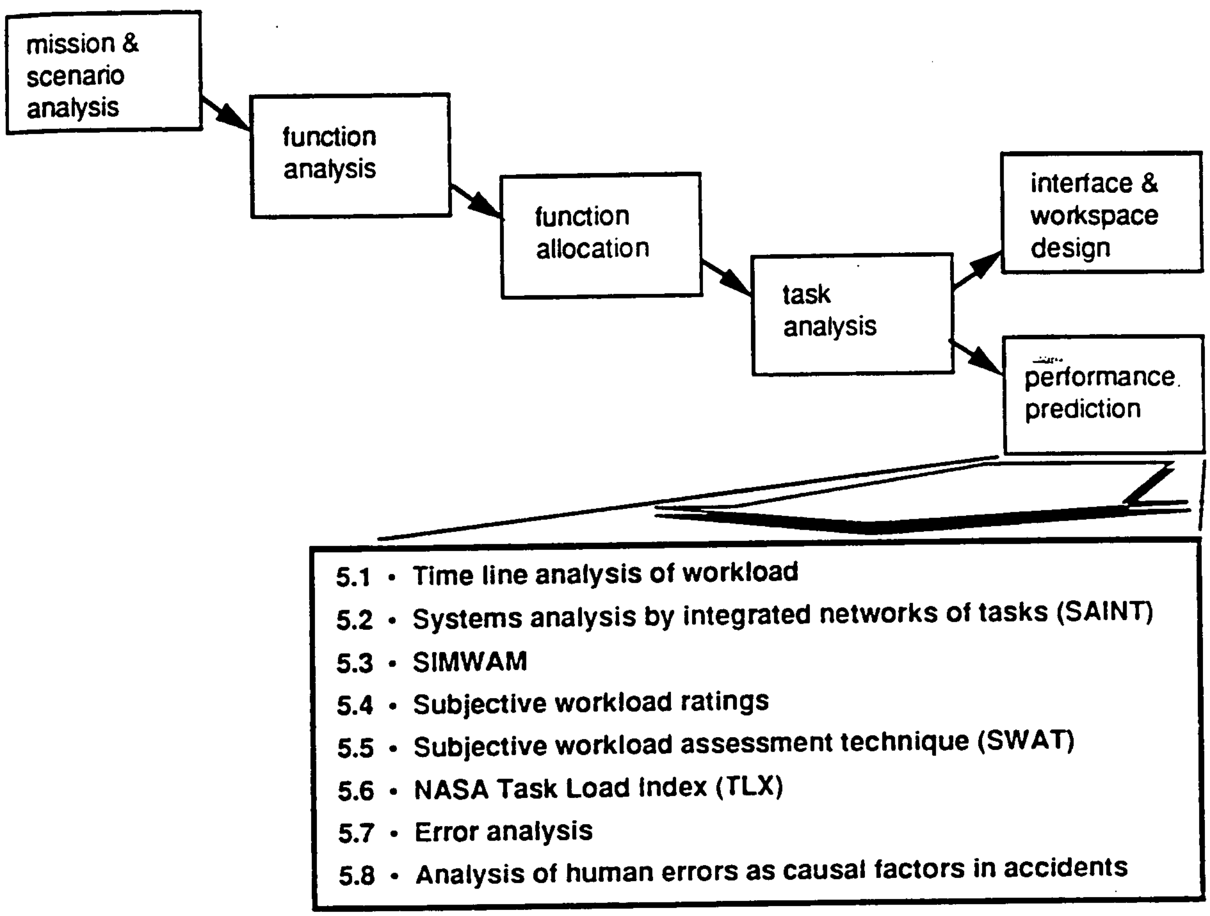
Relationship to system performance requirements

There is no direct relationship between system performance requirements and decision tables. The analyses can be linked to performance requirements via function analyses.

References and Bibliography

1. Edwards, W. (1987). Decision making. In: G. Salvendy (Ed.), Handbook of human factors, (pp. 1061-1104). New York: John Wiley & Sons.
2. McDaniel, H. (1968). An introduction to decision logic tables. New York: John Wiley & Sons.
3. McDaniel, H. (1970). Application of decision tables. New York: John Wiley & Sons.

5 PERFORMANCE PREDICTION



What the techniques do

These techniques are used to predict and analyse how well the operators will perform their assigned tasks once these have been defined by the techniques reviewed in the previous sections. Performance analysis links the results of mission, function, and task analyses to system performance criteria by providing measures such as: distributions of task times compared with the time available; operator workload; probability of successfully completing a task. By providing such measures, they confirm previous decisions about the allocation of functions to, and among, operators and maintainers. The analyses are related to industrial engineering and work study techniques such as Methods Time Measurement (MTM). Performance prediction is related to interface and workspace design, since estimates of human performance are dependent on the features of the human-machine interface (Fig. 5.1).

Such analyses are not the only way of predicting operator performance. Other evaluative techniques which are available include the use of dynamic mockups for working through scenarios[4], full and partial man-in-the-loop simulation or rapid prototyping, and field trials. Those techniques rely on the measurement of operator performance or

[4] Mockups can be provided with simple dynamic features, such as displays run from slide projectors, to provide an element of realism.

on the measurement of subjective workload to verify that system performance requirements will be met. As noted in Volume 1, detailed considerations of the use of prototyping, simulation and field trials are outside the scope of this review. The links between analytical techniques and other approaches are discussed where possible.

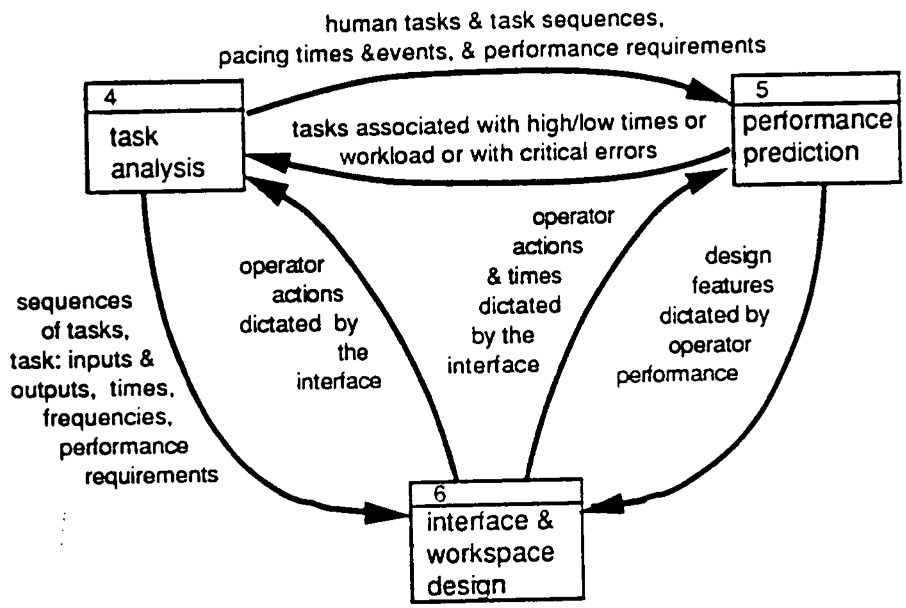


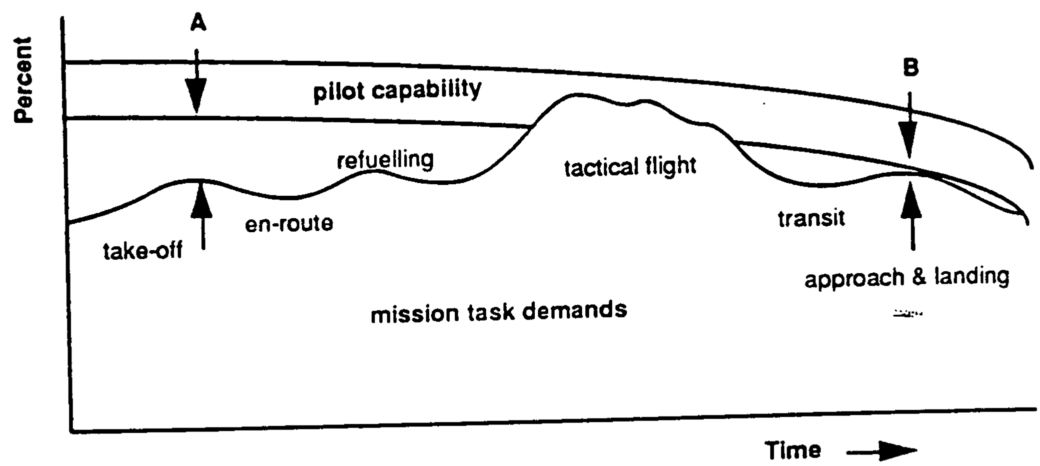
Figure 5.1: Relationship between task analysis, performance prediction and interface and workspace design

Types of analysis available

A variety of approaches are available to predict operator performance analytically (Meister, 1985). Most of them use the concept of operator "workload" rather than a measure of performance itself (Hart & Wickens, 1990). Some established techniques such as the time line analysis of workload (5.1) are normative, based on a single task analysis sequence. Network simulations of operator tasks, such as PERT, SAINT and MicroSAINT (5.2) can be made stochastic so that the external mission events, and the task times and sequences, are drawn from a distribution of times and probabilities. Network simulations can link workload to system performance because they can produce estimates of task success in terms of percentage of tasks completed, or time to complete, using models of human performance, as well as producing estimates of operator workload (Chubb, Laughery & Pritsker, 1987). NATO AC/243 Panel 8/RSG.9 has reviewed and reported on those techniques and on a variety of models of human performance (McMillan et al., 1989, 1991). One specific approach, SIMWAM (5.3) is included here, because of the extensive use made of it for weapon systems development.

Performance predictions can also be made using subjective workload measurement techniques (5.4). For example, although the SWAT technique (5.5) was developed for the evaluation of an existing, or simulated, system, it can be applied projectively (Pro-SWAT) to the prediction of operator workload based on a task analysis. The NASA Task Load Index (TLX) (5.6) can be applied projectively also.

In following either a simulation modelling approach or a subjective workload approach to predicting operator performance, it must be remembered that the relationship between workload and performance is not straightforward. As task demands vary with time, the operators may increase or decrease their effort to compensate, or their effort may decline due to fatigue (Fig. 5.2). Thus at the outset of a mission, the task demand may lie within an operator's capability, whereas at the end of a mission, the same level of task demand may exceed the operator's capability. Hart & Wickens, (1990) discuss the Performance Resource Functions (PRF) which relate workload, performance, and operator effort in different situations.



At point A, pilot capability exceeds mission task demands by 25%
At point B, pilot capability barely exceeds same level of task demands

Figure 5.2: Example of the relationship between mission task demands and operator capability (after Tepper & Haakanson, 1978)

Error analysis is another aspect of performance prediction. A variety of approaches have been taken to error analysis (Leplat et al., 1990; Rasmussen, Duncan & Leplat, 1987). Some approaches use fault tree analysis or failure modes effects analysis to identify those operator actions which could result in a system-critical incident or situation. The Technique for Human Error Prediction (THERP) reviewed by NATO AC/243 Panel-8/RSG.9 (McMillan et al., 1991), is the most well known example. Other approaches attempt to identify design features which are associated with human error. In that context, many of the established human engineering design recommendations are intended to control "design induced error." Woodson (1981) provides examples of lists of quantitative and qualitative approaches to analysing designs for human error. It should be noted, however, that the whole subject of operator error is a contentious one. There are many problems with the definition and classification of human error. For example, error is context dependent and accident and incident analysis require value judgements to be made (Ridley, 1991). Because of such problems, only a simple generic approach to error analysis based on actual application is reviewed here (5.7). The prediction of human error requires a data base for associated probabilities of occurrence. An approach which has been applied to the collection of data from accidents is also reviewed (5.8).

Table 5.1: Applicability of performance prediction techniques to different projects

Technique	Simple system (e.g., rifle, hand-held radio)	Medium complexity system (e.g., 1-man radar console)	High complexity system (e.g., 1-place attack aircraft)	Complex multi-man system (e.g., ship combat centre)
5.1 Time line analysis of workload	low	medium	medium	low
5.2 SAINT	not relevant	medium	hign	high
5.3 SIMWAM	not relevant	medium	high	high
5.4 Subjective workload ratings	not relevant	medium	medium	medium
5.5 SWAT	low	medium	high	high
5.6 NASA-TLX	low	medium	high	high
5.7 Error analysis	low	medium	high	high
5.8 Analysis of human error as causal factors	low	medium	hign	high

References and Bibliography

1. Chubb, G.P., Laughery, K.R. Jr., & Pritsker, A.A.B. (1987). Simulating manned systems. In: G. Salvendy (Ed.), Handbook of human factors. New York: John Wiley & Sons.
2. Hart, S.G., & Wickens, C.D. (1990). Workload assessment and prediction. In: H.R. Booher (Ed), MANPRINT: An approach to systems integration. New York: Van Nostrand Reinhold.
3. Leplat, J., de Terssac, G., Cellier, J.M., Neboit, M., & Oudiz, A. (Eds.). (1990). Les facteurs humains de la fiabilite dans les systemes complexes. Marseille: Editions Octares Entreprises.
4. McMillan, G.R., Beevis, D., Salas, E., Strub, M.H., Sutton, R. & van Breda, L. (Eds). (1989). Applications of human performance models to system design. New York: Plenum. Defense Research Series Vol. 2.
5. McMillan, G.R., Beevis, D., Salas, E., Stein, W., Strub, M.H., Sutton, R., and van Breda, L. (1991). A directory of human performance models for system design. Report AC/243 (Panel-8) TR-1. Brussels: NATO Defence Research Group.
6. Meister, D. (1985). Behavioral analysis and measurement methods. New York: John Wiley & Sons.
7. Rasmussen, J., Duncan, K., & Leplat, J. (1987). New technology and human error. Chichester: John Wiley & Sons. New Technology and Work Series.
8. Ridley, D. (1991). Error: a construct masquerading as a behavioural description? In: E.J. Lovesey (Ed.), Contemporary ergonomics 1991. Proceedings of the Ergonomics Society's Annual Conference. London: Taylor & Francis.
9. Tepper, M.L., & Haakanson, N.H. (1978). Between incident and accident! In: B.O. Hartman (Ed.). Human factors aspects of aircraft accidents and incidents. AGARD CP-254. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
10. Woodson, W.E. (1981). Human factors design handbook, (pp. 985-991). New York: McGraw-Hill Book Co.

5.1 TIME LINE ANALYSIS OF WORKLOAD

What the technique does

The time line approach treats workload as a function of the time available to perform a task. The simplest approaches calculate workload on the basis of:

Workload (%) = time required for tasks / time available for tasks x 100

for sequences of tasks lasting several seconds. Typically, this approach incorporates a concept of time stress (see entries 5.5 SWAT and 5.6 NASA-TLX) in the form of a capacity limit of 70% to 80% time occupied. If the workload level is calculated at 85%, then it could be expected that, in the normal performance of the tasks, the operator would shed some activities to bring his workload below 80% occupied. The approach has been reviewed in more detail by NATO AC/243 Panel-8 RSG.9 (McMillan et al., 1989; 1991).

Inputs to the technique

Analysts require task analyses for the sequences of operator tasks, together with information on the mission segment time, and likely times to complete each task.

Outputs of the technique

The technique produces estimates of operator workload throughout the mission segments. These may be displayed as tables, or, more frequently, as plots of workload against time.

When to use

The analysis may be undertaken in the concept formulation and validation phases. The analysis may be completed once task analysis and mission time line data are available. The analysis confirms the decisions made at the function allocation stage, and may be used to validate assumptions about the ease of operation of the human:machine interface. The analysis can be made more detailed as design definition proceeds. The results also provide the basis for Test and Evaluation criteria.

Related techniques

The technique is a development of time line approaches to task analysis. Time line analyses are also conducted for systems engineering analyses, and there may be some commonality with those activities.

Resources required

The analysis can be completed using paper and pencil methods, but a computer is recommended in order to keep track of the task data (see Linton et al., 1977, for example).

Advantages

The technique is directly compatible with time line task analysis. Users report the ease of use as "medium" or better. The technique is easy to understand and to communicate with other systems engineering disciplines. Parks and Boucek (1989) report encouraging correlations between time line estimates of workload and some physiological and performance measures.

Disadvantages

Most approaches are normative, assuming one sequence of tasks and one completion time per task. Users report that the identification of task completion times can be difficult, and subjective. Some "start up" costs are reported as analysts develop their task time data. The technique does not deal easily with continuous tasks such as holding a course in an aircraft, nor with cognitive tasks, although Parks & Boucek (1989) report what appears to be a promising approach.

Relative contribution

Users report the relative contribution as "medium." Reports suggest it is highly effective for test and evaluation purposes.

Applications

The technique has been used widely in the analysis and prediction of aircrew workload (Brown, Stone & Pearce, 1975; Jahns, 1972; Linton et al., 1977). Parks (1978) traces the use of the time line approach back to 1959. The technique has been used also for the analysis of tasks for a mineswecper, a destroyer operations room, and for tank and artillery operations.

Quality assurance considerations

The analyst must have available a reliable data base of task times.

Relationship to system performance requirements

The results of the analysis can be related to system performance by showing that the time required to perform a sequence of tasks is compatible with the time available.

References and Bibliography

1. Brown, E.L., Stone, G. & Pearce, W.E. (1975). Improving cockpits through flight workload measurement. In: Proceedings of the 2nd advanced aircrew display symposium. (Douglas paper 6355). Patuxent River, MD: US Naval Air Test Center.
2. Jahns, D.W. (1972). Operator workload: what is it and how should it be measured? In: K.D. Cross & J.J. McGrath (Eds.), Crew station design (JANAIR Report). Santa Barbara, CA: Anacapa Sciences Inc.
3. Linton, P.M., Jahns, D.W., & Chatelier, Cdr. P.R. (1977). Operator workload assessment model: an evaluation of a VF/VA-V/STOL system. In: Methods to assess workload. AGARD-CP-216, paper A12. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.
4. McMillan, G.R., Beevis, D., Salas, E., Strub, M.H., Sutton, R. & van Breda, L. (1989). Applications of huma performance models to system design. New York: Plenum Press Defense Research Series, Volume 2.

5. McMillan, G.R., Beevis, D., Salas, E., Stein, W., Strub, M.H., Sutton, R., & van Breda, L. (1991). A directory of human performance models for system design. Report AC/243 (Panel-8) TR-1. Brussels: NATO Defence Research Group.
6. Parks, D.L. (1978). Current workload methods and emerging challenges. In: N. Moray (Ed.), Mental workload: its theory and measurement. New York: Plenum Press.
7. Parks, D.L. and Boucek, G.P. (1989). Workload prediction, diagnosis, and continuing challenges. In: G.R. McMillan, D. Beevis, E. Salas, M.H. Strub, R. Sutton, & L. van Breda (Eds.), Applications of human performance models to system design. New York: Plenum Press Defense Research Series, Volume 2.

5.2 SYSTEMS ANALYSIS BY INTEGRATED NETWORKS OF TASKS (SAINT)

What the technique does

SAINT is a general purpose network modelling and simulation technique that can be used in the design and development of complex human-machine systems. Using a Monte Carlo approach, SAINT provides the conceptual framework and the means for modelling systems whose processes can be described by discrete and continuous functions/tasks, and interactions between them. It provides a mechanism for combining human performance models and dynamic system behaviours in a single modelling structure. SAINT facilitates an assessment of the contribution that personnel and machine components make to overall system performance. The discrete component of a SAINT model consists of nodes and branches, each node representing a task. Tasks are described by a set of characteristics, e.g. performance time duration, priority, and resource requirements. Branches connecting the nodes indicate precedence relations and are used to model the sequencing and looping requirements among tasks. SAINT allows the modelling of predecessor-successor relationships which are deterministic, probabilistic, and conditional. The precedence relations also indicate the flow of entities through the network. Entities are characterized by attributes which specify the flow of information or material. The continuous component of a SAINT model is the state variable description. State variables are defined by writing algebraic, difference, or differential equations that govern time-dependent system behaviour. The use of state variables in SAINT is optional. The interactions between the discrete and the continuous models are initiated either by tasks being completed or by state variables crossing specified threshold values.

Inputs to the technique

For modelling the discrete part, SAINT offers a graphic symbol set for specifying the task network. The analyst must specify every task and the details of each predecessor-successor relationship. This requires information on the specific tasks characteristics and precedence relations. SAINT also offers a special set of variables for describing state variable equations of the continuous model in FORTRAN. To permit the modeller to make assignments to attribute values, to establish task durations, or to specify special output formats, SAINT provides special functions and programs which the user has also to write in FORTRAN.

Outputs of the technique

Once the SAINT model has been built, the modeller can impose a data collection structure to obtain information about the behaviour of the system as it is exercised. Data which can be obtained are 1) statistical descriptions of the execution of specific tasks, e.g. time interval and task completion statistics, 2) resource utilization statistics, e.g. busy/idle status of human (work load) and equipment resources, 3) histograms of the probability and cumulative density functions for distributed variables, e.g. task durations, 4) time traces of state variables.

When to use

The technique can be used in any phase of human-machine system development. It is particularly useful in the concept development and design definition stages, and is most useful if dynamic processes are being controlled, or if the system has multiple-operators.

Table 5.2: Example of a SAINT task statistic

STATISTICS TASK SUMMARY FOR ITERATION 1

ITERATION LENGTH = 0.3000E+03TIME UNITS

TASK NUMBER	TASK LABEL	STAT TYPE	COLCT POINT	AVERAGE VALUE	STANDARD DEVIATION	NUM.OF OBSER	MINIMUM VALUE	MAXIMUM VALUE
5	STATIST	INT	COM	0.2266E+01	0.1595E+01	270	0.5127E+00	0.1270E+02
2	ARRIVAL	INT	COM	0.1059E+01	0.6796E+00	283	0.5000E+00	0.2500E+01
7	FAULT	INT	COM	0.2768E+01	0.2058E+01	13	0.7041E+00	0.6560E+01

Expressions used for the task statistics:

ITERATION LENGTH	the duration of the simulation run in simulation time units
TASK NUMBER	the task at which the statistic is collected
TASK LABEL	the task at which the statistic is collected
STAT TYPE	the type of statistic collected: possible types are: FIR - time of the first occurrence of an event ALL - time of all occurrences of a collection event BET - time between occurrences on a collection event NUM - number of occurrences of a collection event INT - time interval between the marking of an information packet in the task network and the occurrences of a collection event
COLCT POINT	the point used for collecting statistical data. The collection point determines the occurrence of a collection event. The occurrence is defined as one of: REL - the release of the task STA - the start of the task COM - the completion of the task CLR - the clearing of the task
AVERAGE VALUE	the average value of the collected variable: the sum of I observed values divided by I
STANDARD DEVIATION	the positive square root of the variance of the collected variable
NUM. OF OBSER	the number of observations indicating the number of collection events
MINIMUM VALUE	the minimum of all collected values
MAXIMUM VALUE	the maximum of all collected values.

Related techniques

The technique is very much a development of time line analysis, extended into a probabilistic form. The original versions of SAINT incorporated the Siegel-Wolf model of human performance (Siegel & Wolf, 1961). More recent versions do not have that feature. At least three groups have linked SAINT directly to a function analysis carried out using SADT™ (Cherry & Evans, 1989; Chubb & Hoyland, 1989; Mills, 1988). The technique is related to PERT and CPM techniques used for project scheduling, and to the GPSS simulation language used for systems engineering studies. Commercial development of SAINT resulted in the SLAM simulation language (Pritsker, 1986).

Table 5.3: Example of a SAINT resource utilization statistic

RESOURCE UTILIZATION FOR ITERATION 1

ITERATION LENGTH = 0.3000E+03 TIME UNITS

RESOURCE NUMBER	RESOURCE LABEL	TOTAL TIME BUSY	TOTAL TIME IDLE	FRACTION OF TIME BUSY	FRACTION OF TIME IDLE
1	MACHINE	0.2640E+03	0.3599E+02	0.8800E+00	0.1200E+00
2	OPERATOR	0.2305E+03	0.6952E+02	0.7683E+00	0.2317E+00

Expressions used for the resource utilization statistics:

ITERATION LENGTH	the duration of the simulation run in simulation time units
RESOURCE NUMBER	the number assigned to a resource
RESOURCE LABEL	the label assigned to a resource
TOTAL TIME BUSY	the total time which the resource was busy during the simulation run
TOTAL TIME IDLE	the total time which the resource was idle during the simulation run
FRACTION OF TIME BUSY	TOTAL TIME BUSY divided by ITERATION LENGTH
FRACTION OF TIME IDLE	TOTAL TIME IDLE divided by ITERATION LENGTH

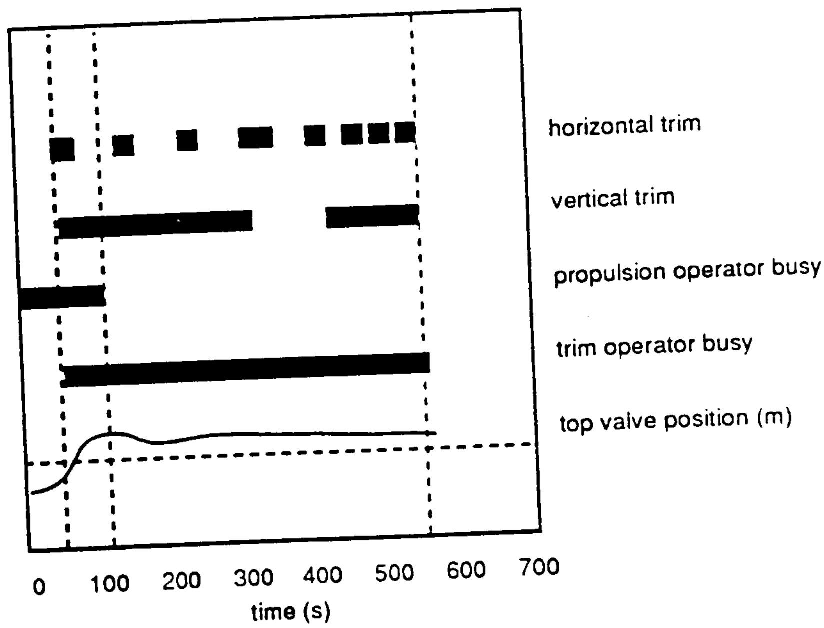


Figure 5.3: Example of a SAINT simulation: Control of the trim of a submarine while snorkelling (see van Breda, 1989)

Resources required

The programme is available as public domain information in the USA. The user must have a suitable computer (VAX or similar) available. Training in the programme language and in network generation is recommended. Commercial versions of SAINT are available which run on personal computers (MicroSAINT), Macintosh® computers, or the VAX family of computers (SAINT PLUS).

Table 5.4: Example of a SAINT histogram

```
*HISTOGRAM OF THE 1ST ITER. VALUES OF THE INT COM STAT FOR TASK    5 (STATIST)*

OBSV RELA CUML    UPPER
FREQ FREQ FREQ  CELL LIMIT 0         20        40        60        80        100
                           +    +    +    -    -    -    -    -    -    +    +
                                                                              +
  0  .00  .00  0.5000E+00 +                                                   +
 21  .08  .08  0.8000E+00 +****                                               +
 51  .19  .27  0.1100E+01 +**********  C                                      +
 34  .13  .39  0.1400E+01 +*******            C                               +
 25  .09  .49  0.1700E+01 +******                C                            +
 16  .06  .54  0.2000E+01 +***                      C                         -
 14  .05  .60  0.2300E+01 +***                         C                      +
 21  .08  .67  0.2600E+01 +****                            C                  +
 18  .07  .74  0.2900E+01 +***                                C               +
 14  .05  .79  0.3200E+01 +***                                   C            -
 10  .04  .83  0.3500E+01 +**                                     C           +
  9  .03  .86  0.3800E+01 +**                                       C         -
  3  .01  .87  0.4100E+01 +*                                         C        -
  4  .01  .89  0.4400E+01 +*                                         C        -
  8  .03  .92  0.4700E+01 +*                                           C      +
  4  .01  .93  0.5000E+01 +*                                            C     +
  3  .01  .94  0.5300E+01 +*                                            C     +
  2  .01  .95  0.5600E+01 +                                              C    -
  4  .01  .97  0.5900E+01 +*                                             C    +
  4  .01  .98  0.6200E+01 +*                                              C   +
  3  .01  .99  0.6500E+01 +*                                                  C
  0  .00  .99  0.6800E+01 +                                                   C
  0  .00  .99  0.7100E+01 +                                                   C
  0  .00  .99  0.7400E+01 +                                                   C
  0  .00  .99  0.7700E+01 +                                                   C
  0  .00  .99  0.8000E+01 +                                                   C
  2  .01 1.00     INF     +                                                   C
                                                                              -
-----                      +    +    +    -    -    -    -    +    -    -    -
 270                       0         20        40        60        80        100
```

Expressions used for the histogram:

OBSV FREQ – Observed frequency: the number of those observed values which fit into the particular cell
RELA FREQ – Relative frequency: the observed frequency divided by the total number of observations
CUML FREQ – Cumulated frequency: the sum of all relative frequencies from the first cell up to a particular cell
UPPER CELL LIMIT – The upper value of the individual histogram cells

Advantages

SAINT was developed specifically for simulating manned systems. Some users have found that its adoption forces the project team to carry out a thorough task analysis, thereby improving the level of application of human engineering and the understanding of human factors problems.

It can be used to identify critical features of system performance prior to hardware being available for man-in-the-loop testing. The results are readily accepted by other project personnel. By using user-written programme modules, the output can be made compatible with statistical packages such as GPSS, SYSTAT, or LOTUS 1-2-3.

Disadvantages

SAINT is not very easy to use. The programme "interface" requires knowledgeable users, and they find the documentation difficult to use. Some published versions of the code have included errors, which users have had to identify and correct.

The commercial versions such as MicroSAINT are easier to use, but are limited in their capability to run large networks, and their use of dynamic state variables. They do not have all the features of the full SAINT program. They do not include an interface to a programming language, but use a reduced set of FORTRAN, so they cannot represent complex logic.

Relative contribution

Some users rate the technique as making a relatively high contribution. One user expressed concern about the cost of learning and familiarization, compared with the results obtained.

Applications

SAINT and MicroSAINT have been used in a number of projects in the Canada, France, F.R.G., The Netherlands, U.K. and USA (see references). Applications have included destroyer combat systems, the study of pilot behaviour during an instrument approach to an airport, the comparison of different submarine control systems, remotely piloted vehicles (RPV) and surface-to-air (SAM) missile systems.

Quality assurance considerations

The technique lends itself to sensitivity analysis. This has been conducted on some projects, although no such activity has been reported in the literature.

Relationship to system performance requirements

The output of a SAINT simulation can usually be related directly to system performance requirements in terms of the distribution of times required for the completion of a series of tasks, or the probability of completion of those tasks.

References and Bibliography

1. Cherry, W.P., & Evans, S. (1989). Use of crew performance models and the development of complementary mathematical techniques to promote efficient use of analytic resources. In: G.R. McMillan, D. Beevis, E. Salas, M.H. Strub, R. Sutton, & L. van Breda (Eds.), Applications of human performance models to system design, (pp. 285-311). New York: Plenum Press. Defense Research Series, Volume 2.

2. Chubb, G.P. & Hoyland, C.M. (1989). Systematic modeling of multi-operator systems to evaluate design concepts. In: G..R. McMillan, D. Beevis, E. Salas, M.H. Strub, R. Sutton, & L. van Breda (Eds.). Applications of human performance models to system design, (pp. 295-311). New York: Plenum Press. Defense Research Series, Volume 2.
3. Chubb, G.P., Laughery, K.R. Jr., & Pritsker, A.A.B. (1987). Simulating manned systems. In: G. Salvendy (Ed.) Handbook of human factors. New York: John Wiley & Sons.
4. Kraiss, K.E. (1981) A display design and evaluation study using task network models. IEEE Transactions on Systems Science and Cybernetics 11 (5), 339-351.
5. Kraiss, K.E., Schubert, E., and Widdel, H. (1983). Untersuchungen zur manuellen Lenkung von U-booten. Wachtberg-Werthoven, F.R.G.: Forschungsinstitut für Anthropotechnik.
6. Mills, R. (1988). The user-assisted GENeric Systems Analyst Workstation (GENSAW): Summary. Presentation to NATO AC/243 Panel-8/RSG.9,Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory.
7. Pritsker, A.A.B. (1986). Introduction to simulation and SLAM II (Third edition). West Lafayette, Indiana: Systems Publishing Corp.
8. Siegel, A.I., and Wolf, J.J. (1961). A technique for evaluating man-machine system designs. Human Factors 3 (1), 18-25.
9. van Breda, L. (1989). Analysis of a procedure for multiple operator task performance on submarines using a network model. In: G.R. McMillan, D. Beevis, E. Salas, M.H. Strub, R. Sutton, & L. van Breda (Eds.), Applications of human performance models to system design, (pp. 231-242). New York: Plenum Press. Defense Research Series, Volume 2.
10. Wortman, D.B., Duket, D.D., & Leifert, D.J. (1976). SAINT simulation of a remotely piloted vehicle/drone control facility: Model development and analysis. Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory.

5.3 SIMULATION FOR WORKLOAD ASSESSMENT AND MODELLING (SIMWAM)

What the technique does

SIMWAM is a commercially available set of integrated, microcomputer-based, task network modelling programs, which permits an analyst to evaluate operator performance and workload distributions in complex human-machine systems (Kirkpatrick & Malone, 1984). It permits analysts to simulate a network of tasks, and evaluate and identify: 1. system manning level requirements; 2. training and cross-training requirements; 3. critical task sequences; 4. critical nodes; 5. reiterative task sequences; 6. task and task-sequence completion times; 7. redundant and/or unnecessary task sequences; 8. critical personnel and over-extended or underutilized personnel. SIMWAM provides all the software and instructions required to create, maintain, and analyse a database of operator-task sequences and the workloads of each operator in a multi-operator system. The technique can also assess the impact on workload distribution of varying the levels of automation in sub-systems, implementing cross-training across different operators, and varying the number of personnel.

Inputs to the technique

Task sequences, predecessor-successor relationships among tasks, details on operators, task priorities and task times (either minimum, mean, and maximum, or selection of a random sampling technique) are required as inputs.

Outputs of the technique

SIMWAM provides a transcript of mission time, task completion status, time spent per task by each operator, active and idle time per operator, and operator utilization.

When to use

SIMWAM applies to all phases of the development process, particularly to concept development and design definition. It can be used once details of the manning concept and of the tasks of specific operators are available.

Related techniques

Like SAINT, SIMWAM is based on the use of a Monte Carlo modelling approach to solving task loading issues and on the Workload Assessment Model (WAM) developed for the US Naval Air Development Center (Malone, Kirkpatrick & Kopp, 1986). It has been incorporated into the MANPRINT Integrated Decision/Engineering Aid (IDEA) developed for the U.S. Army (Heasly, Perse & Malone, 1988; Westerman et al., 1989).

Resources required

SIMWAM was developed for the US Navy and the US Army. The software must be obtained from the developer. It requires a Macintosh® microcomputer.

Advantages

The programs are easy to operate, due to the use of a Macintosh® interface, including menu-driven programs and prompts. SIMWAM provides the flexibility to configure task sequences and operator assignments, to model specific system operations, particularly those where operators can share duties. It can handle large networks of tasks. The tasks can be probabilistic or conditional on logic provided to system process variables.

Disadvantages

The programme is slow in executing large networks. It is limited to triangular distributions of task times. It may require the user to write sub-routines in BASIC, to be merged into the main programme.

Relative contribution

SIMWAM was the basis for reducing the manning level for an aircraft carrier aircraft management system from 36 to 32 operators, a reduction of 11%. In other applications it has been used effectively for evaluating alternative system concepts.

Applications

The programme was used in the evaluation of concepts for several shipboard systems, including the Advanced Combat Direction System for carrier-aircraft management, operator workload in shipboard combat direction systems, and a Damage Control Management System. It was also used for the evaluation of alternate system configurations on crew performance and workload in the US Army's Forward Air Defence System, the Advanced Field Artillery System (AFAS), and the Combat Mobility Vehicle.

Quality assurance considerations

The programme architecture facilitates the checking of task data input.

Relationship to system performance requirements

SIMWAM treats the crew as an integral component of the system and addresses system performance as a function of crew performance.

References and Bibliography

1. Heasly, C.C., Perse, R.M., & Malone T.B. (1988). MANPRINT in the programme initiation phase of system acquisition. Proceedings of the 32nd annual meeting of the Human Factors Society, Anaheim, CA.
2. Kirkpatrick, M. & Malone, T.B. (1984). Development of an interactive microprocessor-based workload evaluation model. Proceedings of the 28th annual meeting of the Human Factors Society. San Antonio, CA.
3. Malone, T.B., Kirkpatrick, M., & Kopp, W.H. (1986). Human factors engineering impact on system workload and manning levels. Proceedings of the 30th annual meeting of the Human Factors Society. Dayton, Ohio.
4. Westerman, D.R., Malone, T.B., Heasly, C.C., Kirkpatrick, M., Eike, D.R., Baker, C.C. & Perse, R.M. (1989). HFE/MANPRINT IDEA: Integrated decision engineering aid. Final report under contract DAAA15-88-C-0031.

5.4 SUBJECTIVE WORKLOAD RATINGS

What the technique does

Workload is a concept which expresses the task demands placed on an operator. Subjective workload ratings provide a measure of the operator's perception of workload, as it varies during the performance of a series of tasks. Subjective ratings are one of four principal approaches to measuring operator workload (the others being primary task measures, secondary task measures, and physiological measures (O'Donnell & Eggemeier, 1986; Hart & Wickens, 1990). The operators rate the workload of their task sequence, either as one overall workload level, or as a it fluctuates from task to task. Subjective workload ratings can be applied by experts at the design stage, prior to a system being built, to predict operator workload in the proposed system. Such projective workload applications can be useful to identify potential high or low workload situations, or to evaluate competing design concepts (Finegold & Lawless, 1989).

There are two approaches to subjective workload measurement: single scale (uni-dimensional) measurement, and multi-dimensional measurement. Uni-dimensional measures of workload treat the task loads as one parameter, which is judged by the operator. Typical approaches require the operator to make a single rating, such as 1 - 10, or to mark the length of a line quantified as 1 - 10 . Alternative approaches use a series of dichotomous questions to identify the rating scale category, which is usually a ten-point scale: the Cooper-Harper rating scale, used for aircraft handling rating is a well known example. A modified version of the Cooper-Harper scale has been developed and used in non-flying applications (Wierwille & Casali, 1983).

Multi-dimensional subjective workload measures treat workload as a function of several factors. The Subjective Workload Assessment Technique (SWAT - 5.5) uses three dimensions: time load, mental effort load, and psychological stress load (Reid & Nygren, 1988). The NASA Task Load Index (NASA-TLX - 5.6) uses six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration level (Hart & Staveland, 1988). Although these techniques were intended for use in the evaluation of workload in actual systems or in man-in-the-loop simulations they can be applied projectively (Eggleston & Quinn, 1984; Kuperman, 1985; Reid et al., 1984).

Inputs to the technique

Users need to be practised in using the workload rating techniques selected, and to have established any weightings for the scales, (needed for NASA-TLX and SWAT). A detailed mission description and task analyses are required, together with a description of the proposed human-machine interface. The users require a full understanding of the time-scale and sequence of events being rated.

Outputs of the technique

The scaled outputs from user ratings show workload as a function of operator tasks, and, by implication, mission events and phases.

When to use

Projective applications of subjective workload ratings are best applied during the concept development phase. They can be used from detailed mission descriptions or function analyses, but, to be effective, they require the detail provided by a task analysis. Their use will be dictated by the availability of task analyses and a description of the human-machine interface.

Related techniques

The rating scale techniques are related to each other.

Resources required

The raters must have experience of similar operations and equipment. Mission analyses, task analyses, and a description of the human-machine interface must be available to brief the raters. It is preferable, but not essential, to have a mockup of the operator workstation available.

Advantages

Projective applications of subjective workload ratings are useful for identifying potential workload problems early in the development cycle, before man-in-the-loop simulations or prototypes are available.

Disadvantages

Applications tend to be more reliable for comparing different design concepts than for identifying the absolute level of workload of a specific design. Reports of projective applications are convincing, but have not been validated thoroughly. Murrell (1969) has shown that the Cooper-Harper scale is not treated as a uni-dimensional, equal-interval scale and that the responses of different pilots cannot be compared.

Relative contribution

The application of subjective rating scales is effective for comparing different design solutions. It does not provide guidance for developing a specific solution. Hart & Wickens (1990) report work showing that a uni-dimensional rating scale is preferable for an overall review of the proposed mission and system, and that multi-dimensional scales are preferable for diagnosis of high or low workload situations. Work by Hendy, Hamilton & Landry (1992) supports this. A uni-dimensional scale proved more sensitive to changes in workload than did multi-dimensional approaches. From the viewpoint of diagnosticity, the NASA-TLX is preferable to SWAT, because it describes more dimensions.

Applications

A uni-dimensional workload scale was used for the development of the crew compartment of a maritime patrol aircraft. SWAT has been used projectively on several aircraft development projects, to compare different human-machine interface concepts.

Quality assurance considerations

Non-parametric statistics must be used when combining or comparing the ratings. Inter-rater variance is a function of familiarity with the proposed operations and system design, the rating scale, and operator experience.

Relationship to system performance requirements

The workload ratings imply system performance: they do not predict it directly (see Hart & Wickens, 1990).

References and Bibliography

1. Eggleston, R.G. & Quinn, T.J.(1984). A preliminary evaluation of a projective workload assessment procedure. Proceedings of the Human Factors Society 28th Annual Meeting, (pp. 695-699). Santa Monica, CA: Human Factors Society.
2. Finegold, L.S., & Lawless, M.T. (1989). Human factors design guidance during the conceptual design phase of system development: a methodological approach. Report AFHRL-TR-89-66. Brooks, Texas: Air Force Human Resources Laboratory, AD-a224-667.
3. Hart, S.G., & Wickens, C.D (1990). Workload assessment and prediction. In: H.R. Boohrer (Ed.), MANPRINT: An approach to systems integration. New York: Van Nostrand Reinhold.
4. Hart, S.G., Staveland, L.E. (1988) Development of NASA -TLX. In: P.A. Hancock & N. Meshkati (Eds.), Human mental workload, (pp. 139-178). North-Holland: Elsevier Science Publishers B.V. Chapter 7.
5. Hendy, K.C.H. , Hamilton, K.M., & Landry, L.N. (1992). Measuring subjective workload: when is one scale better than many? Manuscript submitted for publication.
6. Kuperman, G.G. (1985). Pro-SWAT applied to advanced helicopter crewstation concepts. Proceedings of the Human Factors Society 29th Annual Meeting. Santa Monica, CA: Human Factors Society.
7. Murrell, J.F.(1969). Multidimensional scaling of an aircraft handling rating scale. Ergonomics 12 (6) 925-933
8. O'Donnell, R.D., & Eggemeier, F.T. (1986). Workload assessment methodology. In: K.R. Boff, L.Kaufman, & J.P. Thomas (Eds.), Handbook of perception and human performance. Vol. II, Chapter 42. New York: Wiley Interscience.
9. Reid, G.B., & Nygren, T.E. (1988). The subjective workload assessment technique: a scaling procedure for measuring mental workload. In: P.A. Hancock & N. Meshkati, (Eds.), Human mental workload, (pp. 185-214). North-Holland: Elsevier Science Publishers B.V. Chapter 8.
10. Reid, G.B., Shingledecker, C.A., Hockenberger, R.L. & Quinn, T.J. (1984). A projective application of the subjective workload assessment technique. Proceedings of the IEEE 1984 National Aerospace and Electronics Conference.
11. Wierwille, W.W., & Casali, J.G. (1983). A validated rating scale for global mental workload applications. Proceedings of the Human Factors Society 27th Annual Meeting. Santa Monica, CA: Human Factors Society.

5.5 SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)

What the technique does

Provides a measure of subjective workload. Workload is defined as composed of three orthogonal dimensions: time load, mental effort load, and psychological stress load. Each dimension is represented in SWAT by a three-point rating scale with verbal descriptors. In the first phase, the scale is developed for the application and user population of interest. Individual assessments are scaled, and conjoint analysis (Reid & Nygren, 1988) is carried out on the results, to convert them into a single metric of workload. If the data have a limited number of ordinal-scale features, then the conjoint scaling can develop an interval scale from the data.

In the application phase, the basic SWAT scales are used, and the results converted to a single workload scale using the results of the conjoint scaling. Although the technique was intended for use in the evaluation of workload in actual systems, or in man-in-the-loop simulations, it can be applied by experts at the drawing-board level, to predict operator workload prior to a system being built (Kuperman, 1985). In such applications it is referred to as Pro-SWAT (Projective SWAT).

Table 5.5: SWAT dimensions

TIME LOAD

1. Often have spare time: interruptions or overlap among activities occur infrequently, if at all.
2. Occasionally have spare time: interruptions or overlap among activities occur frequently.
3. Almost never have spare time: interruptions or overlap among activities are very frequent, or occur all the time.

MENTAL EFFORT LOAD

1. Very little conscious mental effort or concentration required: activity is almost automatic, requiring little or no attention.
2. Moderate conscious mental effort of concentration required: complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity; considerable attention required.
3. Extensive mental effort and concentration are necessary: very complex activity requiring total attention.

PSYCHOLOGICAL STRESS LOAD

1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.
2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload: significant compensation is required to maintain adequate performance.
3. High to very intense stress due to confusion, frustration, or anxiety: high to extreme determination and self-control required.

Inputs to the technique

Users need to be practised in using the technique, and to have ranked all combinations of the time-load, mental-load, and stress (27 combinations). Once the rank-order of the 27 combinations has been determined by the individual, the technique can be applied. For Pro-SWAT applications, the user requires a full understanding of the time-scale and sequence of events, and familiarity with the proposed human-machine interface.

Outputs of the technique

The scaled outputs from user ratings show workload on an interval scale of "workload units," between 1 and 100.

When to use

Pro-SWAT can be applied in the concept development or design definition phase, once details of the human-machine interface are available. Man-in-the-loop applications of SWAT require a simulation, and are best suited to the latter stages of design definition, or to Test and Evaluation (Acton & Rokicki, 1986).

Related techniques

SWAT belongs to the family of subjective workload assessment methods, but is distinct in the use of three dimensions and conjoint measurement.

Resources required

The technique requires a set of 27 cards, for each combination of ratings, and the SWAT software.

Advantages

SWAT is straightforward to use, and can easily be applied to many tasks.

Disadvantages

The technique requires a significant administrative commitment, to develop the scales for the potential raters, compare scales across raters, train raters in the application of the technique, and perform the scaling. The output scale of "workload units" does not include criteria for acceptability or for rejection. Therefore, the technique is best used to compare competing designs rather than developing one preferred design. In practice, the use of SWAT for man-in-the-loop applications is sometimes invasive.

Reports of Pro-SWAT applications are convincing, but the technique has not been validated thoroughly in such applications. The technique cannot be applied until details of the human-machine interface are available.

Relative contribution

Users report it as a low cost (or effort) alternative to other approaches such as workload prediction using the time-budget approach. They report "fair" confidence in the results.

Applications

SWAT has been used projectively on several aircraft development projects, to compare different human-machine interface concepts (Eggleston & Quinn, 1984; Reid, Shingledecker, Hockenberger & Quinn, 1984). It has been used in a number of simulator trials (see Schuffel, 1990, for example) and in field trials and test and evaluation (see Acton & Rokicki, 1986, for example) in the USA and France.

Quality assurance considerations

The conjoint scaling technique permits checking for consistency in ratings across raters. Applicants must be careful to develop the conjoint scale for each rater, and each potential application. If several raters are involved, comparisons across raters should be made to check whether one scale, or individual scales should be used. Acton & Rokicki (1986) recommend emphasis on training the operators to use the technique and on briefing them on exactly which tasks are to be evaluated and on the contexts of the tasks.

Relationship to system performance requirements

As with other workload measurement techniques, there is no direct link between the workload ratings and system performance. Users must infer that system performance will be less than preferred if the workload ratings are "excessive" when compared with other design solutions.

References and Bibliography

1. Acton, W.H., & Rokicki, S.M. (1986). Survey of SWAT use in operational test and evaluation. Proceedings of the Human Factors Society 30th Annual Meeting, Dayton, Ohio.
2. Eggleston, R.G. (1984). A comparison of projected and measured workload ratings using the subjective workload assessment technique (SWAT). Proceedings of the IEEE 1984 National Aerospace and Electronics Conference (NAECON).
4. Eggleston, R.G., & Quinn, T.J. (1984). A preliminary evaluation of a projective workload assessment procedure. Proceedings of the Human Factors Society 28th Annual Meeting.
3. Kuperman, G.G. (1985). Pro-SWAT applied to advanced helicopter crewstation concepts. Proceedings of the Human Factors Society 29th Annual Meeting.
4. O' Donnell, R.D., & Eggemeier, F.T. (1988). Workload assessment methodology. In: K.R. Boff, L.Kaufman, J.P. Thomas (Eds.), Handbook of perception and human performance. Vol. II. New York, Wiley Interscience. Chapter 42.
5. Reid, G.B., Shingledecker, C.A., Hockenberger, R.L. & Quinn, T.J. (1984). A projective application of the subjective workload assessment technique. Proceedings of the IEEE 1984 National Aerospace and Electronics Conference.
6. Reid, G.B., & Nygren, T.E. (1988). The subjective workload assessment technique: A scaling procedure for measuring mental workload. In: P.A. Hancock & N. Meshkati (Eds.), Human mental workload. North-Holland: Elsevier Science Publishers B.V.
7. Schuffel, H. (1990). Can one bridgemaster control two bridges? Report C-24. Soesterberg, The Netherlands: TNO-Institute for Perception.

5.6 NASA TASK LOAD INDEX (TLX)

What the technique does

The TLX is a multi-dimensional subjective rating procedure that provides an overall workload score based on the sum of the weighted values of six sub-scales: mental demands, physical demands, temporal demands, own performance, effort, and frustration. The first three subscales relate to the demands imposed on the subject by the task, and the second three relate to the interaction of the subject with the task.

Each subscale ranges from 0 to 100 and can be scored in steps of 5 points. Typically, the ratings are made by marking a line. The degree to which each of the six factors contributes to the workload of a particular task is expressed by the weighting applied to each subscale. Those weightings are derived from the subjects' pair-wise comparisons of the six subscales. The weights can range from 0 (all other subscales are more important) to 5 (no other subscale is more important).

Table 5.6: TLX workload subscales

SCALE	ENDPOINTS	DESCRIPTION
mental demand	low/high	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
physical demand	low/high	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
temporal demand	low/high	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
performance	perfect/failure	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
effort	low/high	How hard did you have to work (mentally and physically) to accomplish your level of performance?
frustration level	low/high	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Inputs to the technique

Users need practice in using the technique, as well as a good understanding of the mission, function and tasks to be performed.

Outputs of the technique

Scores of workload on the six subscales and an overall score of workload based on the sum of the weighted subscales.

When to use

TLX can be used projectively during concept development and detailed design, once sufficiently detailed task analyses are available. It can be used conventionally to evaluate workload using rapid prototypes or man-in-the loop simulation, and it can be used to determine the workload associated with existing systems, as a basis for upgrading.

Related techniques

TLX belongs to the family of subjective workload rating techniques.

Resources required

The raters must be thoroughly familiar with the missions and tasks being rated, as well as with the rating technique. Time must be available to complete the paired comparison of subscales, as well as the task ratings. The rating of actual tasks is facilitated by having videos of the tasks available. The technique can be applied using paper and pencil: a personal-computer based software tool is available.

Advantages

The NASA TLX is easy to use and the descriptions of the subscales are clear. The TLX is more sensitive than many other subjective methods such as SWAT (5.5) and the Cooper-Harper scale (Byers et al., 1988) and the ratings have been shown to correlate with system performance (Hill et al., 1988). The use of six subscales and a weighting procedure results in less inter-rater variability than other techniques.

Disadvantages

The use of six subscales and the weighting procedure requires more time to administer than simple uni-dimensional techniques.
The technique is more suitable for comparisons between different design solutions than for the development of one preferred design.

Relative contribution

No data available.

Applications

The TLX has been used successfully in many experiments in which mental workload was compared in several conditions (e.g. Bortolussi, et al., 1986; Parks & Boucek, 1989; Shively et al., 1987). It has been used to derive operator workload assessments from video tapes of tactical helicopter operations, a mobile air defence system (Hill et al., 1988) and a remotely piloted vehicle (Byers et al., 1988).

Quality assurance considerations

Checking for correct completion of the rating scales is difficult. Comparison between subjects may indicates some discrepancies. Use of other measurement techniques can identify inconsistencies.

Relationship to system performance requirements

There is no direct relationship between workload ratings and performance (see, for example Hart & Wickens, 1990). When a task sequence becomes more difficult, performance depends on the amount of effort invested in the task. So it is possible that performance does not change as the subjective workload increases, or that performance can decrease although the TLX ratings do not change significantly.

References and Bibliography

1. Bortolussi, M.R., Kantowitz, B.H., & Hart, S.G. (1986). Measuring pilot workload in a motion base trainer. Applied Ergonomics 17 (4), 278-283.
2. Byers, J.C., Bittner, A.C., Hill, S.G., Zaklad, A.L., & Christ, R.E. (1988). Workload assessment of a remotely piloted vehicle (RPV) system. Proceedings of the Human Factors Society 32nd Annual Meeting, (pp. 1154-1149).
3. Hart, S.G., & Staveland, L.E. (1988). Development of NASA-TLX (TAsk Load Index): results of empirical and theoretical research. In: P.A. Hancock and N. Meshkati (Eds.), Human mental workload (pp. 139-184). North Holland: Elsevier Science Publishers B.V.
4. Hart, S.G., & Wickens, C.D (1990). Workload assessment and prediction. In: H.R. Boohrer (Ed.), MANPRINT: An approach to systems integration. New York: Van Nostrand Reinhold.
5. Hill, S.G., Zaklad, A.L., Bittner, A.C. Jr., Byers, J.C. & Christ, R.E. (1988). Workload assessment of a mobile air defense system. Proceedings of the Human Factors Society 32nd Annual Meeting, (pp. 1068-1072).
6. Parks, D.L. & Boucek, G.P. (1989). Workload prediction, diagnosis, and continuing challenges. In: G.R. McMillan, D. Beevis, E. Salas, M.H. Strub, R. Sutton & L. van Breda (Eds.), Applications of human performance models to system design, (pp. 47-64). New York: Plenum Press.
7. Shively, R.J., Battiste, V., Hamerman-Matsumoto, J., Pepitone, D.D., Bortolussi, M.R. & Hart, S.G. (1987). Inflight evaluation of pilot workload measures for rotorcraft research. Proceedings of the fourth international symposium on aviation psychology, (pp. 637-643). Columbus Ohio.

5.7 ERROR ANALYSIS

What the technique does

Error analysis techniques are used to identify the most likely sources of operator error in a system, with a view to their prevention through modification of the design, the operational procedures, or by training. The general approach to mission, function, and task analysis, outlined in previous sections of this chapter, provides a good basis for error analysis. Hammer (1972) discusses the use of mission and task analysis as the basis for hazard analysis and system safety. Fadier (1990) reviews a number of analytical techniques, including function block diagrams, flow graphs, and SADT™ as bases for error analysis. He notes that a number of approaches are based in value analysis. The technique RELIASEP, developed in France, is a typical example (Fadier, 1990).

More specific techniques, such as Failure Modes Effects Analysis, are available for the detailed study of system operator error. Technique for Human Error Prediction (THERP) is an approach to error analysis which has been developed and used over a twenty year period (Miller & Swain, 1987). The sequence of analyses used for THERP starts with the a detailed task analysis, including analysis of performance requirements, followed by qualitative performance assessment to determine potential human errors, leading to a quantitative assessment of error probabilities using fault tree analyses, calculation of the probabilities of recovering from errors, and a calculation of the contribution of human error probability to system failure. THERP has been described in detail in the review of human performance models reported by AC/243 Panel-8/RSG.9 (McMillan et al., 1991). The technique is very labour intensive, and will not be discussed further here.

In less rigorous approaches than THERP, errors may be identified based on an analysis of operator tasks, and reference to an error classification. Hammer (1972) provides a list of 34 "causes of primary errors" – both human factors (lack of attention) and human engineering (interference with normal habit patterns) – together with recommended design solutions. Norman (1983) reports an analysis of one class of operator error and uses it to produce recommendations for the design of computer systems. Rouse (1990) provides a classification scheme for 31 types of error in operating systems. Reason (1987) proposes a Generic Error Modelling System (GEMS) which integrates approaches such as Norman's and Rouse's based on Rasmussen's (1983) categories of skill, rule, and knowledge based behaviour. To be applied, these classifications of operator error must be related to the proposed operator tasks. Stoop (1990) reports the use of normative task analysis and GEMS to identify potential errors in the operation of a ship's bridge. In this approach, the task analysis is elaborated to the required level of detail.and the generic error modelling system is then applied.

The limitations of the classifications mentioned above are that they provide no information on the relative probabilities of operator error. Such approaches should involve the development of data bases of likely operator errors. With the exception of AIR Data Store (Munger, Smith, & Payne, 1962), few such data bases exist (see Meister, 1985; Miller, 1987). Hale et al. (1987, 1989) report the development of a computer-based software tool for the collection and analysis of data on accidents and near misses. Their Intelligent Safety Assistant (ISA) is intended to facilitate the interactive collection of such data. More recently the US Coast Guard and the US Air Force have implemented extensive accident reporting and analysis systems, aimed at identifying human engineering factors in accidents.

Inputs to the technique

Detailed (normative) task analyses.
Expert judgment on the possible sources of error and/or deviations from the normative task sequences.
Data on likelihood of operator error, compiled from accident and incident data.

Outputs of the technique

Error classifications such as GEMS produce categories of operator errors, or accident causes based on the characterisucs of their tasks. Error frequency data are collected by approaches such as ISA. Those data can be expressed as possible factors in cognition and decision making, as well as the operation of equipment and adherence to procedures.

When to use

Error data bases such as ISA require a long-term commitment to development: they cannot be developed for a specific weapon system project. Error analyses should be used in the concept formulation and concept validation phases, to avoid design features which are error-prone. They also apply to the interface and workspace design phase, and during the development of operator and maintainer procedures. They require the completion of a detailed task analysis.

Related techniques

Error analysis is related to normative task analysis, and hazards analysis (Woodson, 1981). Errors are sometimes considered as part of a critical task analysis (4.6), under the heading "tolerance of actions." The use of estimates of operator error is based on engineering techniques for failure mode analysis, and to some operational research techniques.

Resources required

Error data bases require access to detailed, consistent and complete information on accidents and incidents.
Error analyses require access to expert operators, and to task analyses and error data bases.

Advantages

ISA is claimed to contribute to consistency in reporting accidents and incidents, and to the development of causal hypotheses. The developers of ISA claim that the "intelligent" structuring of the analysis process contributes to consistency and completeness in the accumulation of data.
Error analyses such as GEMS permit the proactive identification of features which could lead to "design induced error." Error analyses such as GEMS also provide good understanding of the difference between the "normative" behaviour described in typical task analyses and that likely to occur in practice.

Disadvantages

The development of accident/incident/error data-bases requires a long-term commitment which is generally incompatible with any specific systems acquisition project. The work requires rigour and consistency in approach to data collection and to the analysis and recording of the data. Reliable data require a large number of observations, which are difficult to obtain.
Error analyses such as GEMS can identify design features likely to incur operator error, but not the frequency of error. GEMS users report difficulty in determining the appropriate level at which to stop the task analyses, and the lack of a systematic weighting of the contribution of each error factor to accidents in practice.

Relative contribution

No comments have been volunteered by users.

Applications

Error analysis was conducted in 10 of 33 projects surveyed by the RSG, including howitzers, ship's operations rooms and ship sensors, and an RPV.
ISA has been used on accidents in harbours in The Netherlands, on incidents in chemical plants, and on critical incidents in a hospital (Hale et al., 1987; 1989).
GEMS was used in The Netherlands for the redesign of the bridge deck of a fishing vessel for beam trawling (Stoop, 1990).

Quality assurance considerations

Error analysis can be reviewed by experts in current operations, to identify any conclusions which appear to deviate from their understanding.

Relationship to system performance requirements

Error analysis can identify conditions or actions which might occur which would deviate from the required system performance.

References and Bibliography

1. Fadier, E. (1990). Fiabilite humaine: methodes d'analyse et domaines d'application. In: J. Leplat, G. de Terssac, J.M. Cellier, M Neboit, & A. Oudiz (Eds.), Les facteurs humains de la fiabilite dans les systemes complexes. Marseille: Editions Octares Entreprises.
2. Hale, A.R., Otto, E., Vroege, D. & Burdoff, A. (1987). Accidents in ports: report of a pilot study to set up an accident registration system in the port of Rotterdam. Delft: University of Technology, Safety Science Group.
3. Hale, A.R., Karczewski, F., Koornneef, F., Otto, E., & Birdoff, L. (1989). An intelligent, end-user interface for the collection and processing of accident data. Proceedings of the 6th Eurodata Conference. Siena: Springer-Verlag.
4. Hammer, W. (1972). Handbook of system and product safety. Englewood Cliffs, NJ: Prentice-Hall Inc.
5. McMillan, G.R., Beevis, D., Salas, E., Stein, W., Strub, M.H., Sutton, R., & van Breda, L. (1991). A directory of human performance models for system design. Report AC/243 (Panel-8) TR-1. Brussels: NATO Defence Research Group.
6. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
7. Miller, D.P., & Swain, A.D. (1987). Human Error and human reliability. In: G. Salvendy (Ed.), Handbook of human factors. Chapter 2.8, (pp. 219-250). New York: John Wiley and Sons.
8. Munger, S.J., Smith, R.W., & Payne, D. (1962). An index of electronic equipment operability: Data Store. Report AIR-C43-1/62-RP(1). Pittsburg, PA: American Institute for Research.
9. Norman, D.A. (1983). Design rules based on analyses of human error. In: Communications of the ACM, 26 (4), 254-258.
10. Rasmussen, J. (1983). Skills, rules, knowledge; signals, signs and symbols; and other distinctions in human performance models. IEEE Transactions on Systems, Man and Cybernetics, SMC-13 (3).

11. Rasmussen, J., Duncan, K., & Leplat, J. (1987). New technology and human error. Chichester: John Wiley & Sons. New Technology and Work Series.
12. Reason, J. (1987). Generic error-modelling system (GEMS): a cognitive framework for locating common human error forms. In J. Rasmussen, K.Duncan, & J. Leplat (Eds.), New technology and human error. Chichester: John Wiley & Sons. New Technology and Work Series.
13. Reason, J. (1990). Human error. Cambridge University Press.
14. Rouse, W.B. (1990). Designing for human error: Concepts for error tolerant systems. In H.R. Booher (Ed.), MANPRINT: An approach to systems integration. New York: Van Nostrand Reinhold.
15. Stoop, J. (1990). Redesign of bridge layout and equipment for fishing vessels. The Journal of Navigation 43 (2).
16. Woodson, W.E. (1981). Human factors design handbook, (pp. 985-991). New York: McGraw-Hill Book Co.

5.8 ANALYSIS OF HUMAN ERRORS AS CAUSAL FACTORS IN ACCIDENTS

What the technique does

The analysis of how an accident happened can be represented by a network. Events leading to an accident are connected by logical AND/OR gates, revealing the causal factors. In the case of AND-gates, the related deviations from normative performance all need to be present for the occurrence of the accident. In the case of OR-gates, there is only one factor deviating from the normative approach needed. The transmission from the accident description to the schematized network of AND/OR gates is dependent on the interpretation of the described data. The approach is primarily relevant if a number of accidents, for instance more than 100, are reported. The analysis of factors, after the process of indicating the chain of events leading to an accident, will show factors to remedy accidents by improvement of hardware and software design, operational procedures, and selection and training procedures.

Inputs to the technique

Descriptions of a number of accidents (at least 100) suitable for interpretation to provide data to generate a causal network.

Outputs of the technique

The approach produces a set of causal factors.

When to use

Because of the need to develop the data base over a long period, the technique should not be restricted to application within any one project development cycle. The technique should be used early in the design phases of a specific system to identify possible human factors leading to accidents.

Related techniques

Fault tree analysis techniques.

Resources required

The technique can be used with only a paper and pencil. It requires access to a collection of consistently reported accident and incident data. Analysts may develop their own networks of causal factors, or use an established taxonomy of human errors (e.g., Feggetter, 1982; Rasmussen, 1982).

Advantages

The technique provides a set of causal factors suitable for remedying design-induced error.

Disadvantages

The interpretation of accidents is subjective. The descriptions of the accidents may suffer from insufficiencies in data collection and recording. The use of an established causal network may influence the collection and reporting of data. Retrospective reviews of accident reports do not incorporate the knowledge of the persons involved.

Relative contribution

No data available.

Applications

As a result of an analysis by causal networks of 100 shipping accidents, Wagenaar & Groeneweg (1987) identified several major types of human error. With the same approach, Schuffel (1987) showed that 68% of causal factors of shipping accidents could be reduced by improved bridge design.

Quality assurance considerations

The analysis is dependent on the data collection and their interpretation. In general, a group of experts from the various disciplines is necessary to reach reliable interpretations of the data.

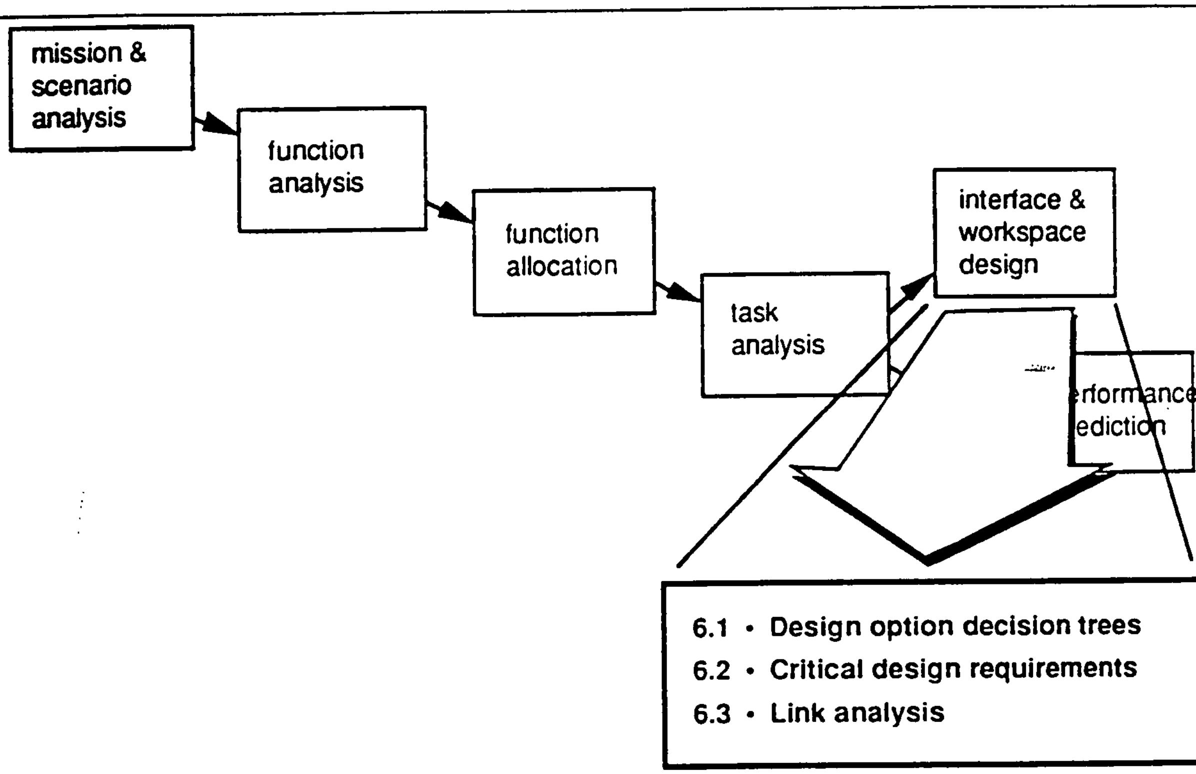
Relationship to system performance requirements

The technique indicates dangerous coincidences of critical factors, or operator error types that could prejudice system performance.

References and Bibliography

1. Feggetter, A.J. (1982). A method for investigating human factors aspects of aircraft accidents and incidents. Ergonomics 27, 1065-1075.
2. Rasmussen, J. (1982) A taxonomy for describing human malfunction in industrial installations. Journal of Occupational Accidents 4, 311-333.
3. Schuffel, H. (1987). The automated ship's bridge: human error resistant? Soesterberg, The Netherlands: TNO Institute for Perception.
4. Wagenaar, W.A., Groeneweg, J. (1987). Accidents at sea: Multiple causes and impossible consequences. International Journal of Man-Machine Studies 27, 587-598.

6 INTERFACE AND WORKSPACE DESIGN



What the techniques do

The aim of human engineering is to apply knowledge of human capabilities and limitations to the design of equipment and systems which people use, to ensure effectiveness, safety, and comfort. Thus, the final goal of the human engineering analyses reviewed in the previous sections is to identify design requirements, and to facilitate the application of human factors knowledge to the design of systems and equipment. Few publications have provided information on the process of translating the specification for operator tasks defined through mission, function, and task analysis into a specification for the design of human-machine interfaces, workspaces, workplace, and/or the environment (Engel & Townsend, 1989, provide some guidance). Three techniques have been reported, and are reviewed here. (Note that there are many techniques and tools available for evaluating the operator workspace, based on anthropometric models: some of those models have been reviewed by NATO AC/243 Panel-8/RSG.9 (McMillan et al., 1989; 1991)).

The lack of design techniques need not impede the application of human engineering in the design process, because the role of the human engineering specialist is not necessarily to design. Because the design process is creative, it is ill-defined and varies from project to project or design team to design team. As Bishop & Guinness (1966) suggest, a fruitful symbiosis can be established between human factors (or human engineering) specialists and designers. Using many of the techniques reviewed in this document, human engineering specialists can provide a systematic definition of a problem as well as ways to quantitatively evaluate competing design solutions, while the designer produces creative solutions to particular problems.

Types of analysis available

Design Option Decision Trees (6.1) are a means of systematically reviewing design options in the context of predicted operator tasks and human factors design requirements. Task analyses, especially Information/Action or Action/Information analyses (4.4) identify features of the human-machine interface by analysing operator tasks which require information or action, thereby identifying requirements for displays and controls. The analysis of Critical Design Requirements (6.2) extends this approach into a formal procedure which concentrates on operator tasks which are critical to system performance. Task analyses also document the sequence of operator actions, thereby providing information which can be used in Link analyses (6.3) to evaluate the links between successive operator actions, either hand and eye movements, body movements, or communication with other operators. Once operator tasks have been identified, the information can be used to evaluate possible design options.

Table 6.1: Applicability of interface and workspace design techniques to different projects

Technique	Simple systems (e.g.rifle, hand-held radio)	Medium complexity system (e.g., 1-man radar console)	High complexity system (e.g 1-place attack aircraft)	Complex multi-man system (e.g., ship combat centre)
6.1 Design option decision trees	low	low	medium	medium
6.2 Critical design requirements	medium	medium	high	high
6.3 Link analysis	not relevant	medium	high	high

References and Bibliography

1. Bishop, E.W., & Guinness, G.V. Jnr. (1966). Human factors interaction with industrial design. Human Factors, 8 (4) 279-289.
2. Engel, R., & Townsend, M. (1989). Guidelines for the design and evaluation of operator interfaces for computer based control systems. DCIEM Contract Report. Toronto: Engel & Townsend.
3. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
4. McMillan, G.R., Beevis, D., Salas, E., Strub, M.H., Sutton, R. & van Breda, L. (Eds). (1989). Applications of human performance models to system design. New York: Plenum. Defense Research Series Vol. 2.
5. McMillan, G.R., Beevis, D., Salas, E., Stein, W., Strub, M.H., Sutton, R., & van Breda, L. A directory of human performance models for system design. (1991). Report AC/243 (Panel-8) TR-1. Brussels: NATO Defence Research Group.
6. Woodson, W.E. (1981). Human factors design handbook, (pp. 961-964). New York: McGraw-Hill Book Co.

6.1 DESIGN OPTION DECISION TREES

What the technique does

Design option decision trees (DODT) are a means of formally reviewing design options for the human factors implications of design choices (Meister, 1985). The original DODT approach was developed by Askren & Korkan (1971) to locate points in the design process for the input of human factors data. Independent work in Canada led to a similar approach to the documentation of human factors design data for specific systems (Beevis, 1981).

Inputs to the technique

The technique requires a comprehensive understanding of the human factors issues and costs associated with the class of system being developed, together with information on possible technological choices This requires the equivalent of a "state-of-the-art" review of human factors issues for the particular class of system.

Outputs of the technique

The analysis produces a tree of design decisions which have significant human factors costs, and detailed descriptions of the human engineering issues associated with each decision.

When to use

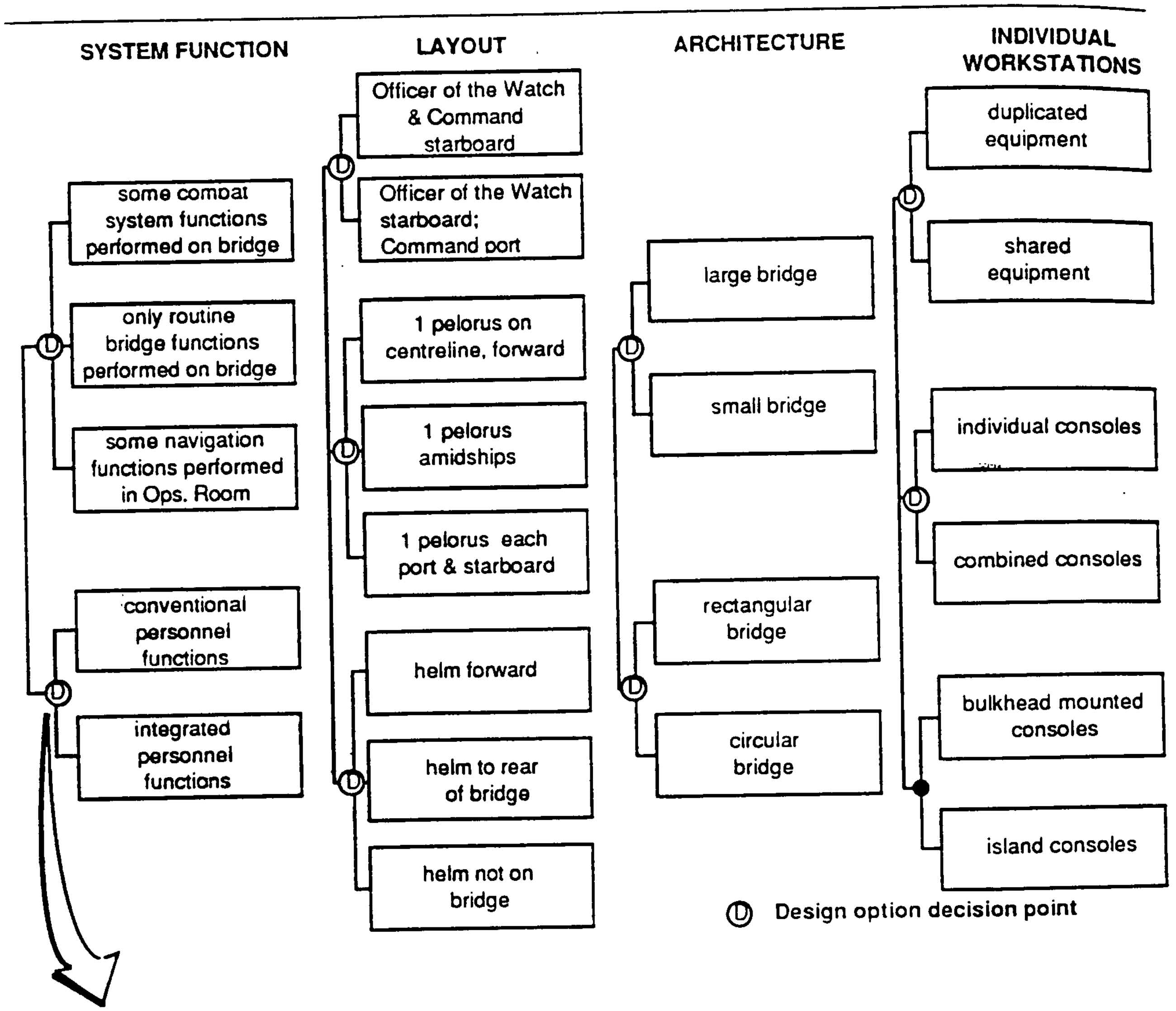
The technique should be used in the system concept development phase, when different concepts are being explored. The need for information on human factors issues requires that existing systems be analysed and compared.

Related techniques

The approach is related to that of *design approach tradeoff studies* (Woodson, 1981). Some aspects of tradeoff studies are addressed in an allocation of functions analysis (3.3).

Resources required

Design option decision trees can be completed by hand. The major resource required is information on the technological choices and human factors issues.



Tradeoffs for design option: Integrated vs conventional personnel functions

	Conventional personnel functions	Integrated personnel functions
Advantages	• maintains current career streams • exploits current training plan	• smaller complement reduces costs • develops more skilled personnel • smaller complement reduces delays, errors, misunderstandings in procedures • permits small bridge with good visibility
Disadvantages	• current manning levels are expensive • increasing manning problems expected • large complement incurs delays & errors in execution of bridge procedures • bridge must be large, reducing visibility of OOW	• increased capital & training costs likely • performance not easily predicted • requires higher standard of design than conventional bridge • changes career streams & training plan requirements

Figure 6.1: Example of design option decision tree and tradeoff table for a ship's bridge (after Beevis, 1981)

Advantages

Design option decision trees use a graphic presentation to make clear the design choices which involve significant human factors issues, such as manning levels, skill requirements, or operator performance factors.

Disadvantages

The technique is labour intensive, and requires a considerable amount of experience in human engineering of a particular class of system. The available human performance data do not facilitate a clear choice between many competing design concepts. The use of expert ratings to distinguish between design concepts (Meister, 1985) is subject to bias based on experience with a particular technological approach. The assumption that designers work through a formal tree of design choices is not supported by practical observation.

Relative contribution

No data available.

Applications

The technique was used in the analysis of automobile design choices, and for jet engine design (Askren & Korkan, 1971), and for the preparation of a ship bridge design guide (Beevis, 1981). Application of the latter information has been very limited. The technique was also used to evaluate candidate designs for an infantry used air target warning system.

Quality assurance considerations

The technique cannot be checked for consistency with other human engineering analyses. It requires careful scrutiny of relevant human factors information.

Relationship to system performance requirements

Each junction in the decision tree has human performance data associated with it. No technique has been used for summarizing the effects on system performance of the overall sequence of design choices, although some mathematical techniques, such as optimization, may be appropriate to the problem.

References and Bibliography

1. Askren, W.B., & Korkan, K.D. (1971). Design option decision trees: a method for relating human resources data to design alternatives. AFHRL-TR-71-52. Ohio: Air Force Human Resources Laboratory, Wright-Patterson AFB.
2. Beevis, D. (1981). Bridge design – a human engineering approach in Canada. Proceedings, Sixth Ship Control System Symposium, Vol 2, (pp. E1/2-1 - E1/2-6). Ottawa, Canada: National Defence Headquarters.
3. Meister, D. (1985). Behavioral analysis and measurement methods. New York: Wiley Interscience.
4. Woodson, W.E. (1981). Human factors design handbook, (pp. 961-964). New York: McGraw-Hill Book Co.

6.2 CRITICAL DESIGN REQUIREMENTS

What the technique does

The technique identifies design requirements which are critical to the operation of the system, to provide a basis for interface and workspace design. The technique identifies the following information (Morgan, Cook, Chapanis & Lund, 1963):

- the functions performed by the system
- the operator tasks
- the outputs of each task
- the critical operating variables for each task
- the critical design requirements that affect these variables

The critical operating variables, or the design requirements identified by the analysis, may be weighted to facilitate evaluation of competing design concepts (Bishop & Guinness, 1966; Woodson, 1981).

Inputs to the technique

The analyst requires a task analysis for the system operator(s) which identifies the critical operator tasks. An annotated Operational Sequence Diagram (4.3), Information/Action analysis (4.4), or Critical Task Analysis (4.5) are suitable inputs.

Outputs of the technique

A list of critical design requirements for the human-machine interface, workspace, and operating environment, ordered by operator functions and tasks.

When to use

Critical design requirements can only be identified once a detailed task analysis is available, either from the sequence of analyses described in previous sections, or from the elaboration of an existing analysis. This limits the technique to application in the latter stages of concept development or preliminary design.

Related techniques

The analysis of critical design requirements is related closely to several task analysis techniques. It is also related to Design approach trade-off analyses (Woodson, 1981).

Resources required

The analyst requires information on the operator tasks, critical tasks and operator outputs, and potential choices for components of the human-machine interface. The analyst also requires knowledge of human engineering principles and data, in order to be able to identify the critical requirements.

Table 6.2: Example of critical design requirements analysis for an air-intercept control system

Function	Task	Output	Critical operating variables	Critical design requirements
Detection and position reporting (Operator)	• monitor scope, • detect new targets, • acquire target, • re-acquire target, • initiate tracking	• target track data (position, course, speed)	• track density (number and frequency), • probable distribution of detection ranges; • probability of detecting targets, • track initiation rate, • errors in cursor positioning	• design & location of displays, • lighting, • number of operators, • cursor control design
Threat evaluation and weapon assignment (Evaluator)	• observe tracks, • decide which interceptors should be used, • communicate assignments to air controller	• assignment commands, • acquisition data	• threat evaluation effectiveness, • evaluation and assignment rate	• design and location of displays, • number of evaluators & target density, • means of communicating with air controller,
Air intercept control (Controller)	• receive assignments, • develop intercept data, • communicate data to aircraft operations, • receive intercept reports, • communicate reports to evaluator	• intercept data, • interceptor status reports	• probable distribution of vectoring errors, • intercept data communication rate, • intercept report communication rate	• design and location of displays, • communication with aircraft ops., • communication with evaluator, • number of controllers

Advantages

The use of this technique formalizes the design decision- making process for critical operator tasks and system variables. It is suited to a wide range of design problems, from simple, hand-held devices to complex command and control systems.

Disadvantages

As with many of the techniques reviewed, the analysis of critical design requirements requires expert knowledge of the type of operation being analysed, the problems typically encountered with the operation, and the possible technical implementations for the human-machine interface. The technique can be labour intensive, if applied to a detailed task analysis.

Relative contribution

No data available.

Applications

Critical design requirements analyses have been used since the early 1960s. Morgan et al. (1963) provide an example from a command and control application. Bishop & Guinness (1966) report the use of such a technique for the development of design requirements for the evaluation of competing designs of a rifle. It was used for the identification of design requirements for a Landing Signals Officer (LSO) compartment for a helicopter-carrying destroyer, and for the control cabins for Resupply at Sea (RAS) operations for destroyers in Canada.

Quality assurance considerations

The technique is dependent on the expertise of the analyst, and the information on critical operator tasks and potential human-machine interface solutions.

Relationship to system performance requirements

The analyses are related directly to system performance requirements by concentrating on critical operator tasks and critical system variables.

References and Bibliography

1. Bishop, E.W. & Guinness, G.V. Jnr. (1966). Human factors interaction with industrial design. Human Factors, 8 (4) 279-289.
2. Morgan, C.T., Cook, J.S., Chapanis, A., & Lund, M.W. (1963). Human engineering guide to equipment design. New York: McGraw-Hill Co. Inc.
3. Woodson, W.E. (1981). Human factors design handbook, (pp. 961-964). New York: McGraw-Hill Book Co.

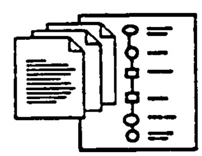
6.3 LINK ANALYSIS

What the technique does

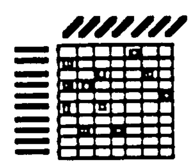
Link analysis is a technique for evaluating and improving the layout of equipment and the operator-machine interface by minimizing the "costs" associated with transitions between different items of equipment, or different components of the interface. It is concerned with the relative positions, frequencies, and importance of use of the different components, and how their use can be arranged most effectively. It can be applied to the layout of a specific human-machine interface (Shackel, 1961), or to the layout of a crew compartment for several operators and items of equipment (US DoD, 1987).

A *link* is any connection between two *elements* of an interface or crew compartment, either visual, aural, or by movement of a limb or person. An *element* is any item of the interface or crew compartment which is used during the operations being analysed. Costs are associated with each link based factor such as frequency, importance, time, strength, sequence, and distance. Link analysis attempts to reduce associated costs by minimizing the length of the links associated with highest cost.

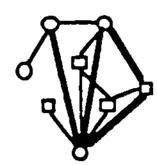
Initially, a task analysis, or an activity analysis of an actual system, is completed, identifying the links between operator and equipment. Convention uses numbers for humans and letters for equipment.



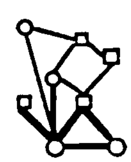
The links are charted as a to-from matrix, noting the frequency and/or strength or importance of the links.



The links are superimposed on the proposed or existing layout. If a new design is being developed, the higher cost links are drawn first, then the lower cost links are added. Sequence of the links is also used to determine layout. Convention uses circles to identify humans, squares to identify equipment.



The layout is refined by modifications which reduce the lengths of the higher cost links, and avoid crossing links wherever possible.



Link analysis can be used to reduce the likelihood of operator error by simplifying the sequences required to use controls and displays. The examples reported by Cornell (1968) and Shackel (1961) are based on single sequences of links used in setting up and operating equipment.

There have been several attempts to improve the analysis of the cost function data, particularly for complicated problems (see Laughery & Laughery, 1987). Freund & Sadosky (1967) applied linear programming to the solution of the cost problem. Siegel, Wolf & Pilitis, (1982) applied multi-dimensional scaling to the treatment of the link data. Wierwille (1981) reported the use of optimization procedures for the instrument layout problem. Hendy (1989) extended link analysis to include the angular relationship between links as well as link length, through the use of a variety of cost functions and the application of mathematical optimization techniques.

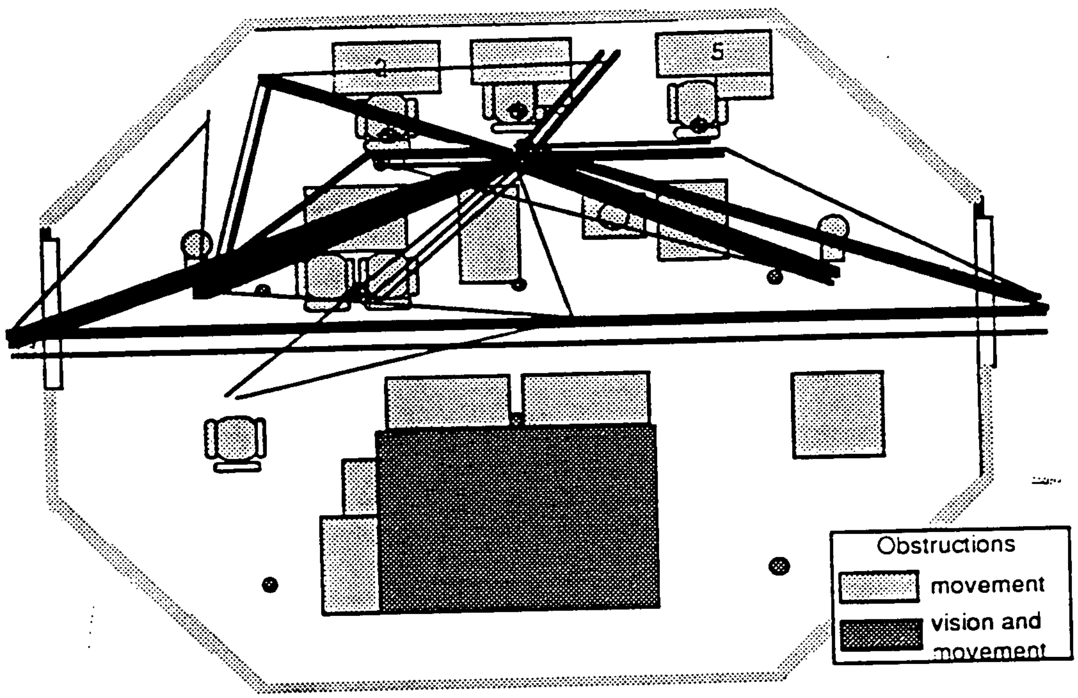


Figure 6.2.a: Officer of the Watch movements (links) on a destroyer bridge during three harbour entrances and exits showing obstacles to movement

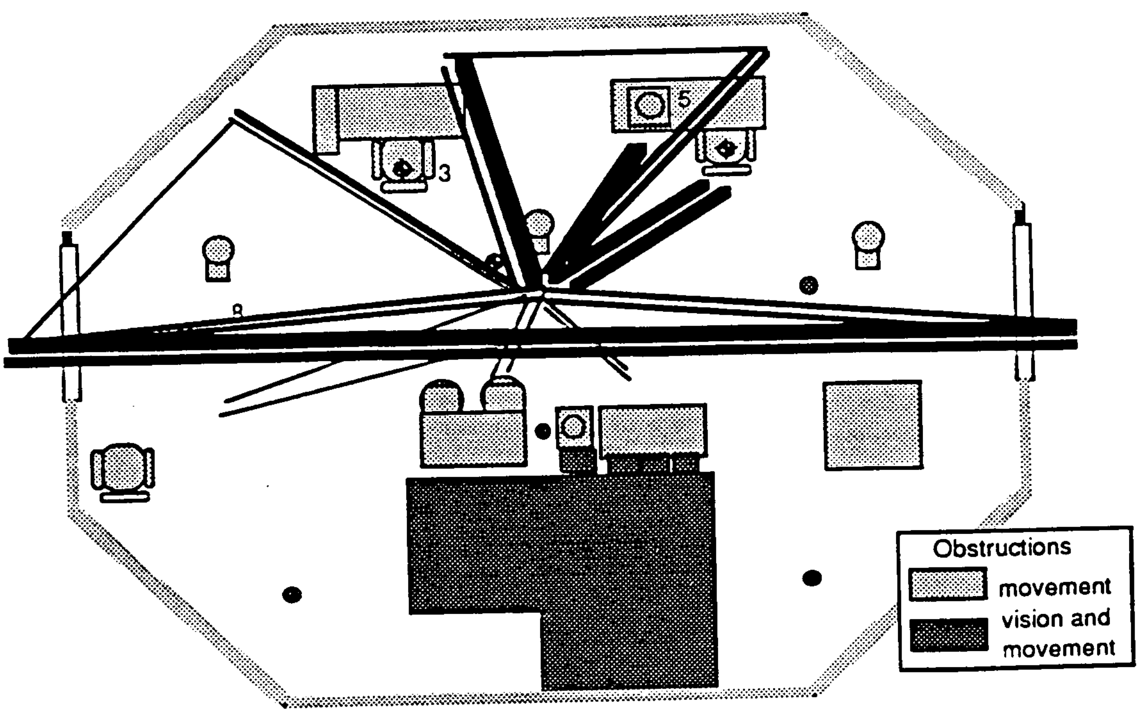


Figure 6.2.b: Improved bridge layout developed from link analysis
(Evans, Walker, & Beevis, 1984)

Inputs to the technique

Link analysis requires information on the elements, the links between them, and their frequency and importance of use. That information can be derived from studies of an existing system, using eye movement records, time-lapse film, video, or manual records, or from a detailed task analysis. The technique could also use the output from some SAINT simulations (5.2). The data are usually presented in a table (or correlation matrix), showing the frequencies of the links between the different elements.

Outputs of the technique

The technique results in diagrams or drawings of the layout of the equipment or interface (see Fig. 6.2.b for example).

When to use

Link analysis should be used early in the design phase, once data are available for the analysis. It requires input from a detailed task analysis, or from an analysis of an existing system (an activity analysis).

Related techniques

Link analysis is an Industrial Engineering technique. It is related to some operational research techniques for the solution of transportation problems.

Resources required

Link analysis can be conducted using paper and pencil, if necessary. More advanced techniques such as the use of linear programming, or Hendy's LOCATE approach (Hendy, 1989), require computing facilities.

Advantages

Link analysis is very effective for summarizing the multitude of details provided by task analyses, and reducing them to a form which is directly applicable to the design of the system.

Disadvantages

The choice of the cost function can be subjective. The solution of a link analysis problem becomes very difficult if more than eight or ten items are being considered. The validation of competing designs is difficult and time consuming.

Relative contribution

Few data are available. Some users rate its contribution very highly.

Applications

Link analysis has been used for the development of a number of human-machine interfaces. Shackel (1961) reported an application to the design of a prototype radar using the standard sequence for operating the equipment (a widely cited example by Cornell (1968) was actually an hypothetical application). Link analysis was used to evaluate competing human-machine interface designs during the selection of a maritime patrol aircraft. Recently the technique was used for the development of interface designs for a forward air defence system. Link analysis has also been used widely in crew compartment design, for example for patrol aircraft, for army command posts, and for the development of improved designs of destroyer bridges.

Quality assurance considerations

The analysis is dependent on the frequencies and weightings used to weight the different links. The weightings are subjective.

Relationship to system performance requirements

Operator performance is implicit in the use of the "cost" function to determine the arrangement of system components, resulting in reduced operator times, and errors. The cost function chosen will determine the exact relationship to system performance.

References and Bibliography

1. Cornell, C.E. (1968). Minimizing human errors. Space/Aeronautics. March, p.79.
2. Evans, S., Walker, C., & Beevis, D. (1984). A human engineering evaluation of DDH280 bridge design proposals. DCIEM No. 84-R-43. Toronto: Defence and Civil Institute of Environmental Medicine.
3. Freund, L.E. & Sadosky, T.L. (1967). Linear programming applied to optimization of instrument panel and workplace layout. Human Factors 9 (4), 295-300.
4. Hendy, K. (1989). A model for human-machine-human interactions in workspace layout problems. Human Factors 31 (5), 593-610.
5. Laughery, K.R. Snr., & Laughery, K.R. Jr. (1987). Analytic techniques for function analysis. In: G. Salvendy (Ed.), Handbook of human factors. New York: John Wiley & Sons.
6 Shackel, B. (1961). Ergonomics in equipment design. Instrument Practice, June., pp. 705-712.
7. Siegel, A.I., Wolf, J.J., & Pilitis, J. (1982). A new method for the scientific layout of workspaces. Applied Ergonomics 13 (2), 87-90.
8. US Department of Defense (1987). Human engineering procedures guide. Washington D.C.: DoD-HDBK-763.
9. Wierwille, W.W. (1981). Statistical techniques for instrument panel arrangement. In: J. Moraal & K.F. Kraiss (Eds.), Manned system design. New York: Plenum Press.

VOLUME 2 PART 2

DECOMPOSITION AND REPRESENTATION OF SYSTEMS

1. INTRODUCTION

This chapter is intended to provide users with examples of decomposition and representation of concepts, to assist in the analysis and design of new human-machine systems. This is necessary because it has been found difficult to use this approach on new systems without the benefit of reference to earlier applications. The identification of system functions plays an important role in the system development process. It allows a system concept to be explored without considering any hardware, software, or lifeware implementation. It is the basis for developing different design concepts, from which the appropriate alternative can be selected by means of trade-off studies. System functions can also be used as a common basis for communication between different design experts and within design teams.

1.1. IMPORTANCE OF SYSTEM FUNCTIONS IN SYSTEM DESIGN

As described in Volume 1, Chapters 2 and 3, typically, the design goals for a new human-machine system are derived from the operational requirements which the system has to fulfil. System functions can be viewed as broadly defined operations, or activities, which the system has to accomplish to achieve its goals. System functions are activities which produce required outputs from given inputs. When system functions are described at the appropriate level of detail, the means for implementing them can be established. At the upper levels, the 'allocation of functions' process includes gross representations of human-machine system functions, for instance, 'detect targets' and 'track targets'. These functions will be accomplished by the radar equipment and its human operator or by the sonar equipment and its human operator, respectively. At lower levels, the process can identify tasks which the operators must perform within these systems, e.g. 'monitor radar screen', 'adjust sonar device'.0

Functions represent one level in the hierarchy of total system activities. This hierarchy comprises various levels of which the highest level describes system missions and the lowest level describes operator task elements (Fig 1.1). To identify relevant system functions, the analysis starts with the mission of the human-machine system. By decomposing the mission, mission scenarios and then system operations can be identified which are required for fulfilling the mission. Finally, the partition of system operations leads to the system functions which are the basis for all human engineering activities during system development. The lowest activity level which human engineers deal with is the level of operator task elements.

Functions tend to be similar for a specific class of human-machine systems. For example, destroyers, frigates, patrol boats all belong to the class of ship systems. At the upper levels, ship systems can be described with the same functions, neglecting differences at the detailed implementation levels. System designers and engineers think in terms of specific implementations, however, rather than abstract system functions. To overcome this difficulty, it is recommended that the analysis of an existing, or predecessor human-machine system, should be used as a basis for developing concepts of future system functions and future system components. These may then be developed by considering the requirements of future human-machine systems, and, e.g., interpreted in terms of new technological possibilities for implementation. This approach is shown in Figure 1.2. The reader should note that, despite the importance of system functions, design/development team responsibilities are usually allocated according to the system components or sub-systems. Project work breakdown structures (WBS) are usually a matrix of products (sub-systems) and tasks (work items or activities). Human engineering responsibilities and activities are likely to be organized on that basis. For that reason, typical system/sub-system decomposition for a work breakdown structure have been included for Air force systems (Chapt. 3.1.), Army systems (Chapt. 3.2.), and Navy systems (Chapt. 3.3.).

1.2. TYPES OF ANALYSIS AVAILABLE

The analyses may proceed from one of several different viewpoints. Such a view may be system, function, or state oriented (Table 1.1). With each view hierarchical or behavioural relationships can be considered. Therefore, an analysis may deal with hierarchies of sub-systems, system functions, or system states. On the other hand, the analysis could reflect behavioural relationships, i.e., the material, energy, or informational flows between sub-systems or system functions, procedural and chronological sequences of system functions, or event driven transitions between system states. These options are shown in Table 1.1 and explained in detail in section 2. A ship propulsion system has been selected for the examples given in section 2. To facilitate the identification of analyses a template which indicates the category of the described analysis is used.

In section 3 examples of system and function hierarchies as well as chronological function representations (flow diagrams) are given for different system classes. Due to different viewpoints or purposes of applied analyses differences can be noticed in the examples. The given representations may assist system designers and engineers in developing system concepts. The different system classes include aircraft, land vehicle systems, ship systems, and an anti-tank weapon system.

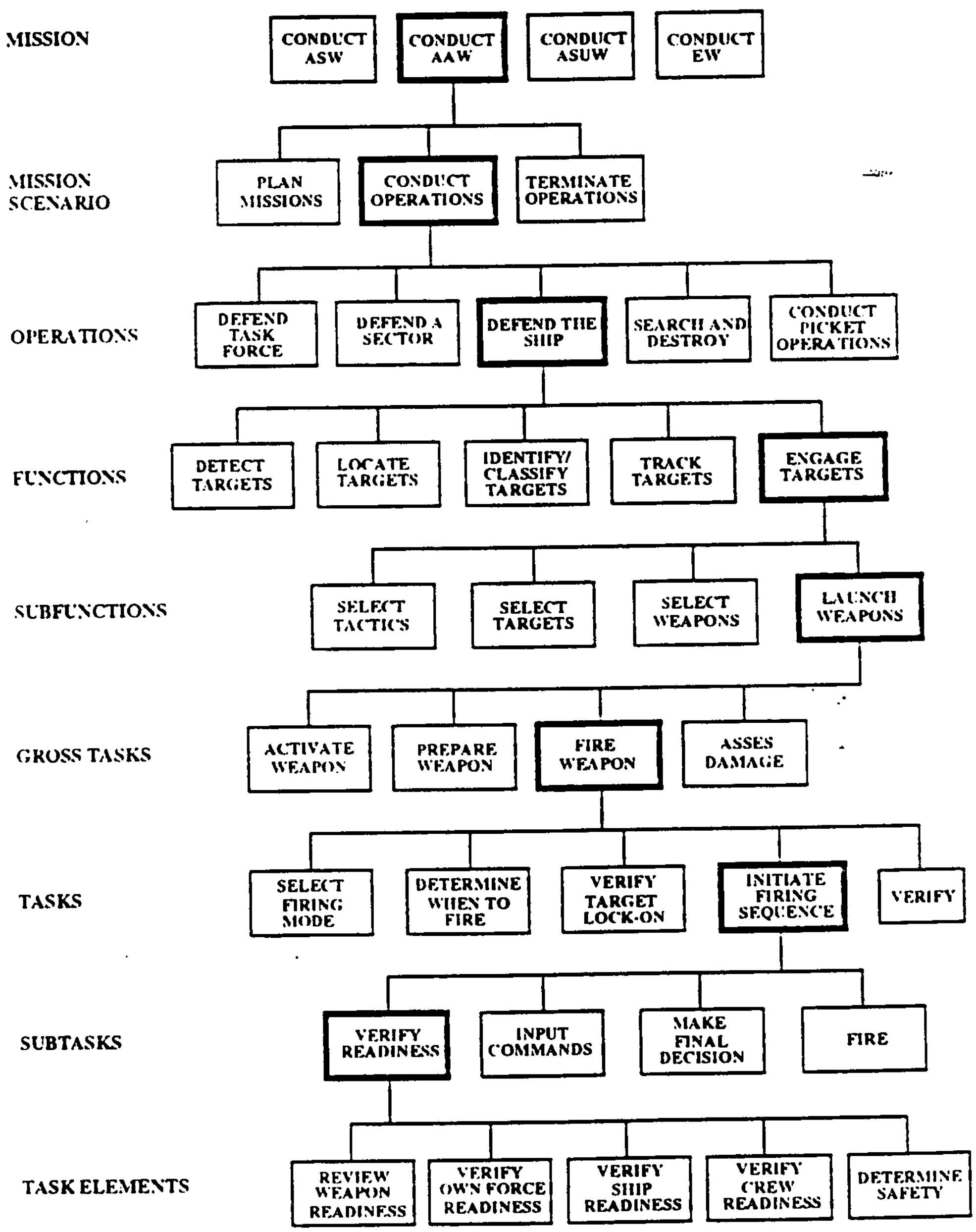


Fig. 1.1: System activity hierarchy

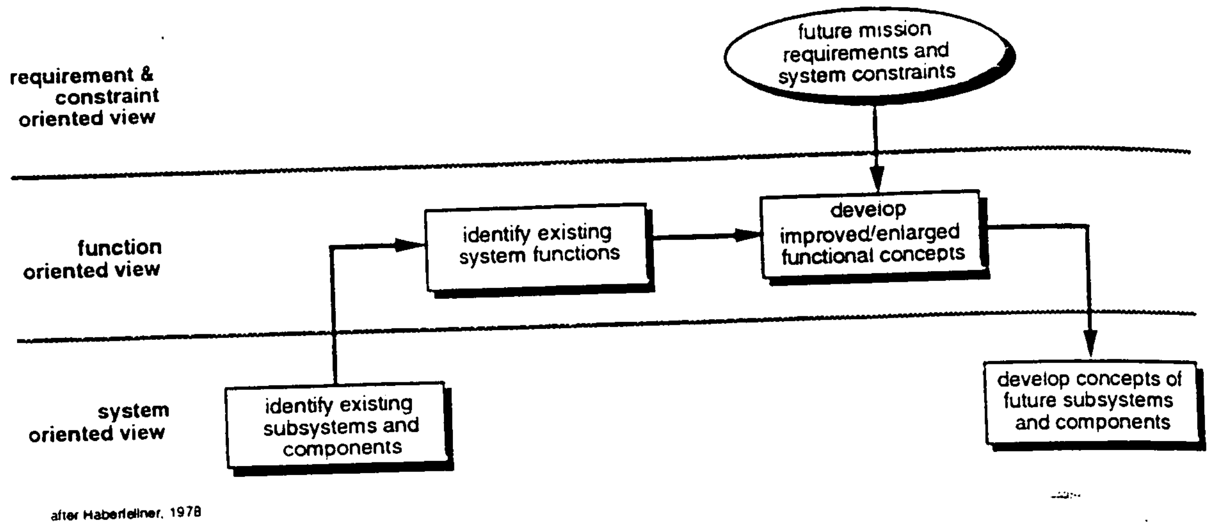


Fig. 1.2: Approach for developing a new system

Table 1.1: Types of analyses

View	Analysis of: Hierarchical System Relationships H	Analysis of: Behavioural System Relationships B
1. system oriented S	Hierarchy of system and subsystems. Example: 2.1.1.1. and 2.1.1.2.	Material, energy, and information flows between sub systems. Example: 2.1.2.
2. function oriented F	Hierarchy of system function and subfunctions. Example: 2.2.1.1. and 2.2.1.2.	Material, energy, and information flows between system subfunctions. Example: 2.2.2.1.
		Procedural and chronological sequences of system subfunctions. Example: 2.2.2.2.
3. state oriented ST	Hierarchy of system states and substates. Example: 2.3.1.1. and 2.3.1.2.	System states and state transitions. Example: 2.3.2.1.

2. TYPES OF ANALYSES

2.1. SYSTEM ORIENTED VIEW

2.1.1. System oriented hierarchical relationships

2.1.1.1. Listing of system oriented hierarchical relationships

2.1.1.2. Diagram of system oriented hierarchical relationships

2.1.2. System oriented behavioural relationships

2.2. FUNCTION ORIENTED VIEW

2.2.1. Function oriented hierarchical relationships

2.2.1.1. Listing of function oriented hierarchical relationships

2.2.1.2. Diagram of function oriented hierarchical relationships

2.2.2. Function oriented behavioural relationships

2.2.2.1. Function oriented material, energy, and information flow

2.2.2.2. Procedural and chronological sequences of system functions

2.3. STATE ORIENTED VIEW

2.3.1. State oriented hierarchical relationships

2.3.1.1. Listing of state oriented hierarchical relationships

2.3.1.2. Diagram of state oriented hierarchical relationships

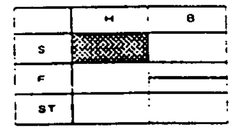
2.3.2. State oriented behavioural relationships

2.3.2.1. States and state transitions

2.1. SYSTEM ORIENTED VIEW

A system oriented view can be applied for determining the parts of a system, i.e., human-machine systems, machine and/or personnel subsystems, their structure and their interactions.

2.1.1. System oriented hierarchical relationships



The application of system oriented hierarchical relationships results in a decomposition structure of the considered system, i.e., a hierarchy of subsystems. A hierarchy can be represented as a list (2.3.1.1.1) or as a diagram (2.3.1.1.2).

2.1.1.1. Listing of system oriented hierarchical relationships

Example: Hierarchical decomposition of a ship system focussed on its human operators.

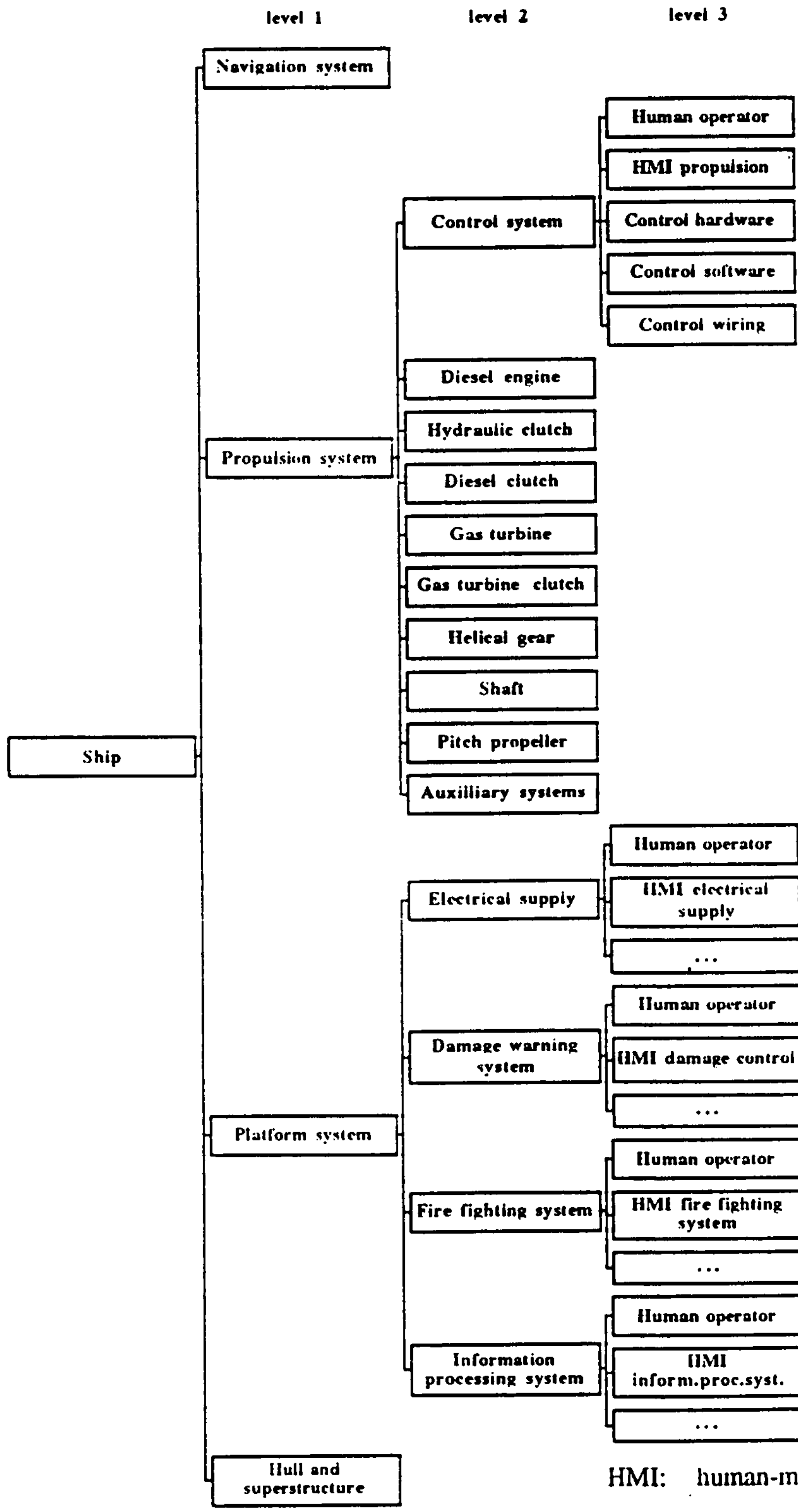
Ship

I. **Navigation system**
II. **Propulsion system**
   A. **Control system**
      1. **Human operator**
      2. **HMI propulsion**
      3. **Control hardware**
      4. **Control software**
      5. **Control wiring**
   B. **Diesel engine**
   C. **Hydraulic clutch**
   D. **Diesel clutch**
   E. **Gas turbine**
   F. **Gas turbine clutch**
   G. **Helical gear**
   H. **Shaft**
   I. **Pitch propeller**
   J. **Auxilliary systems**
III. **Platform system**
   A. **Electrical supply**
      1. **Human operator**
      2. **HMI electrical supply**
      3. **...**
   B. **Damage warning system**
      1. **Human operator**
      2. **HMI damage control**
      3. **...**
   C. **Fire fighting system**
      1. **Human operator**
      2. **HMI fire fighting system**
      3. **...**
   D. **Information processing system**
      1. **Human operator**
      2. **HMI inform.proc.syst.**
      3. **...**
IV. **Hull and superstructure**

* HMI: human-machine interface

2.1.1.2. Diagram of system oriented hierarchical relationships

Example: Hierarchical decomposition of a ship system focussed on its human operators

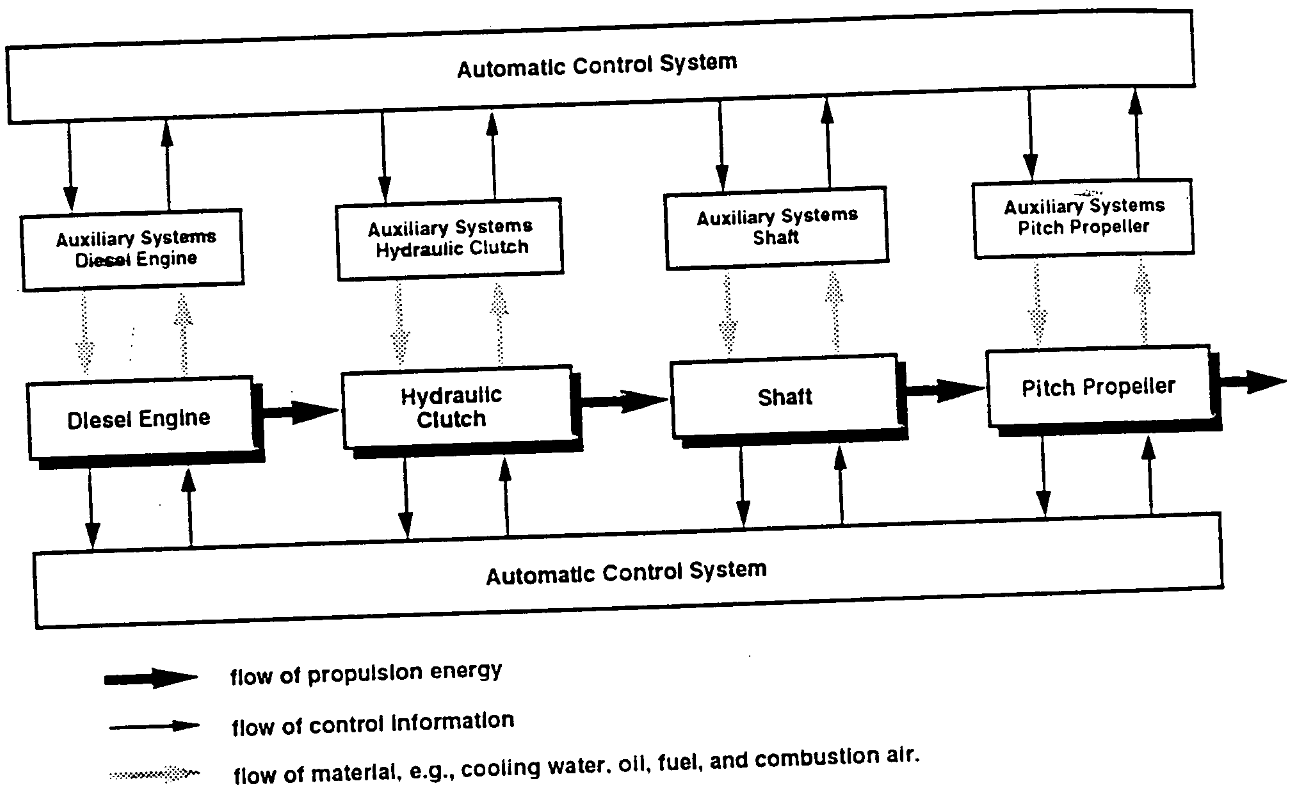


HMI: human-machine interface

2.1.2. System oriented behavioural relationships

System oriented behavioural relationships describe how subsystems interact. Interactions arise through the flow of material, energy, and information between subsystems. The flow is generated by system inputs and outputs. System oriented behavioural relationships can be represented by a block diagram in which rectangles represent subsystems and arrows correspond to flows.

Example:
Flow of propulsion energy, control information, and material between machine subsystems of a ship propulsion system.



2.2. FUNCTION ORIENTED VIEW

A function oriented view can be applied for determining activities of a system, i.e., system functions and subfunctions, their hierarchical structure and their interactions.

2.2.1. Function oriented hierarchical relationships

	H	B
S		
F		
ST		

The application of hierarchical relationships results in a decomposition structure of system functions, i.e., a hierarchy of subfunctions. The hierarchy can be represented as a list (2.2.1.1) or as a diagram (2.2.1.2).

2.2.1.1. Listing of function oriented hierarchical relationships

Example: Hierarchical decomposition of functions of a ship engine control system

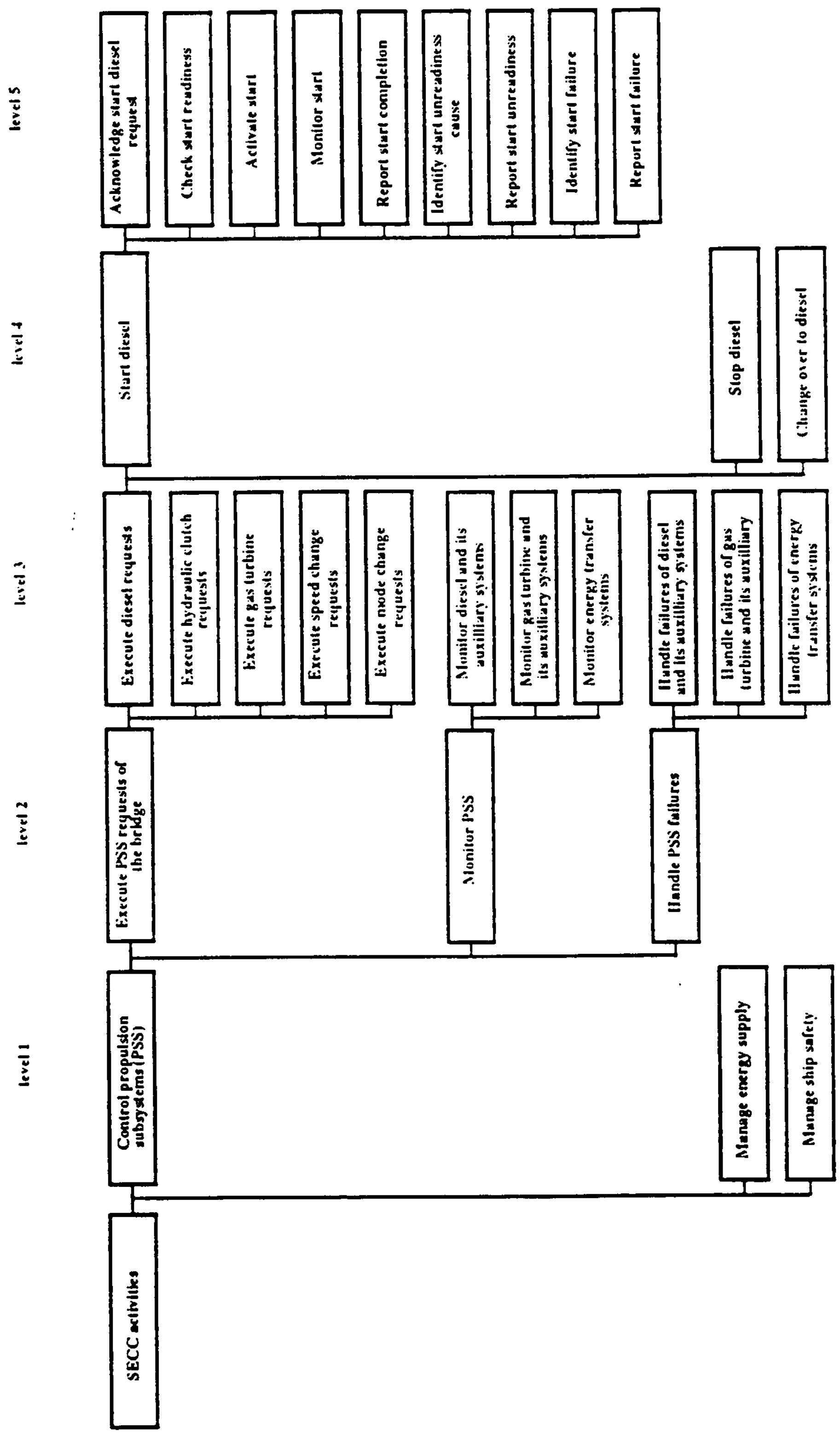
I. **Control propulsion subsystems (PSS)**
  A. **Execute PSS requests of the bridge**
    1. **Execute diesel requests**
      a) **Start diesel**
        (1) Acknowledge start diesel request
        (2) Check start readiness
        (3) Activate start
        (4) Monitor start
        (5) Report start completion
        (6) Identify start unreadiness cause
        (7) Report start unreadiness
        (8) Identify start failure
        (9) Report start failure
      b) **Stop diesel**
      c) **Change over to diesel**
    2. **Execute hydraulic clutch requests**
      a) **Fill hydraulic clutch**
      b) **Empty hydraulic clutch**
    3. **Execute gas turbine requests**
      a) **Start gas turbine**
      b) **Stop gas turbine**
      c) **Change over to gas turbine**
    4. **Execute speed change requests**
    5. **Execute mode change requests**
  B. **Monitor PSS**
    1. **Monitor diesel and its auxilliary systems**
    2. **Monitor gas turbine and its auxilliary systems**
    3. **Monitor energy transfer systems**
  C. **Handle PSS failures**
    1. **Handle failures of diesel and its auxilliary systems**
    2. **Handle failures of gas turbine and its auxilliary systems**
    3. **Handle failures of energy transfer systems**

II. **Manage energy supply**

III. **Manage ship safety**

2.2.1.2. Diagram of function oriented hierarchical relationships

Example: Hierarchical decomposition of functions of a ship engine control system (SECC)



2.2.2. Function oriented behavioural relationships

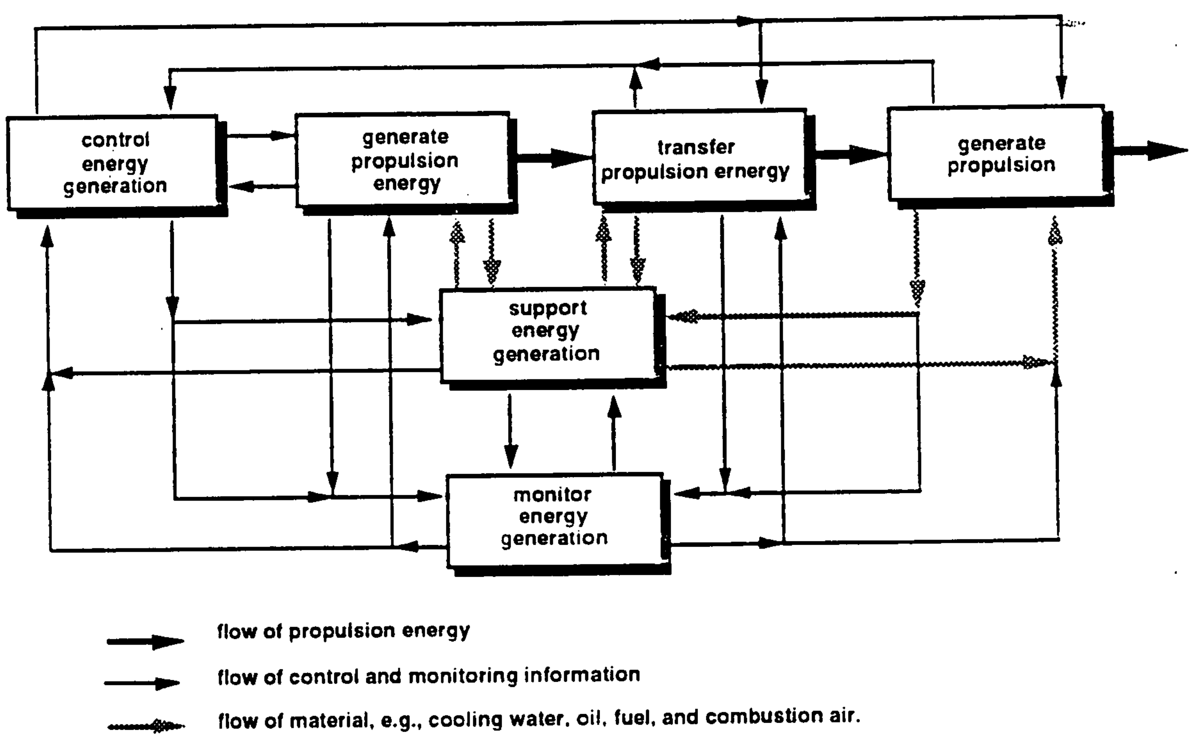
Function oriented behavioural relationships describe how subfunctions interact. The interactions can be described through the flow of material, energy, and information or as predecessor/succesor relationships between subfunctions.

2.2.2.1. Function oriented material, energy, and information flow

	H	B
S		
F		
ST		

The flow of material, energy, and information is generated by connecting inputs and outputs of subfunctions. This type of relationship can be represented by a block diagram in which rectangles represent functions and arrows corresponding flows.

Example: Flow of propulsion energy, control information, and material between subfunctions of a ship propulsion system.



2.2.2.2. Procedural and chronological sequences of system functions

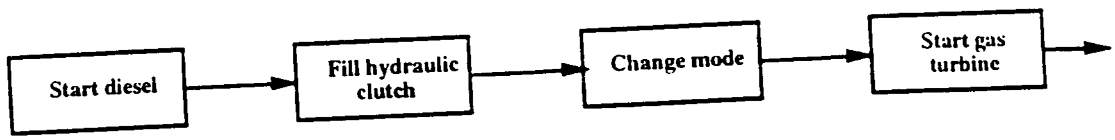
	H	B
S		
F		
ST		

Another type of behavioural relationship is the time-dependent relationship. It can be represented by showing mission dependent sequences of functions. In this case rectangles again represent functions but arrows show predecessor/successor relationships between functions.

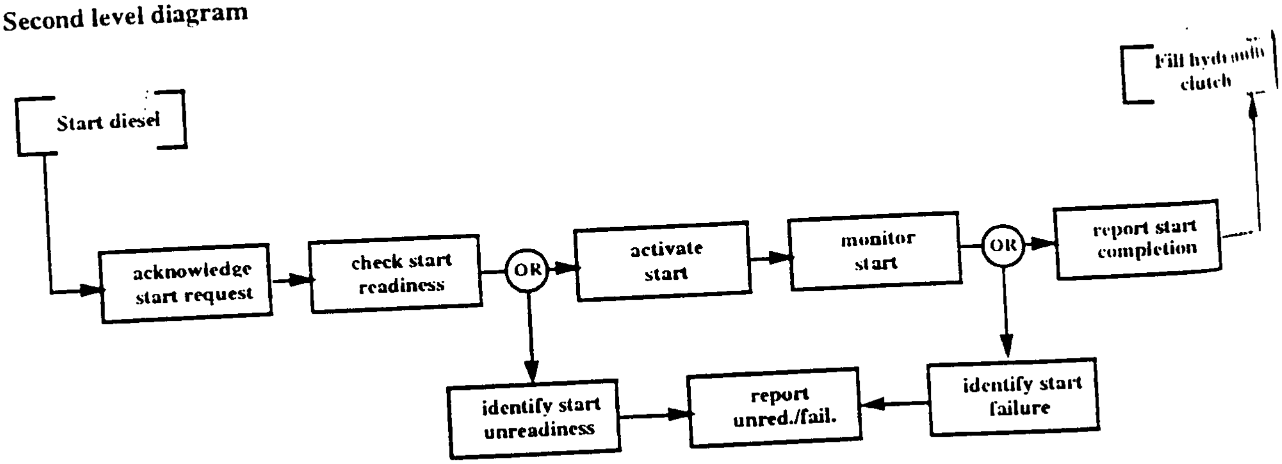
To describe time-dependent system behaviour, procedural and chronological sequences of system functions can be established. The sequences depend on events and their chronology that arise during the system mission. Functional flow block diagrams can be used for representing those sequences. In this diagram rectangles represent functions, and arrows show predecessor/successor relationships between functions (see chapter 2: items 2.2.1 and 2.2.2).

Example: Partial sequence of functions of a ship engine control system during a mission of the ship.

First level diagram



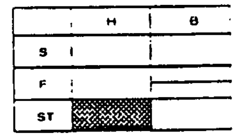
Second level diagram



2.3. STATE ORIENTED VIEW

The state oriented view is applied to look at the time-dependent system behaviour that is characterized by system states and state transitions. A system state is decribed by a set of attributes characterizing the system at a given time.

2.3.1. State oriented hierarchical relationships



By means of state oriented hierarchical relationships system states can be partitioned into sub-states. The state hierarchies can be represented in a list (2.3.1.1.) or as a diagram (2.3.1.2.).

2.3.1.1. Listing of state oriented hierarchical relationships

Example: Hierarchical decomposition of ship propulsion system states.

ship propulsion system states

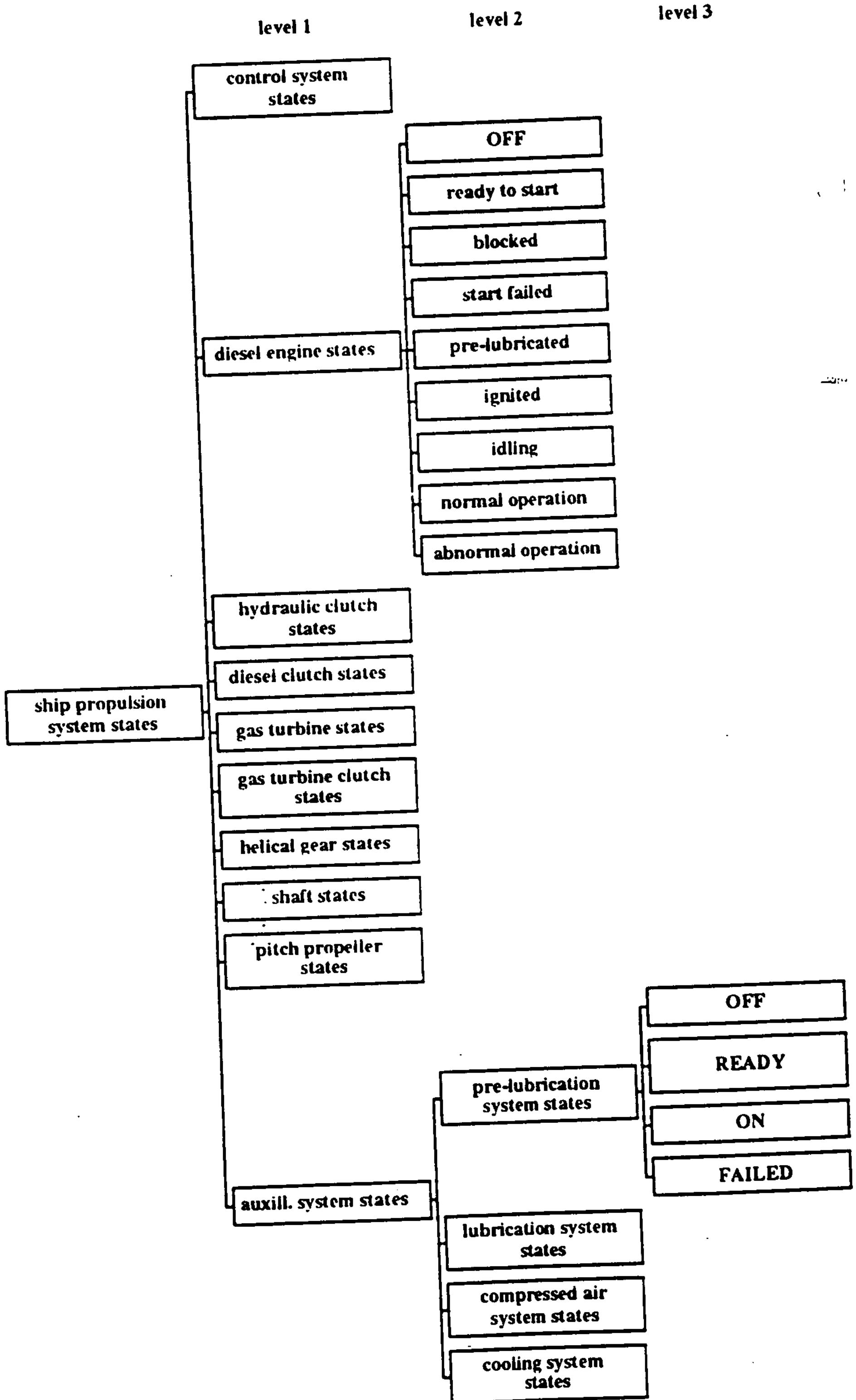
I. automatic control system states

II. diesel engine states
- **A. OFF**
- **B. ready to start**
- **C. blocked**
- **D. start failed**
- **E. pre-lubricated**
- **F. ignited**
- **G. idling**
- **H. normal operation**
- **I. abnormal operation**

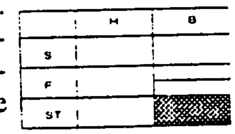
III. hydraulic clutch states
IV. diesel clutch statesG6
V. gas turbine states
VI. gas turbine clutch states
VII. helical gear states
VIII. shaft states
IX. pitch propeller states
X. auxill. system states
- **A. pre-lubrication system states**
  - **1. OFF**
  - **2. ready to pre-lubricate**
  - **3. pre-lubricating**
  - **4. pre-lubrication failed**
- **B. lubrication system states**
- **C. compressed air system states**
- **D. cooling system states**

2.3.1.2. Diagram of state oriented hierarchical relationships

Example: Hierarchical representation of ship propulsion system states.



2.3.2. State oriented behavioural relationships

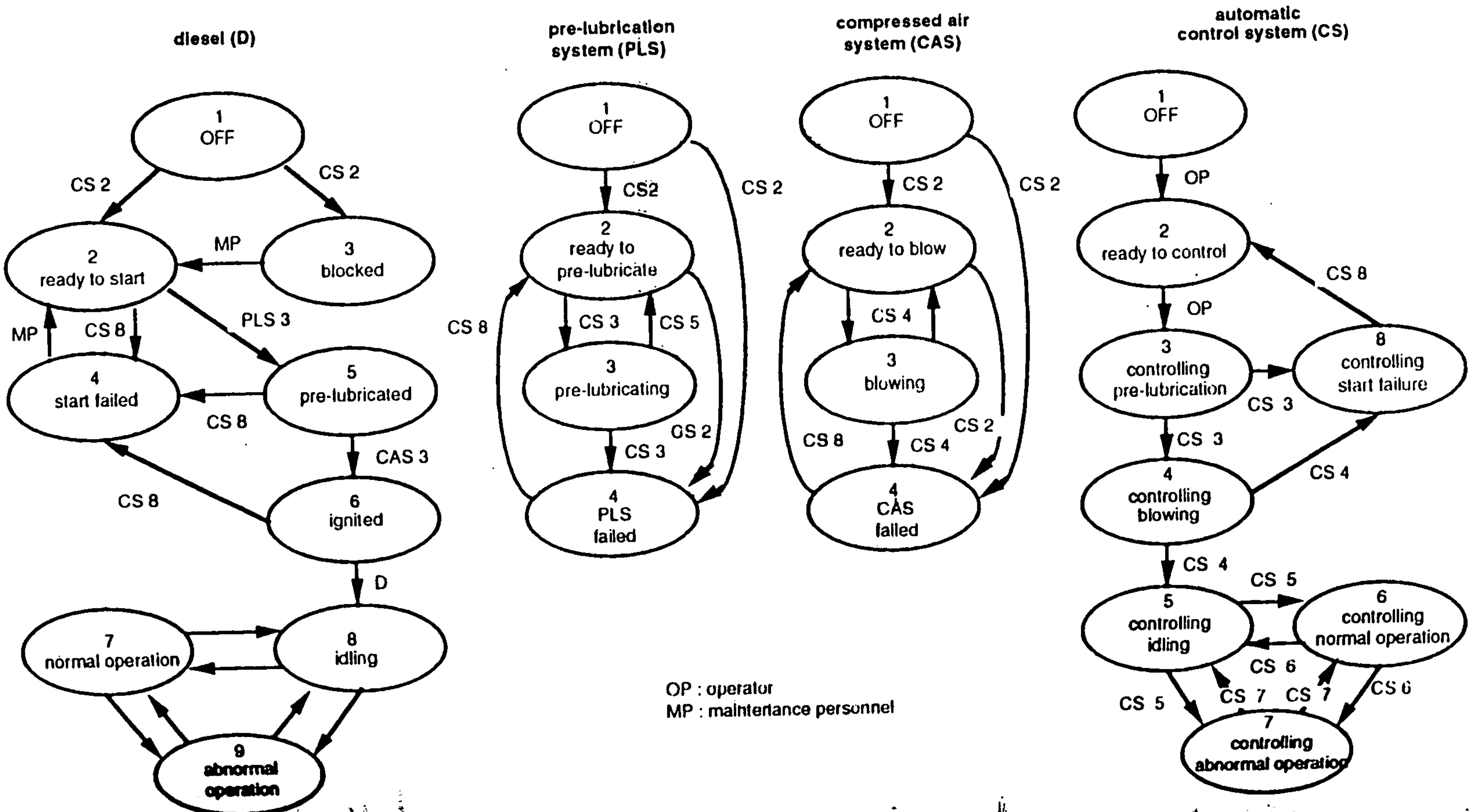


Time-dependent system behaviour can be described by means of a state and state changes. Each state that the system can be in represents a period of time during which the system exhibits some observable behaviour. Associated with each state change is one or more conditions (the event or circumstances that caused the change of state) and zero or more actions (the response, output, or activity that takes place as part of the change of state).

2.3.2.1. States and state transitions

In a state transition diagram states are represented as rectangles or ellipses. Arrows that connect the states show the state change or transition from one state to another.

Example:
As an example some subsystem states and state transitions of a ship propulsion system during diesel start up are shown. The subsystems are: the diesel engine (D), the control system (CS), the pre-lubrication system (PLS), and the compressed air system (CAS). States and transitions are represented in the diagram as ovals and arrows, respectively. Transitions in the diagram have been labelled with a code. The code represents that subsystem and state which generate the event that causes the respective transition. For example, the transition between diesel states 2 and 5 is labeled PLS 3 which indicates that the corresponding event is caused by the pre-lubrication system if it is in PLS state 3.


diesel (D)
1 OFF
2 ready to start
3 blocked
4 start failed
5 pre-lubricated
6 ignited
7 normal operation
8 idling
9 abnormal operation
CS 2
MP
PLS 3
CS 8
CAS 3
D
pre-lubrication system (PLS)
1 OFF
2 ready to pre-lubricate
3 pre-lubricating
4 PLS failed
CS2
CS 3
CS 5
CS 2
CS 8
compressed air system (CAS)
1 OFF
2 ready to blow
3 blowing
4 CAS failed
CS 2
CS 4
CS 8
automatic control system (CS)
1 OFF
2 ready to control
3 controlling pre-lubrication
4 controlling blowing
5 controlling idling
6 controlling normal operation
7 controlling abnormal operation
8 controlling start failure
OP
CS 3
CS 4
CS 5
CS 6
CS 7
CS 8
OP : operator
MP : maintenance personnel

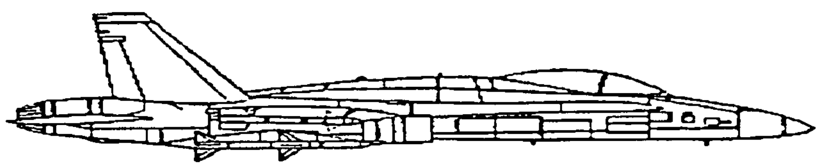
3. EXAMPLES OF SYSTEM DECOMPOSITIONS AND REPRESENTATIONS

3.1. AIR FORCE SYSTEMS

3.2. ARMY SYSTEMS

3.3. NAVY SYSTEMS

3.1. AIR FORCE SYSTEMS



3.1.1. System hierarchy of an aircraft

3.1.2. Function hierarchy of an ASW aircraft

3.1.3. Function hierarchy of an ASW helicopter

3.1.4. Functional flow block diagrams of a fixed-wing, maritime patrol aircraft

3.1.1. System hierarchy of an aircraft

Air vehicle

I. **Airframe**
   A. Basic Structure (wings, fuselage & associated manual flight control system etc.)
   B. Air induction system, inlets, exhausts etc.
   C. Fuel control system
   D. Landing gear (tyres, tubes, wheels, brakes, hydraulics etc.)
   E. Secondary power
   F. Furnishing (cargo, passenger, troop etc.)
   G. Engine controls
   H. Instruments (flight, navigation, engine etc.)
   I. Environmental control
   J. Racks, mounts, cabling etc.

II. **Propulsion**

III. **Communications**
   A. Intercom
   B. Radio system(s)
   C. IFF
   D. Data link
   E. Control boxes & integrated
   F. Control units

IV. **Navigation/guidance**
   A. Radar
   B. Radio
   C. Radar altimeter
   D. Direction finding
   E. Doppler compass
   F. Computer
   G. Other equipment

V. **Fire control**
   A. Radars
   B. Other sensors
   C. Navigation and air data system displays
   D. 'Scopes or sights
   E. Bombing computer
   F. Control & safety devices

VI. **Penetration aids**
   A. Ferret & search receivers
   B. Warning devices
   C. ECM
   D. Jamming transmitters
   E. Chaff
   F. Infrared jammers
   G. Terrain-following radar
   H. Other devices

VII. **Reconnnaissance equipment**
   A. Photographic equipment
   B. Electronic equipment
   C. Infrared sensors
   D. Search receivers

E. Recorders
F. Warning devices
G. Magazines
H. Data link

VIII. **Automatic flight control**

A. Autopilot
B. Flight control mechanism
C. Mechanical & electrical signal & power transmission equipment
D. Reference sensors
E. Stability augmentation equipment
F. Air data computer

3.1.2. Function hierarchy of an ASW aircraft

ASW mission functions

I. **Preflight**
  A. **Brief**
  B. **A/C status records**
  C. **Board A/C**
  D. **A/C preflight**
    1. **Acoustic systems preflight**
    2. **Non-acoustic systems preflight**
    3. **TACCO systems preflight**
    4. **NAV/COMM systems preflight**
    5. **Technician preflight**
    6. **Ordnance operator preflight**
    7. **Flight crew system preflight**

II. **Transit-out (4 HRS)**
  A. **Taxi**
  B. **Takeoff**
  C. **Climb to altitude**
    1. **Flight crew A/C systems check**
  D. **Cruise**
    1. **Perform inflight ASW systems checks**
      a) Perform acoustic system checks
      b) Perform non-acoustic system checks
      c) Perform TACCO system checks
      d) Perform NAV/COM system checks
      e) Perform technician system checks
      f) Perform ordnance system checks
    2. **Perform airways navigation**
      a) Perform navigation procedures
        (1) Insert FTP's
        (2) Update fix position
    3. **Transit communications**
      a) Position
      b) Operational
    4. **Employ sensors**
      a) Radar
      b) ESM
      c) IRDS

III. **ASW mission (4HRS)**
- **A. Search**
  - **1. Sample environment**
    - a) Gather BT data
    - b) Gather ANM data
    - c) Gather RF interference data
  - **2. Update environmental predictions**
  - **3. Construct sonobuoy pattern**
    - a) Convergence zone pattern
    - b) Direct path pattern
  - **4. Deploy sonobuoys**
  - **5. Employ sensors**
    - a) Acoustic sensors
    - b) Non-acoustic sensors
    - c) ASW associated equipment
  - **6. Conduct tactical navigation**
    - a) Perform OTPI procedures
    - b) Perform SRS procedures
- **B. Detect and classify**
  - **1. Exercise ASW sensors**
    - a) Exercise acoustic sensor
    - b) Exercise non-acoustic sensors
    - (1) Radar
    - (2) IRDS
    - (3) ESM
    - (4) MAD
    - c) IFF
    - d) Exercise ASW associated systems
- **C. Localize and track**
  - **1. Construct sonobuoy pattern**
    - a) Construct barrier pattern
    - b) Construct active patterns
  - **2. Conduct tactical navigation**
    - a) Perform OTPI procedures
    - b) Perform SRS procedures
  - **3. Perform tactical communications**
    - a) Perform contact report
    - b) Perform position reports
    - c) Perform status reports
  - **4. Update sensor readings**
  - **5. Deploy additional sensors**
    - a) Deploy MAD
  - **6. Update target position**
- **D. Attack / reattack**
  - **1. Perform precise attack navigation**
    - a) Perform OPTI procedures
    - b) Perform SRS procedures
  - **2. Achieve and recognize attack criteria**
  - **3. Conduct operational communications**
  - **4. Employ armament/ordnance**
  - **5. Employ self defense (as required)**

a) Employ ECM
b) Employ self defense tactics

6. **Assess damage**
7. **Conduct reattack (if required)**
8. **Climb**
   a) Conduct operational communications

IV. **Transit-to-base (4.5 HRS)**
   A. **Climb to transit altitude**
   B. **Cruise to base**
      1. **Analyze collect and collate mission data**
      2. **Prepare required reports**
      3. **Continue monitoring non-acoustic sensors**
         a) Radar
         b) ESM
         c) IRDS
         d) IFF
      4. **Conduct overwater navigation**
      5. **Conduct airways navigation**
      6. **Conduct communication**
         a) Airways
         b) Operational
   C. **Descend**
   D. **Approach**
   E. **Land**
   F. **Secure A/C**

3.1.3. Function hierarchy of an ASW helicopter

ASW helicopter functions

I. **Start-up aircraft**
   A. Perform pre-start checks
   B. Start APU (pre-flight)
   C. Spread blades/pylon
   D. Set-up/check aircraft systems
   E. Initialize navigation system
   F. Initialize communication system
   G. Start engines
   H. Engage rotor

II. **Prepare aircraft for take-off**
   A. Perform pre-taxi checks
   B. Taxi aircraft
   C. Perform taxi checks
   D. Perform pre-takeoff checks

III. **Take-off**
   A. Take-off
   B. Perform post-takeoff checks

IV. **Departure**
   A. Transition to forward flight
   B. Departure

V. **Control aircraft during mission**

A. Climb
B. Cruise
C. Descent
D. Approach to hover
E. Maintain hover
F. Depart hover
G. Precision maneuver
H. Autorotation

VI. **Perform mission functions**
A. Overfly sonobuoy
B. Evaluate MAD
C. Perform vectored attack
D. Monitor EW environment
E. Perform surface search
F. Manage aircraft stores

VII. **Approach**
A. Approach
B. Transition to hover

VIII. **Maintain navigation situation**
A. Develop/Revise navigation plans
B. Manage navigation system
C. Maintain situation awareness

IX. **Perform helicopter in-flight re-fuel**
A. Perform HIFR checks
B. Monitor HIFR progress
C. Maintain hover during HIFR

X. **Manage aircraft systems**
A. Manage fuel subsystem
B. Manage hydraulic subsystem
C. Manage electrical subsystem
D. Manage aircraft engine subsystems
E. Manage anti-icing and de-icing subsystems
F. Manage emergency subsystems

XI. **Manage communication system**
A. Manage communication system
B. Establish communications

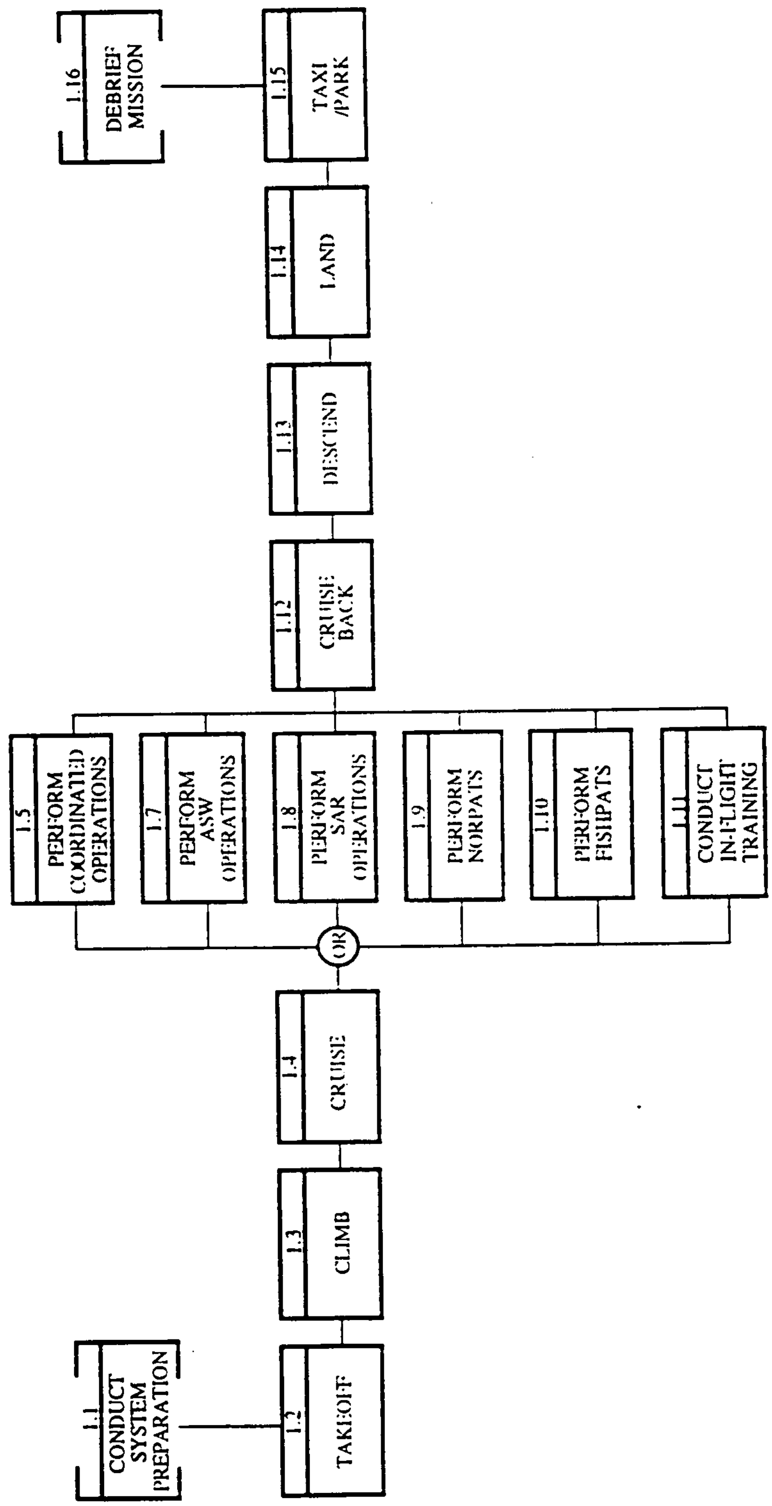
XII. **Land aircraft**
A. Perform pre-landing checks
B. Prepare/check HHRSD
C. Land aircraft

XIII. **Prepare aircraft for shutdown**
A. Perform post-landing checks
B. Taxi aircraft

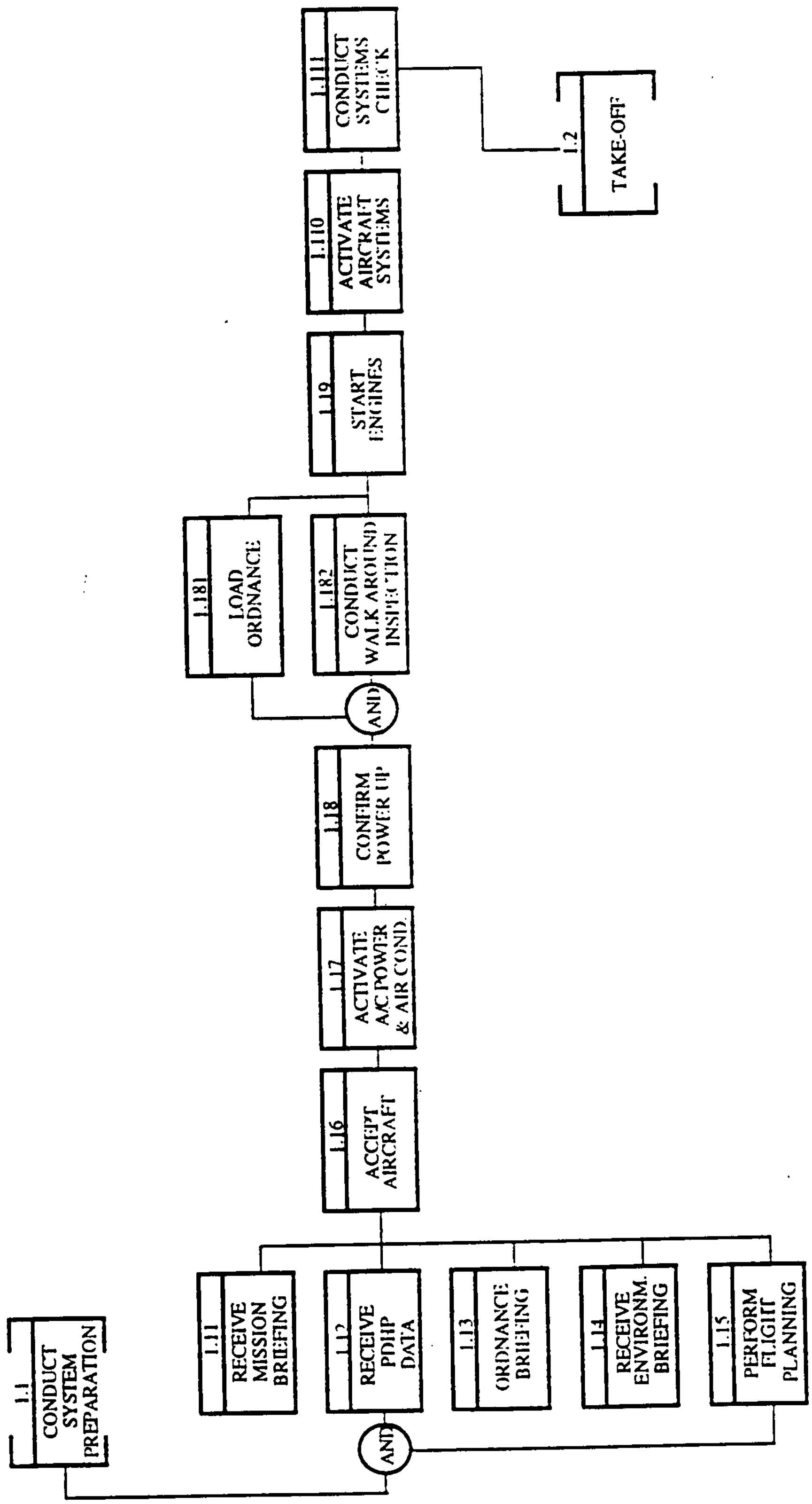
XIV. **Shutdown Aircraft**
A. Perform pre-shutdown checks
B. Start APU (post-flight)
C. Engine shutdown
D. Fold blades/pylon
E. Shutdown aircraft systems

3.1.4. Functional flow block diagrams of a fixed-wing, maritime patrol aircraft

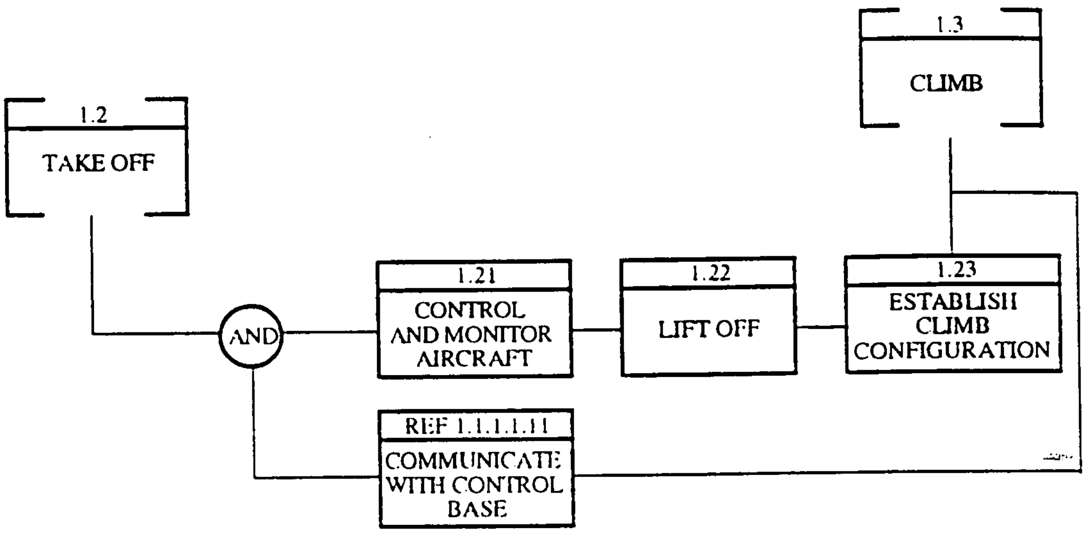
3.1.4.1. Overall mission function flow



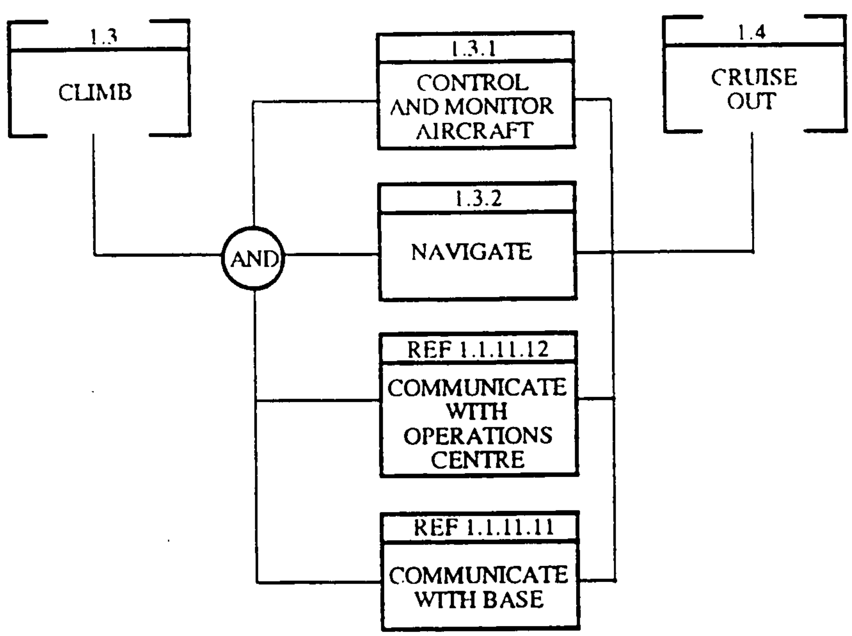
3.1.4.2. Aircraft systems preparation function flow



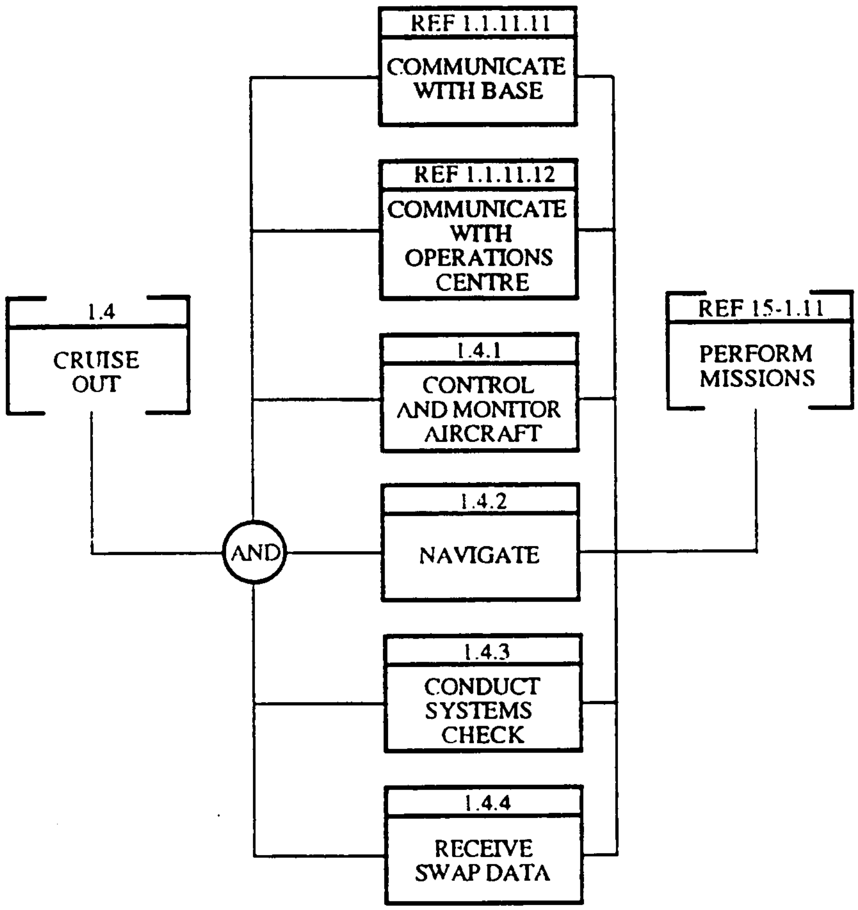
3.1.4.3. **Takeoff function flow**



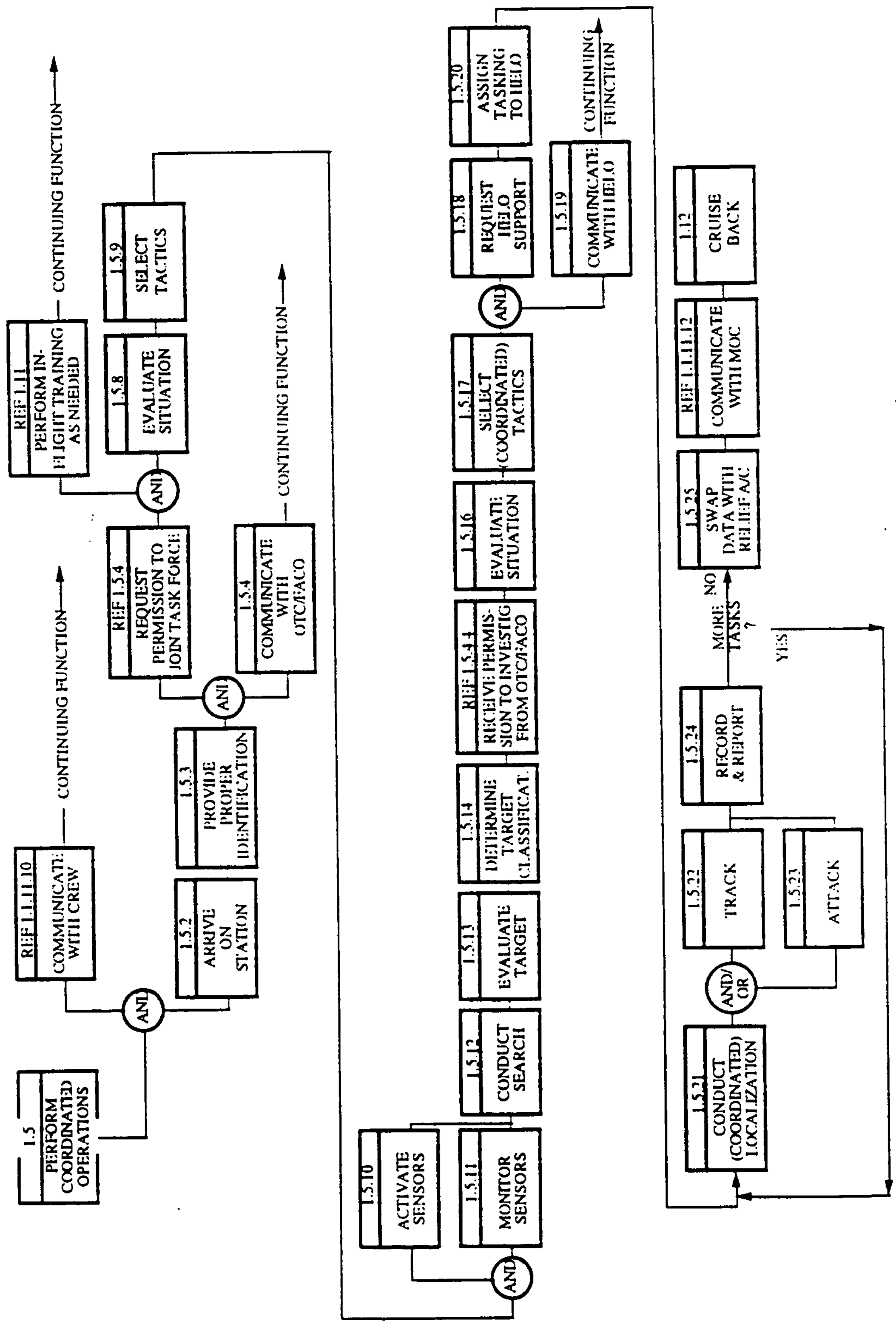
3.1.4.4. **Climb function flow**



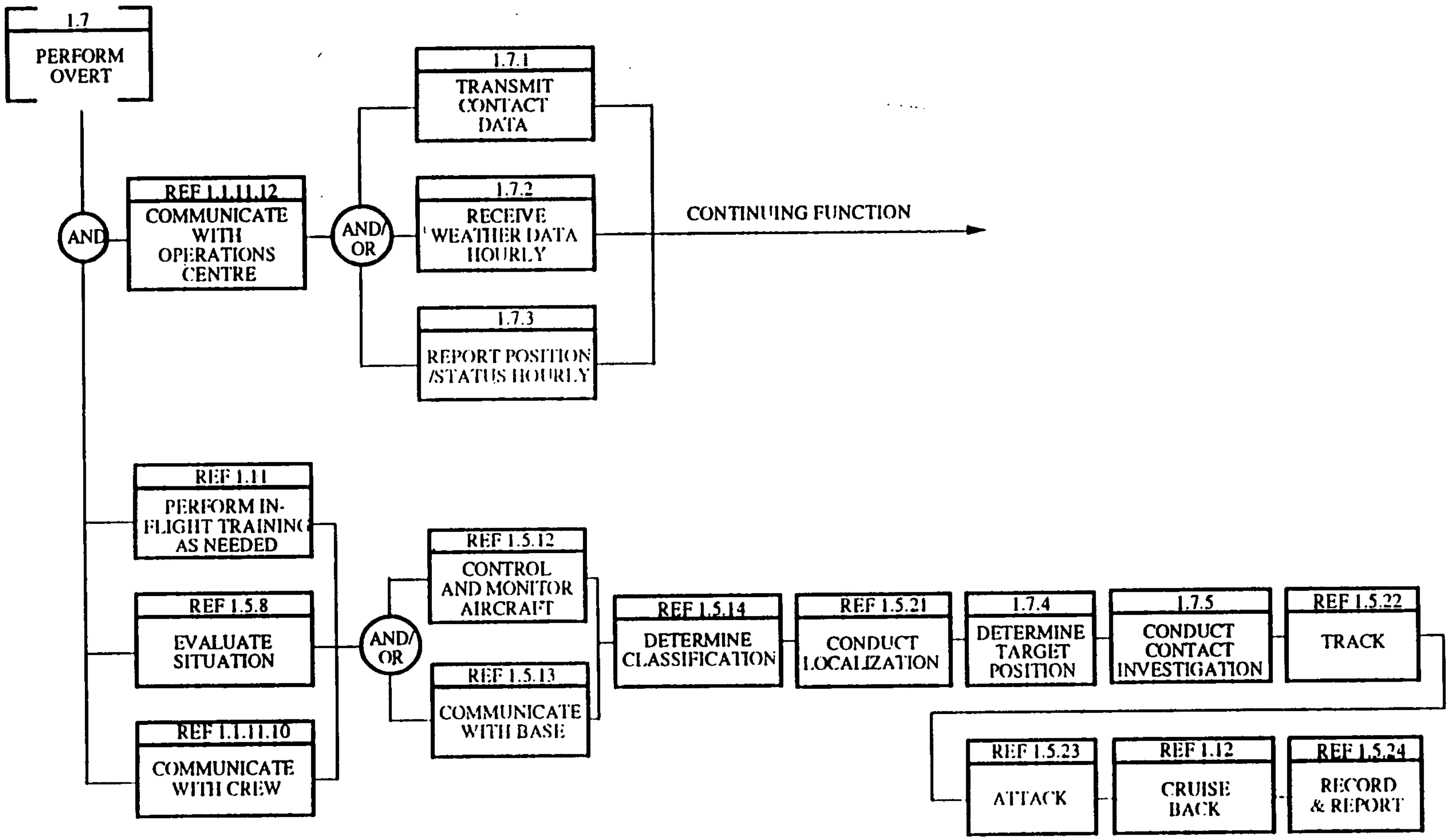
3.1.4.5. Cruise out function flow



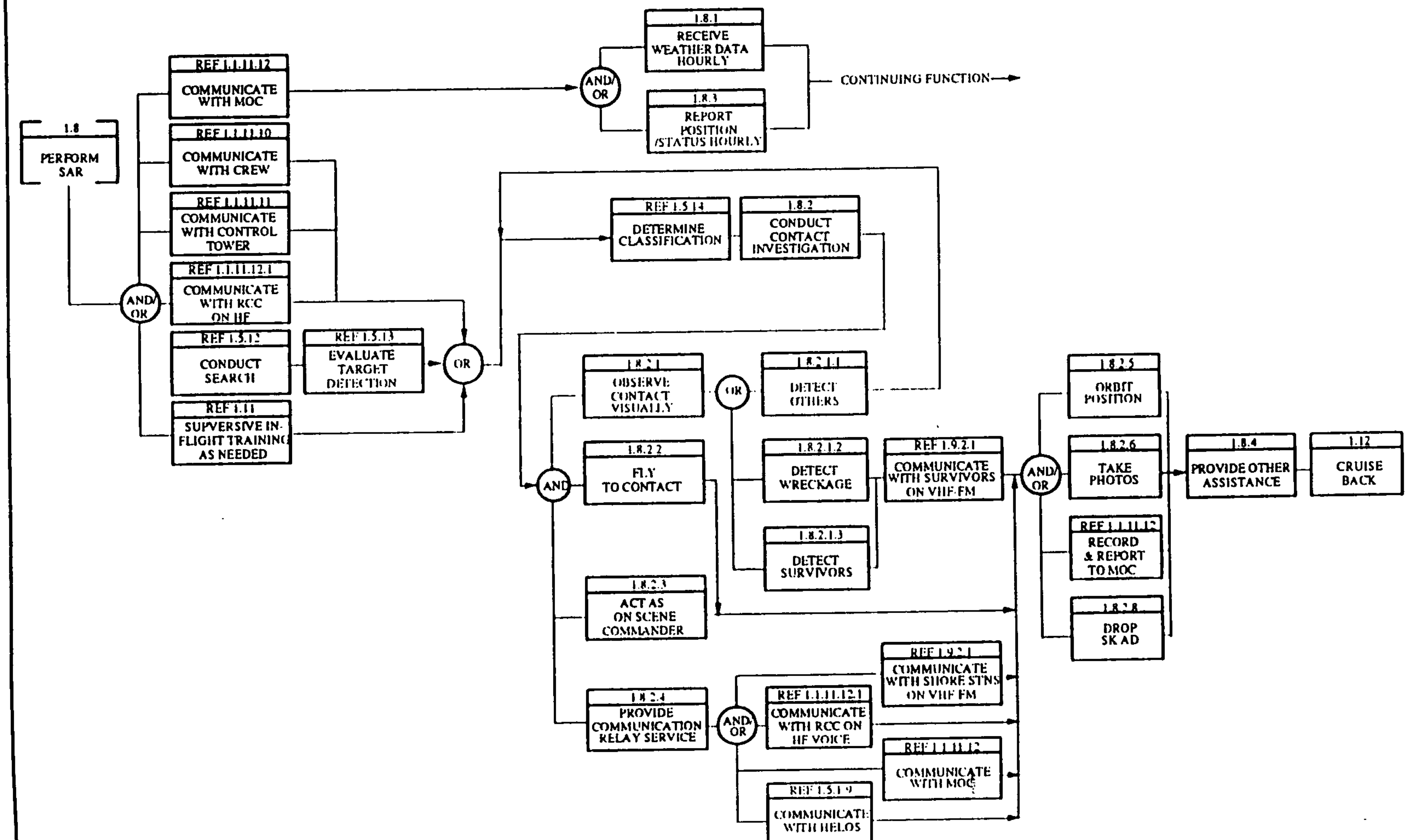
3.1.4.6. Coordinated operation mission function flow



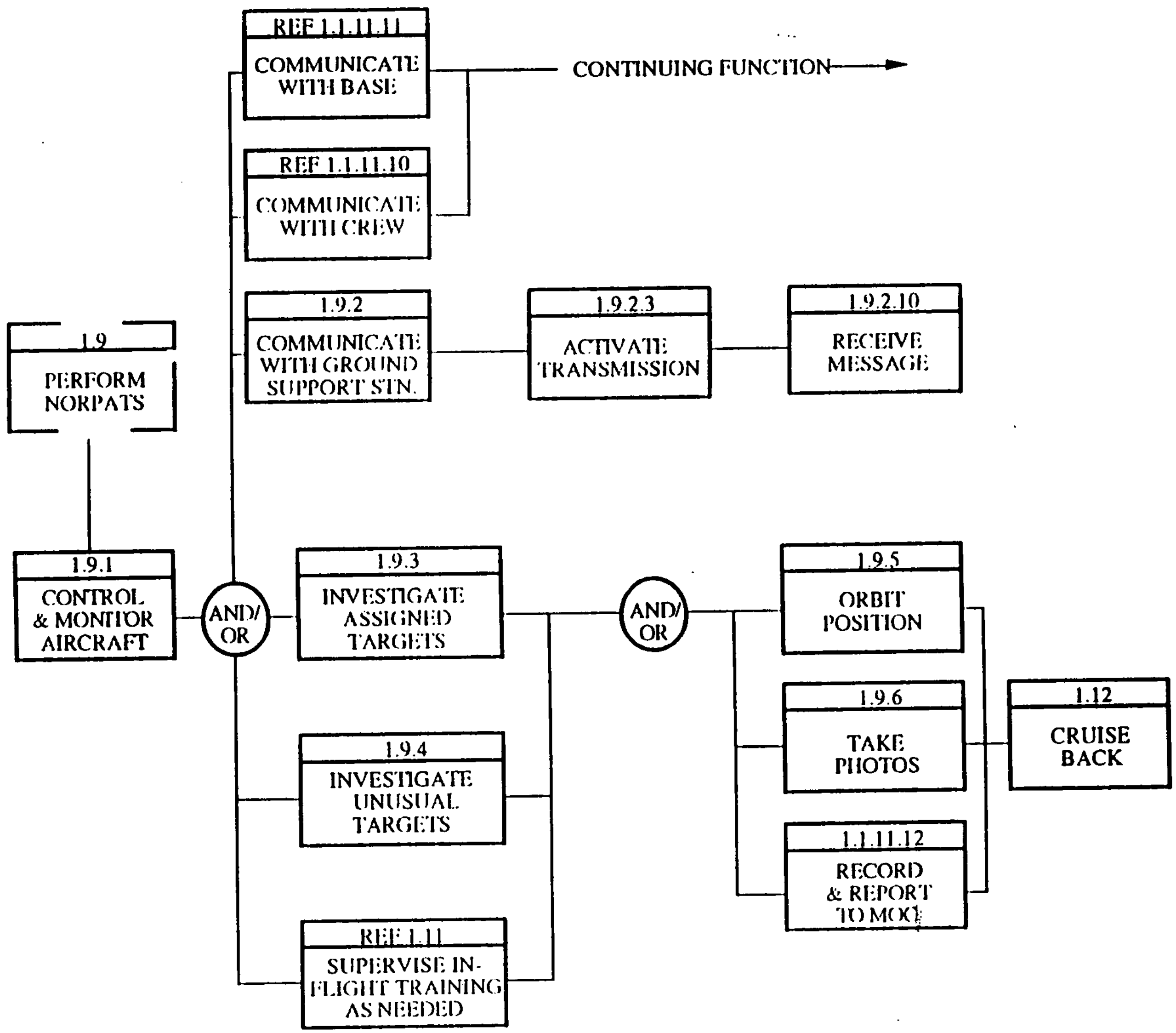
3.1.4.7. ASW mission function flow



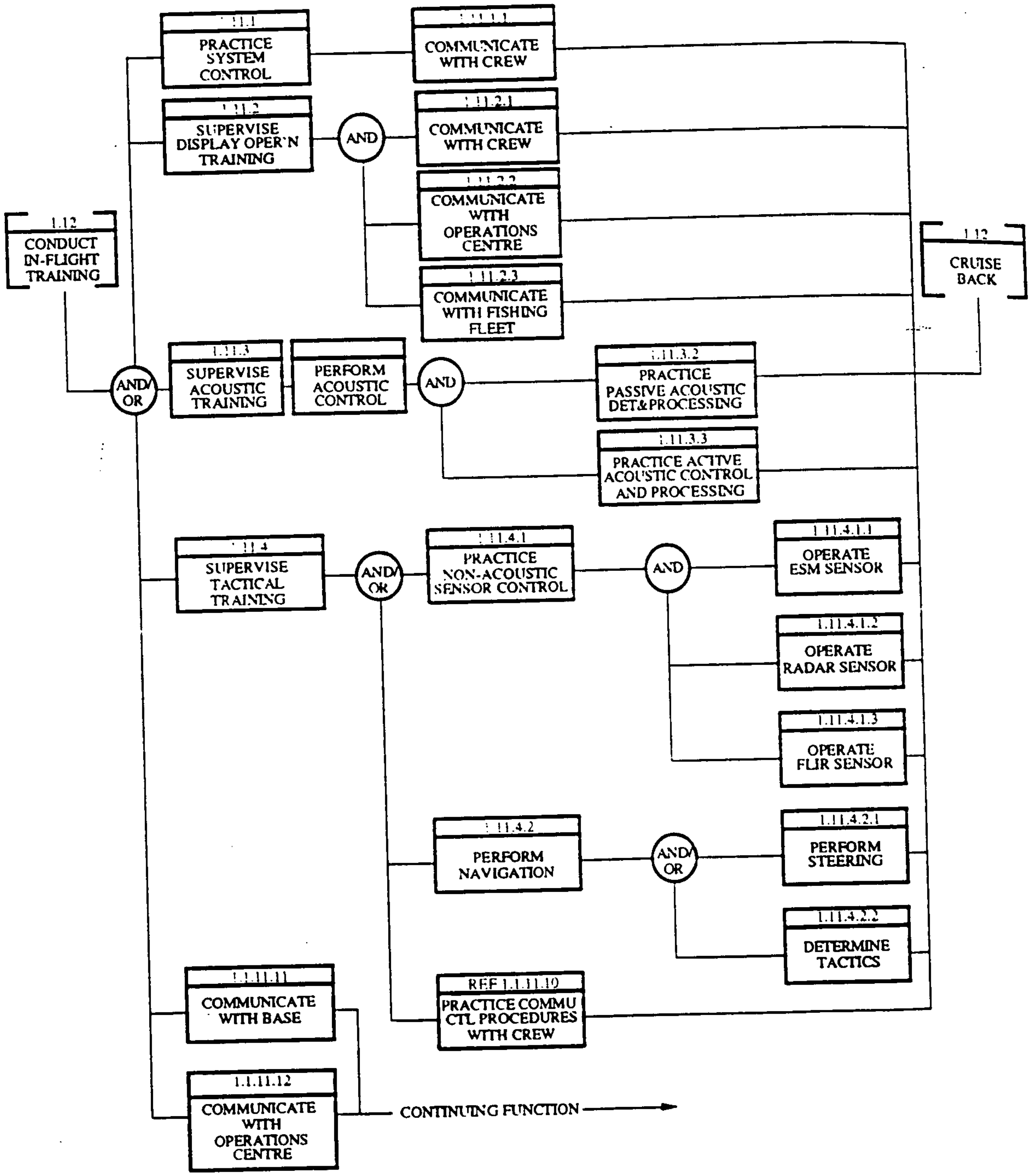
3.1.4.8. Search and rescue mission function flow



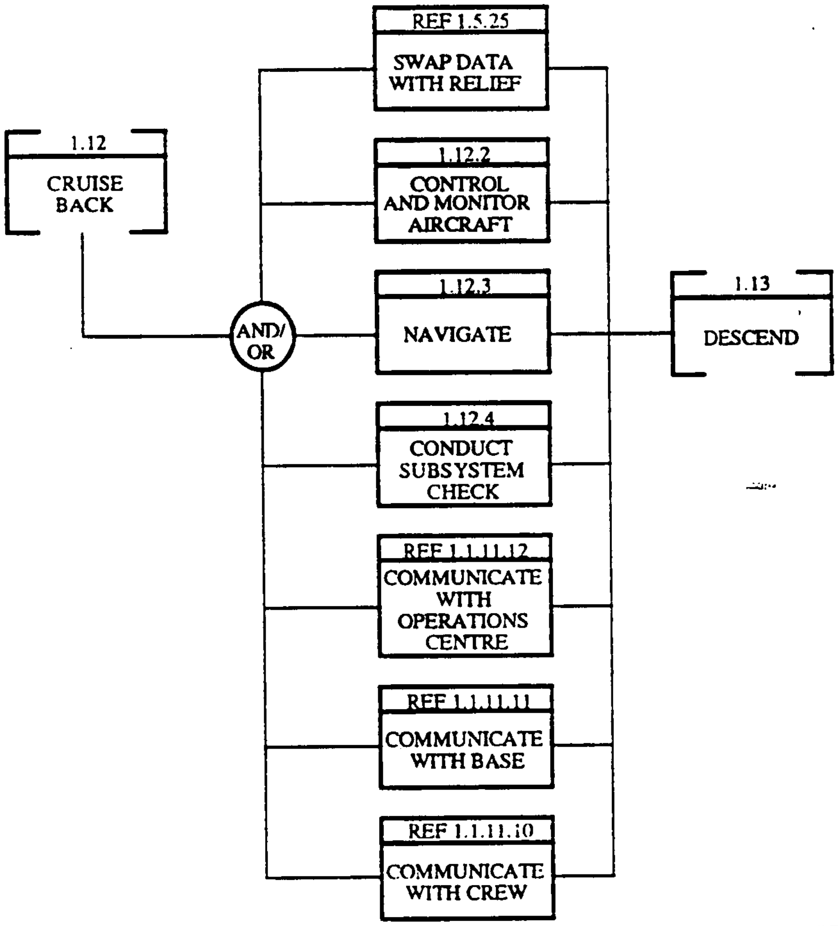
3.1.4.9. Northen patrols mission function flow



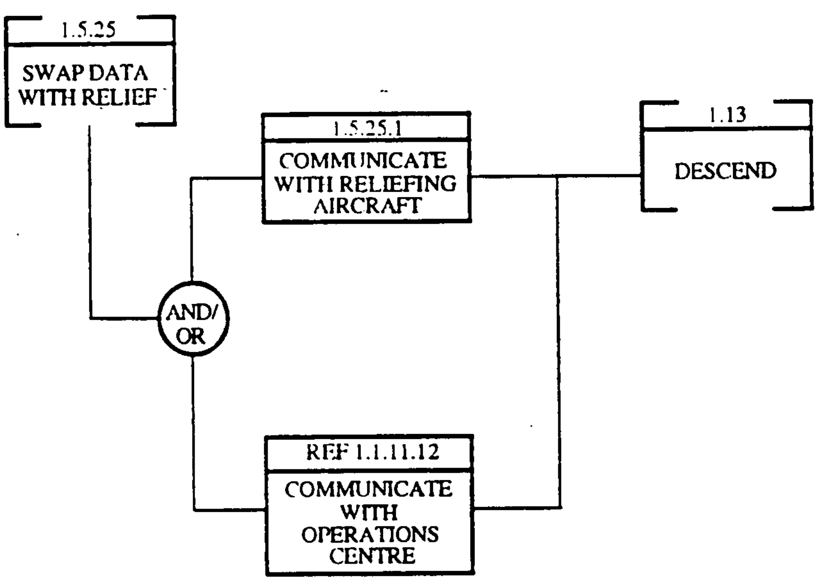
3.1.4.10. In-flight training mission flow



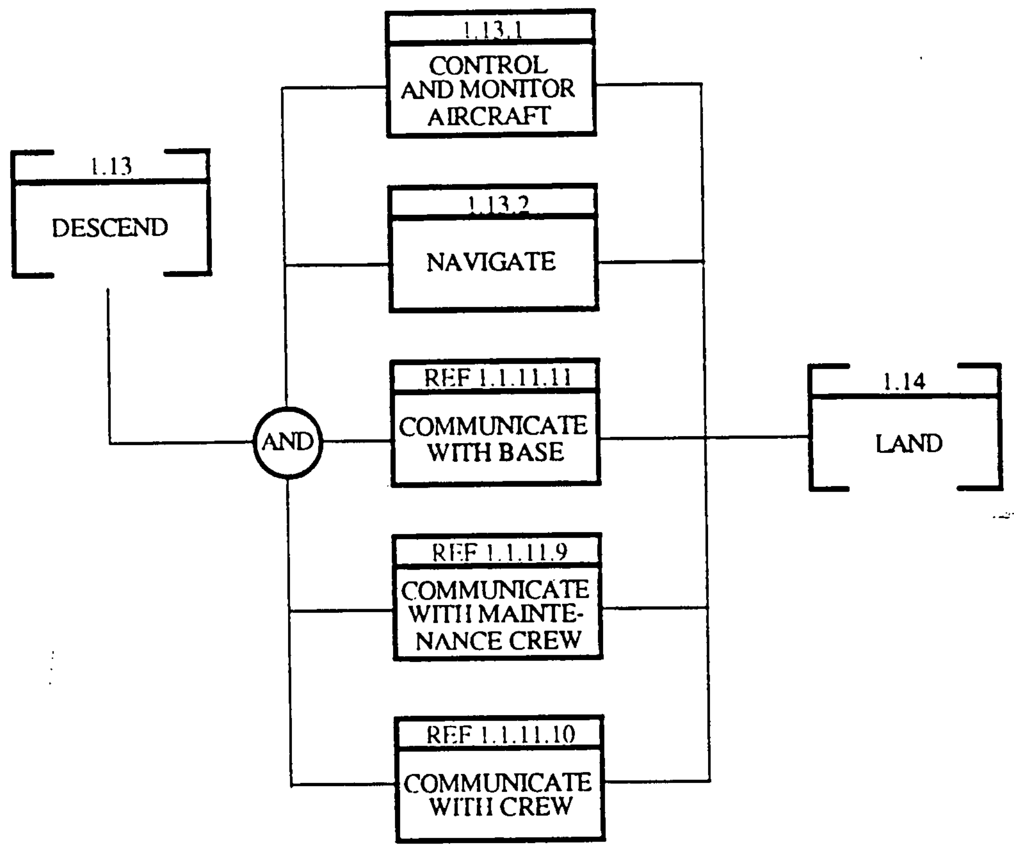
3.1.4.11. Cruise back function flow



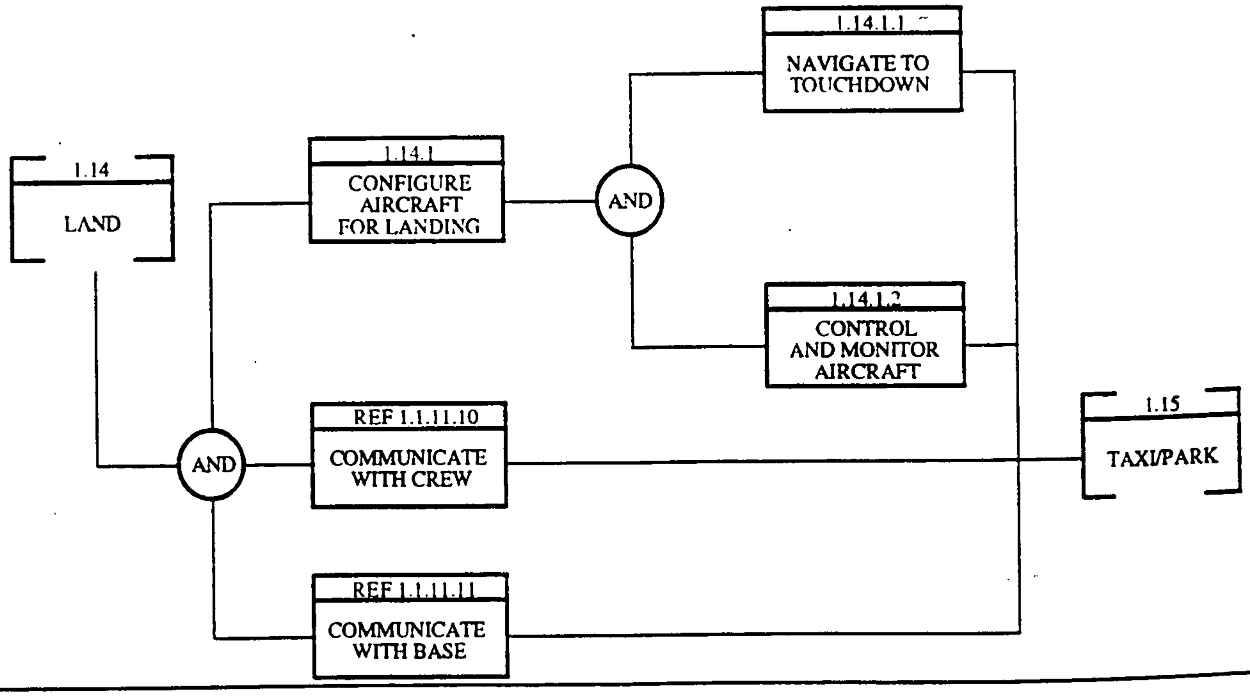
3.1.4.12. Swap data function flow



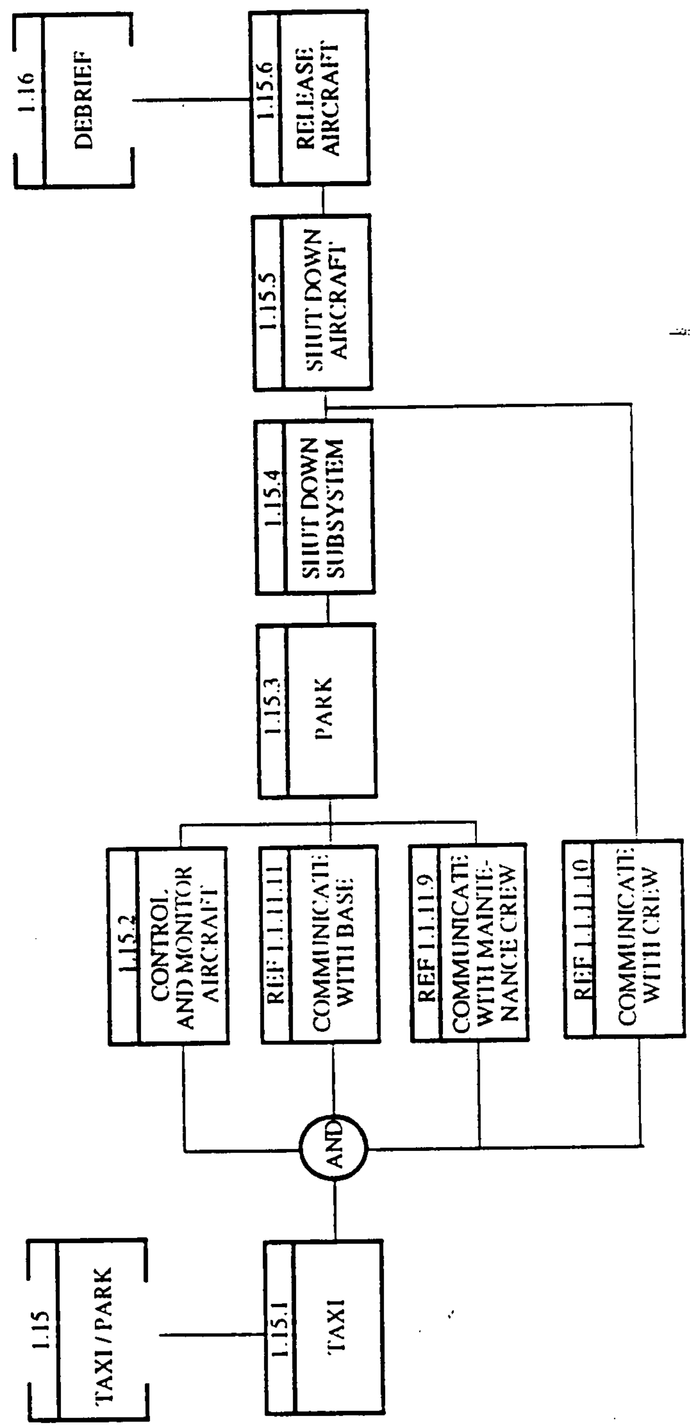
3.1.4.13. Descent function flow



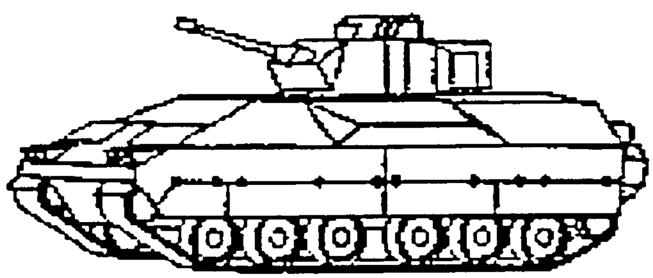
3.1.4.14. Land function flow



3.1.4.15. Taxi/Park function flow



3.2. ARMY SYSTEMS



3.2.1. System hierarchy of a military land vehicle

3.2.2. Function hierarchy of a battle tank engagement

3.2.3. Function flow diagrams of a battle tank engagement

3.2.4. Function hierarchy of a tank regiment in reserve

3.2.5. Hierarchy of operator tasks with a portable anti-tank weapon system

3.2.1. System hierarchy of a military land vehicle

Primary land vehicle

I. **Hull/frame**
  A. Hull or frame assembly
  B. Towing and fittings, bumpers, hatches, & grills
  C. Accommodation for sub-systems: suspension, weapons, turret, truck body, cab etc.

II. **Suspension/steering**
  A. Wheel/tracks
  B. Brakes
  C. Steering gears
  D. Rudder thrust devices & trim vanes
  E. Springs, shock absorbers & skirts

III. **Power packages/drive train**
  A. Engine
  B. Engine mounted auxiliaries, ducting & manifolds
  C. Controls & instrumentation
  D. Exhaust systems & cooling
  E. Clutches, transmission, shafting assemblies, torque converters, differentials, final drives, & power takeoffs

IV. **Auxiliary automotive systems**
  A. Electrical system
  B. Fire extinguisher system
  C. Winch & power takeoff
  D. Tools & equipment
  E. Crew accommodation

V. **Turret assembly**
  A. Armour & radiological shielding
  B. Hatches & cupolas
  C. Turret electrical system
  D. Accommodation for personnel, weapons & command & control

VI. **Fire control**
  A. Radar & other sensors
  B. Sights and scopes
  C. Computer
  D. Computer programmes

VII. **Armament**
  A. Main gun
  B. Launchers
  C. Secondary armament

VIII. **Body/cab**
  A. Accommodation for personnel
  B. Cargo sub-system

IX. **Special equipment**
  A. Blades, booms, winches
  B. Furnishings & equipment for command, medical & other special purpose vehicles

X. **Communications & navigation equipment**
  A. Radio receivers & transmitters
  B. Intercom
  C. External phone system
  D. Visual signalling devices
  E. Navigation system & data displays

3.2.2. Function hierarchy of a battle tank engagement

Battle tank functions

- I. **Detect Target**
  - A. **Search Target**
    1. Define Search Field
    2. Select Search Strategy
    3. Select Search Mode
    4. Activate Search Aids
    5. Perform Search
  - B. **Detect Presence**
    1. Identity Signatures
    2. Assess Signatures
    3. Determine Number of Objects
    4. Integrate Detection Data
  - C. **Localize Target**
    1. Receive Bearing Elevation of Air Threat
    2. Receive Bearing Elevation of Surface Threat
    3. Determine Air Threat Deployment/Prox.
    4. Determine Surface Threat Deployment/Prox.
    5. Integrate Localization Data
- II. **Identify Target**
  - A. **Recognize Threat Type**
    1. Compile Signatures
    2. Interpret Signatures
    3. Recognize Object
  - B. **Identify Friend or Foe**
    1. Acquire/Interpret Add. Signatures
    2. Identify As Friend
    3. Identify As Foe
    4. Identify As Unknown
  - C. **Classify Threat**
    1. Acquire/Interpret Ass Signatures
    2. Recognize Specific Type
- III. **Establish Priority**
  - A. **Assess Threat/Action**
    1. Assess Threat Capability
    2. Assess Own Defensive Offensive Posture
    3. Integrate Threat Data
    4. Classify Threat Lethality
    5. Select Course of Action
  - B. **Select Target**
    1. IntegratePrioritization Data
    2. Assign Priorities
    3. Select Target
- IV. **Engage Target**
  - A. **Select Weapon(s)**
    1. Inventory Own Weapon Capability
    2. Establish Target Vulnerability
    3. Select Weapon
    4. Select Ammo
  - B. **Acquire Target**

1. Course Align Weapon With Target
2. Fine Align Weapon With Target
3. Determine Range to Target
4. Maintain Track
5. Acquire Target

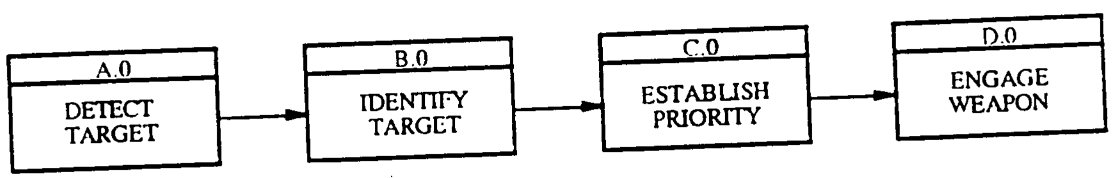
C. **Fire**
1. Verify Readiness
2. Fire
3. Verify Fire

D. **Validate Effect**
1. Verify Hit
2. Determine Kill
3. Determine Non-Kill
4. Determine Miss Distance/Direction
5. Make Corrections

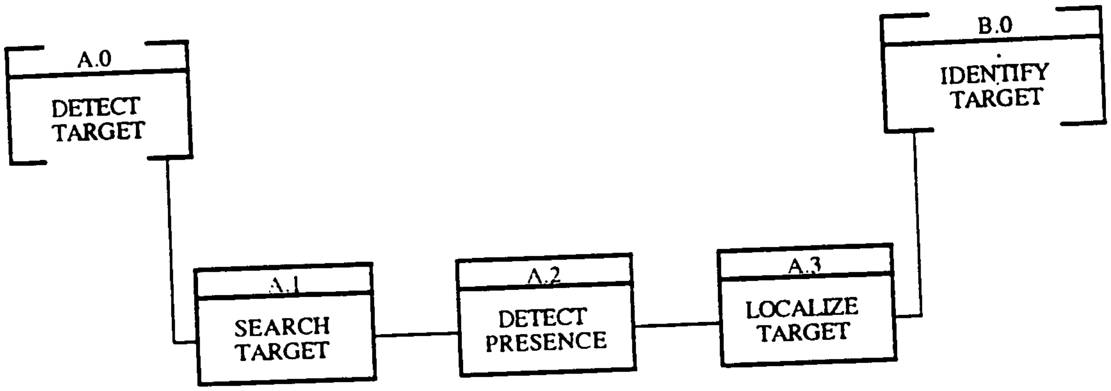
E. **Reload Weapon**
1. Acquire Shell
2. Charge Weapon
3. Verify Readiness

3.2.3. Function flow diagrams of a battle tank engagement

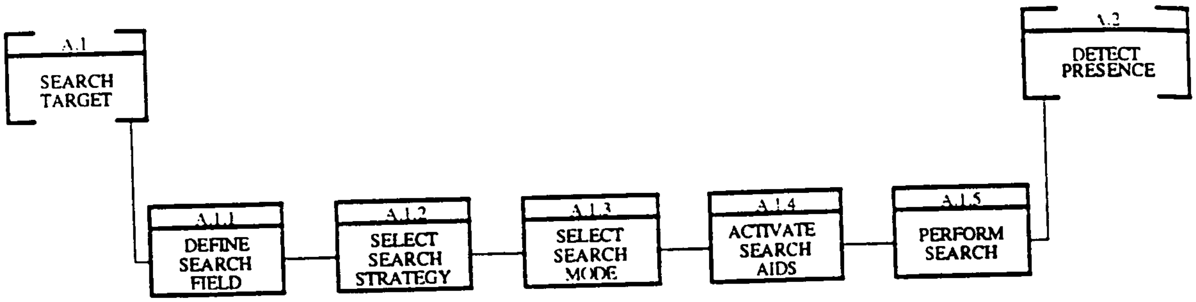
Combat mission functions



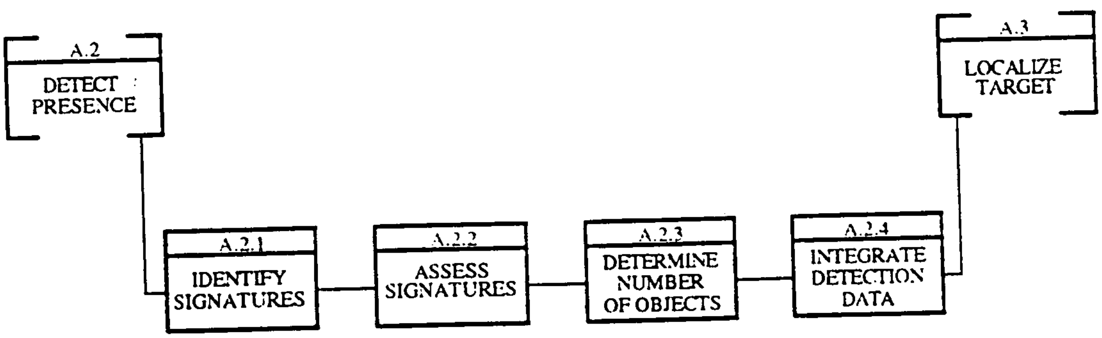
A.0. Detect target



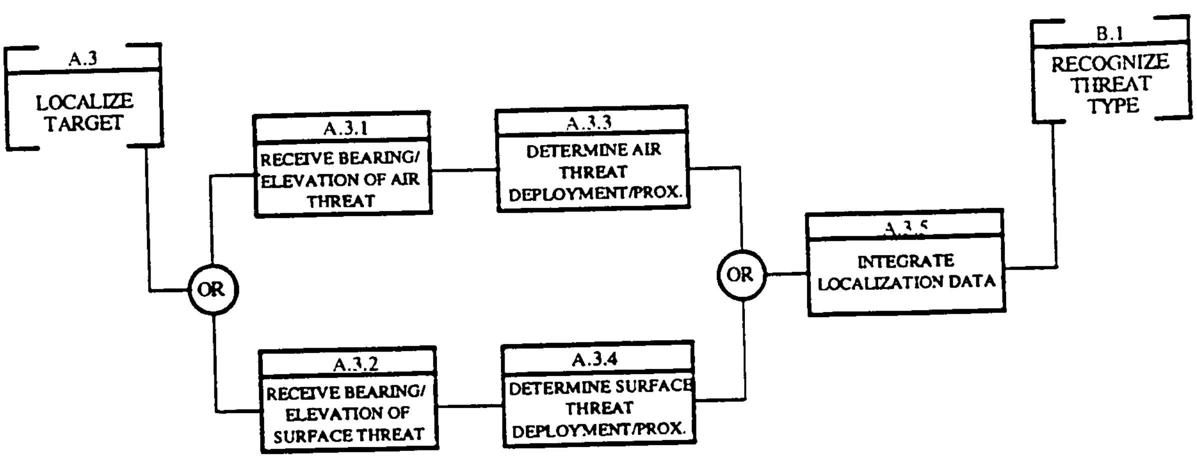
A.1. Search target



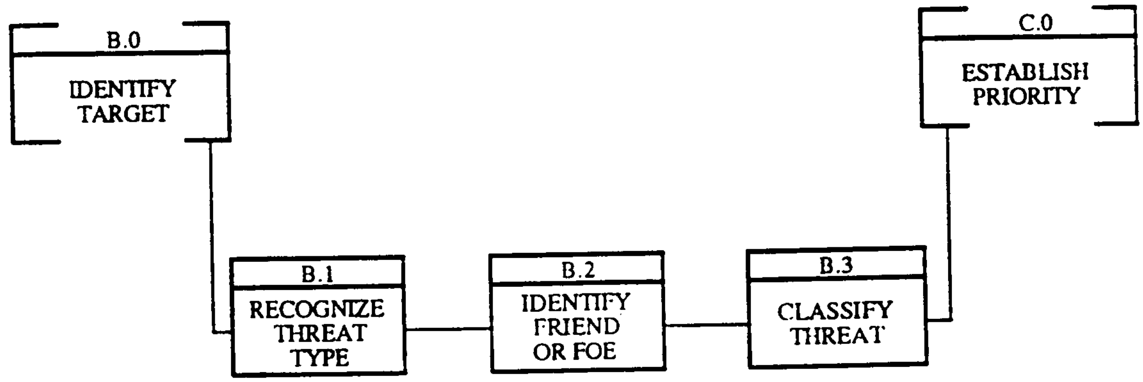
A.2. Detect presence



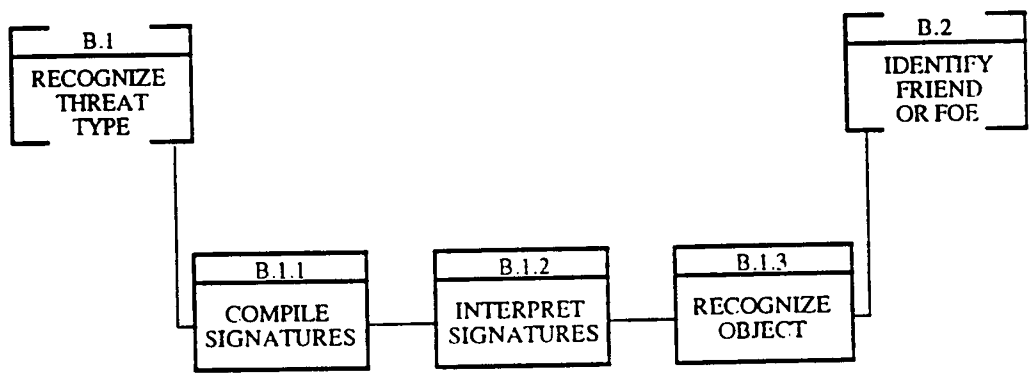
A.3. Localize target



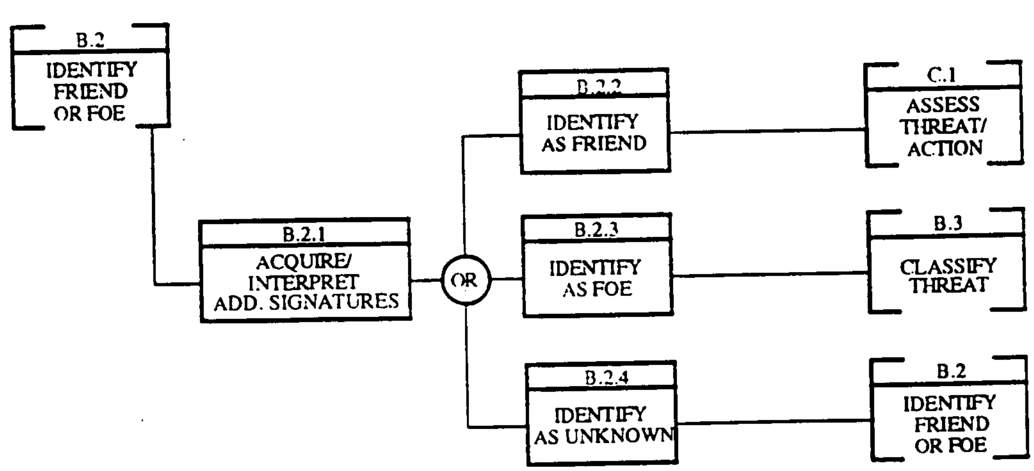
B.0. Identify target



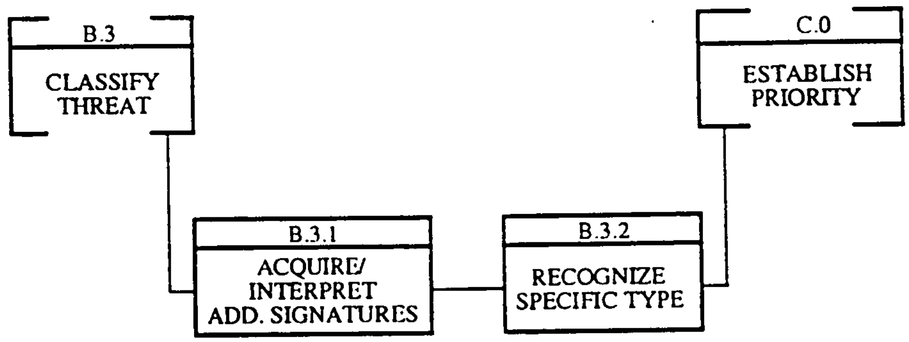
B.1. Recognize threat type



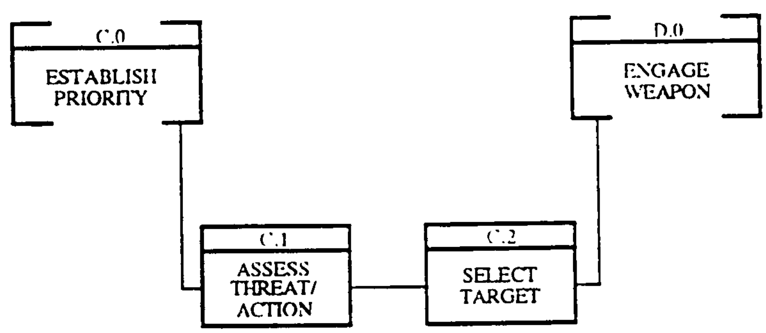
B.2. Identify friend foe



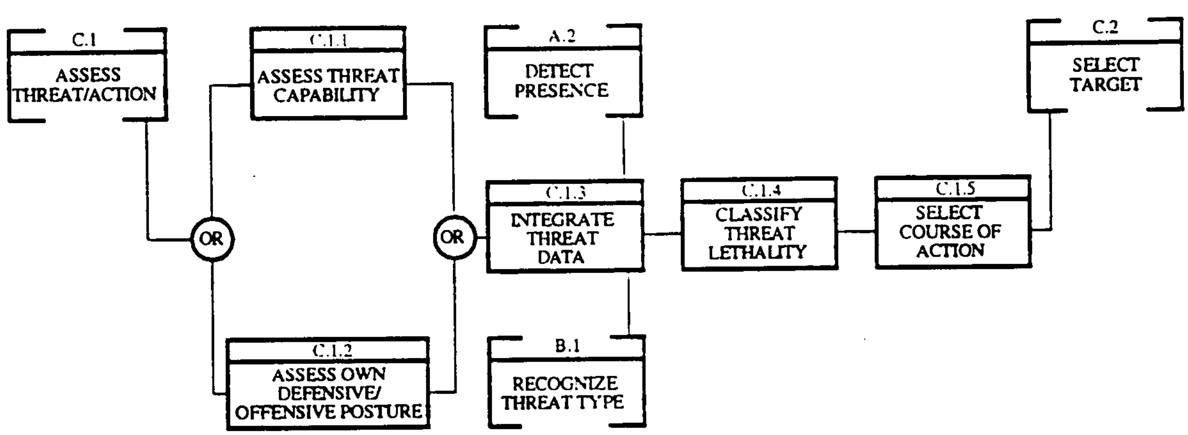
B.3. Classify threat



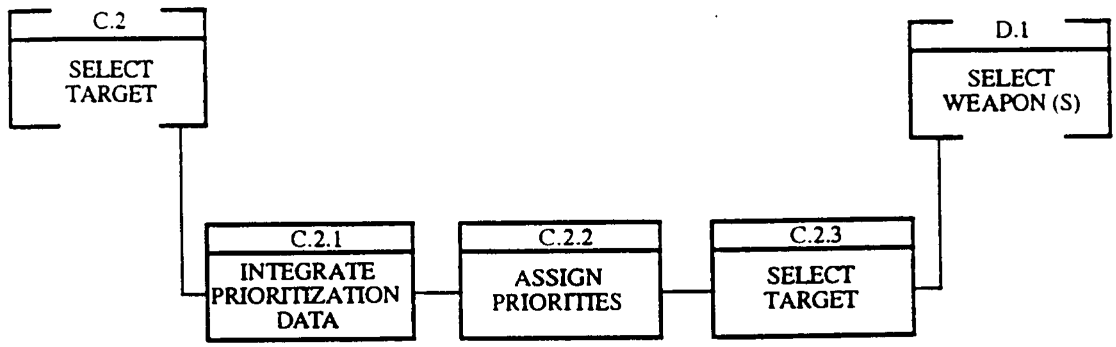
C.0. Establish Priority



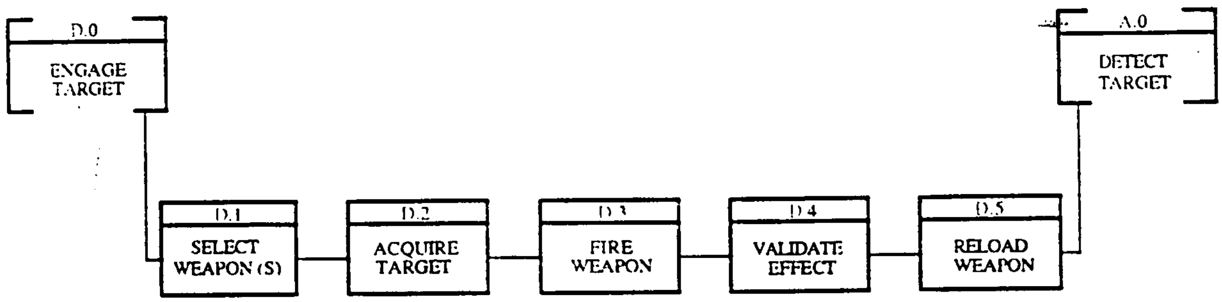
C.1. Assess threat/action



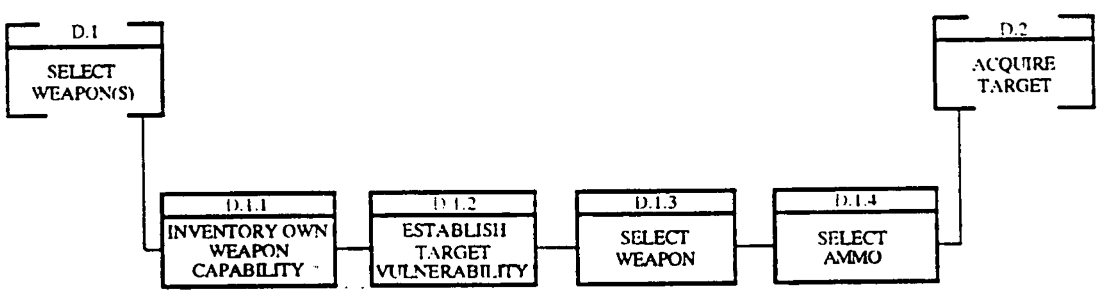
C.2. Select target



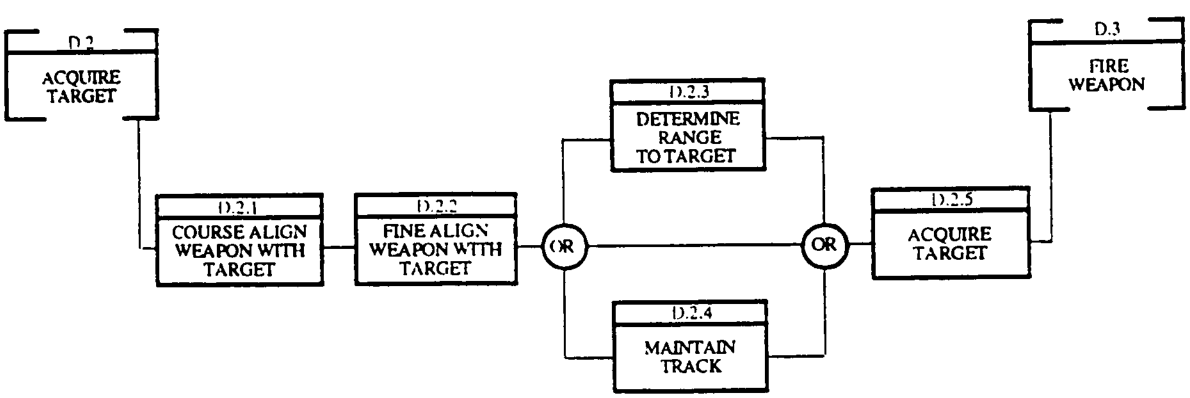
D.0. Engage target



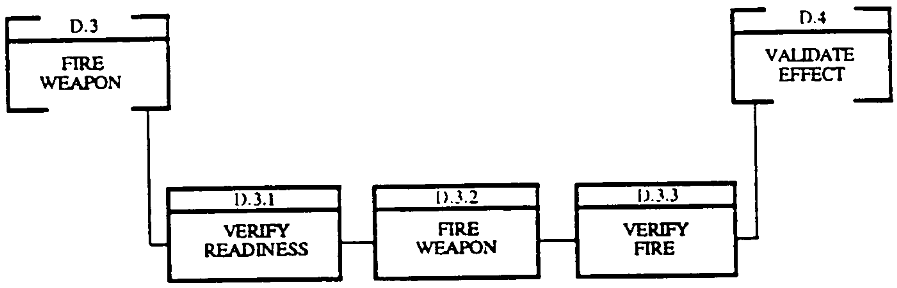
D.1. Select weapon(s)



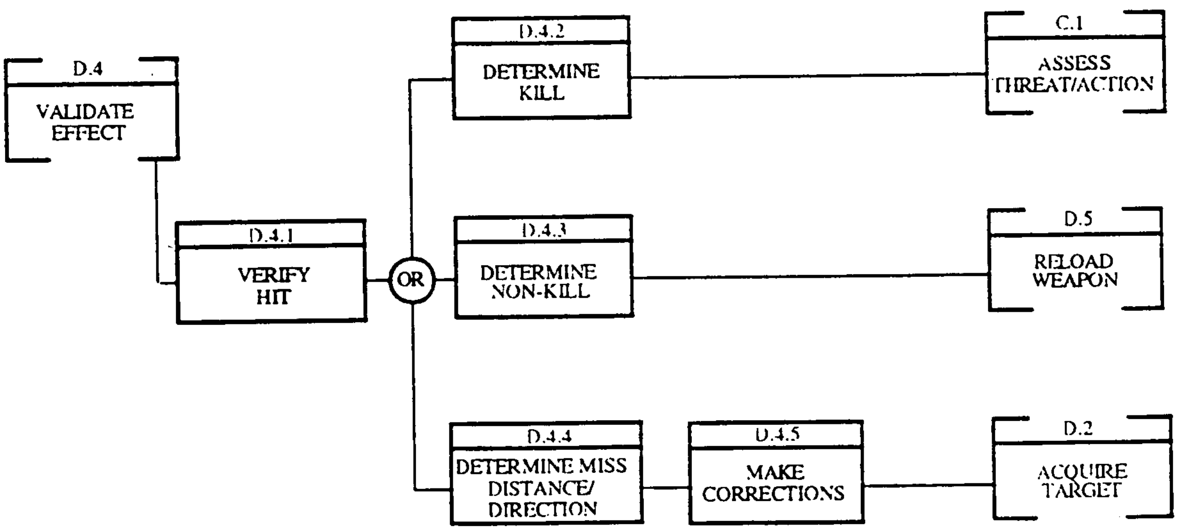
D.2. Acquire target



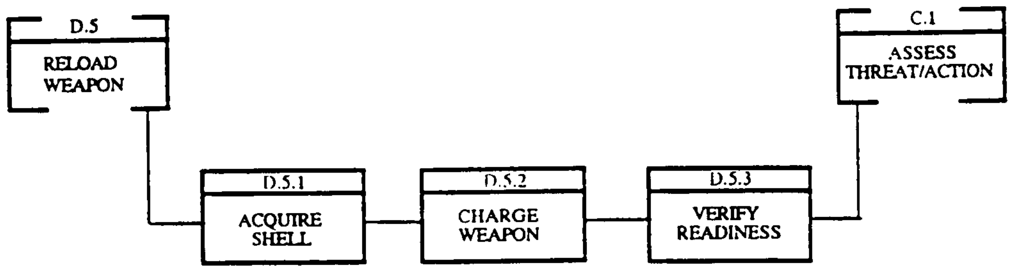
D.3. Fire weapon



D.4. Validate effect



D.5. Reload Weapon



3.2.4. Function hierarchy of a tank regiment in reserve

Functions of a tank regiment in reserve

I. **Support tank regiment in reserve**
   A. Manage overall support
   B. Accomplish corrective maintenance (main assembly and sub-assemblies)
      1. Carry out operational checks and diagnose faults
      2. Decide what corrective repairs are needed
      3. Procure spares as necessary
      4. Carry out repairs
      5. Perform operational tests
   C. Accomplish preventive maintenance (main assembly and sub-assemblies)
      1. Work through maintenance/service check-list
      2. Decide which components need replacing before next service
      3. Procure spares/components as necessary
      4. Exchange time-expired components
      5. Perform operational tests
   D. Procure replacement spares/components for workshops and units (including storage)

II. **Increase availability**
   A. Accelerate repair rate making more operational equipment available
   B. Increase stock of spares

III. **Optimize transfer from peacetime to wartime**
   A. Use wartime support resources
   B. Use similar logistic framework for peace/wartime
   C. Ensure support self-sufficiency for each tank regiment
   D. Ensure support self-sufficiency from division level support organization

IV. **Integrate effects of equipment changes**

V. **Manage operational resource potential**
   A. Ensure efficient management of weapon systems
   B. Ensure efficient management of support equipment

VI. **Protect system**
   A. Protect crews
   B. Protect auxiliary facilities
   C. Protect equipment
      1. Prevent sabotage

3.2.5. Hierarchy of operator tasks with a portable anti-tank weapon system

As already shown in Fig 1.1. system activities required to fulfill the system mission can be decomposed with increasing levels of detail. That means, similar to system functions, operator tasks can also be partitioned and structured hierarchically. To demonstrate such a partition in the following, tasks which an operator has to perform when handling an anti-tank weapon system are listed as an example:

I. **Prepare logistic containers for logistic transport**
   A. **Prepare transport on pallets**
      1. Stack containers on a pallet
      2. Bind containers on a pallet
   B. **Prepare normal transport**
      1. Stack containers

2. Bind containers

II. **Accomplish logistic transport**
   A. **Load logistic containers**
   B. **Transport logistic containers**
      1. Transport containers securely
         a) Tie down containers
         b) Transport containers
         c) Untie containers
      2. Transport containers normally
         a) Transport containers
   C. **Unload logistic containers**

III. **Prepare logistic containers for tactical transport**
   A. **Prepare munition**
      1. Open containers
      2. Remove the munition
   B. **Prepare firing post**
      1. Split up the logistic containers
      2. Open a container
      3. Remove the different items
   C. **Prepare thermal imager**
      1. Split up the logistic containers
      2. Open a container
      3. Remove the different items

IV. **Accomplish tactical transport**
   A. **Prepare items for transportation**
      1. Assemble the different tactical items on the special accessories
   B. **Displace the special accessories by foot**
      1. Load accessories
      2. Carry accessories
      3. Put-down accessories
   C. **Displace the special accessories by vehicle**
      1. Load accessories
      2. Transport accessories by vehicle
         a) Transport accessories securely
            (1) Tie down accessories
            (2) Transport accessories
            (3) Untie accessories
         b) Transport accessories normally
            (1) Transport accessories
      3. Unload accessories
   D. **Dismantle special accessories if the case arrises**

V. **Set up weapon system**
   A. **Prepare munition**
      1. Take a munition
      2. Remove the end cap
   B. **Set up firing post**

      1. Install tripod
      2. Mount ramp, sight/projector on tripod
      3. Check firing post
   C. **Set up thermal imager**

1. Mount thermal imager
2. Check thermal imager

D. **Place firing post in position**

E. **Load the munition**

VI. **Prepare weapon system for firing**

A. **Set the firing post level**

B. **Observe search field**

C. **Detect target**

D. **Recognize target**

E. **Identify target**

F. **Sight aim at target**

G. **Track target**

VII. **Firing weapon system**

A. **Release safety device**

B. **Press firing command**

C. **Track target to impact**

D. **Monitor impact**

E. **Verify effectiveness**

F. **Unload the tube**

VIII. **Change position**

A. **Change position with system ready to fire and distance ≤ 50 m**
1. Safe the weapon
2. Carry firing post with munition in place
3. Place firing post with its munition in position

B. **Change position with 50 m < distance < 400 m**
1. Safe the weapon
2. Unload munition
3. Remove the end caps
4. Carry assembled firing post and munition separately

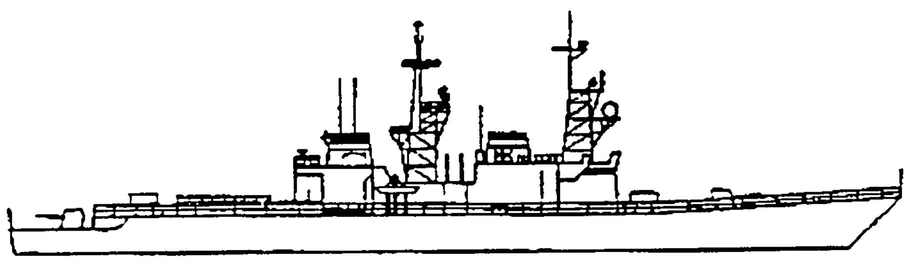
C. **Change position with distance > 400 m**
1. Unload munition
2. Remove the end caps
3. Dismantle firing post and make up the tactical loads

IX. **Prepare dismantled weapon system for logistic transport**

A. **Open logistic containers**

B. **Place different items in their respective containers**

3.3. NAVY SYSTEMS



3.3.1. System hierarchy of a ship

3.3.2. Functions of a merchant vessel´s bridge system

3.3.2.1. Listing of the function hierarchy

3.3.2.2. Diagrams of the function hierarchy

3.3.2.3. Function flow diagrams of the bridge system

3.3.3. System hierarchy of a fast patrol boat

3.3.3.1. Listing of the system hierarchy

3.3.3.2. Diagram of the system hierarchy

3.3.4. Function hierarchy of a fast patrol boat

3.3.5. Function flow diagrams of a fast patrol boat (in part)

3.3.6. Function hierarchy of a ship engine control centre

3.3.1. System hierarchy of a ship

Ship

1. **Hull structure**
   - 1.1. Shell plating, framing, platforms & decks, superstructure, foundations, bulkheads, enclosures
   - 1.2. Doors & closures
   - 1.3. Kingposts, masts & service platforms
   - 1.4. Sonar domes
2. **Propulsion plant**
   - 2.1. Boilers & energy converters
   - 2.2. Propulsion units
   - 2.3. Condensers & air ejectors
   - 2.4. Shafting, bearings & propellors
   - 2.5. Combustion air supply, & uptakes
   - 2.6. Propulsion control system
   - 2.7. Main stream, feedwater & condensate
   - 2.8. Circulating & cooling water
   - 2.9. Fuel oil service & lubricating oil systems
3. **Electric plant**
   - 3.1. Electric power generation
   - 3.2. Power distribution system
   - 3.3. Switchboards
   - 3.4. Lighting system
4. **Communication & control**
   - 4.1. Navigation system
   - 4.2. Interior communication systems
   - 4.3. Gun fire-control system
   - 4.4. Non-electronic countermeasures
   - 4.5. Electronic countermeasures
   - 4.6. Missile fire control systems
   - 4.7. ASW fire control systems & torpedo fire control systems
   - 4.8. Radar systems
   - 4.9. Radio communications systems
   - 4.10. Electronic navigation systems
   - 4.11. Sonar systems
   - 4.12. Electronic tactical data systems
5. **Auxiliary systems**
   - 5.1. Heating, ventilation, & air-conditioning systems
   - 5.2. Refrigeration spaces
   - 5.3. Plant & equipment
   - 5.4. Gasoline, JP-5, liquid cargo, oxygen-nitrogen & aviation lubricating oil systems
   - 5.5. Plumbing installations, salt-water service systems, fire extinguishing systems, drainage, etc.
   - 5.6. Steering systems, mooring, towing, anchor handling systems, deck machinery, elevators, etc.
   - 5.7. RAS & cargo-handling systems
6. **Outfit and furnishings**
   - 6.1. Hull fittings
   - 6.2. Boats, boat stowage & handling
   - 6.3. Rigging & canvas
   - 6.4. Ladders & gratings
   - 6.5. Non-structural bulkheads
   - 6.6. Storerooms, stowage & lockers

6.7. Equipment, utility spaces, workshops, laboratories etc.
6.8. Living spaces, offices, control centres, machinery spaces

7. **Armament**
 7.1. Guns & gun mounts
 7.2. Ammunition handling & stowage
 7.3. Special weapons handling & stowage
 7.4. Rocket & missile launching devices
 7.5. Torpedo tubes handling & stowage
 7.6. Small arms & pyrotechnic stowage, air-launched weapons handling systems
 7.7. Cargo munitions handling and stowage

3.3.2. Functions of a merchant vessel's bridge system

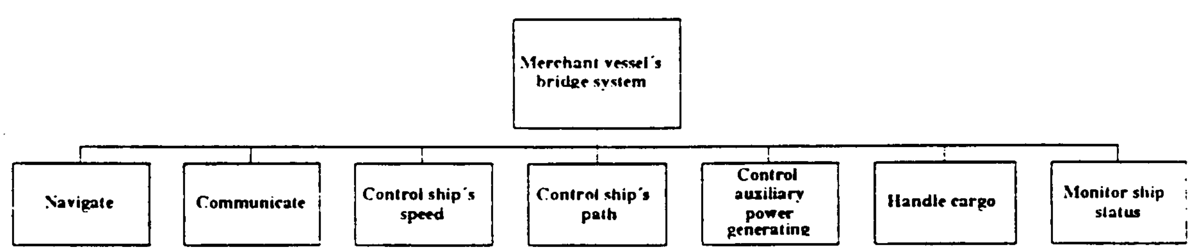
3.3.2.1. Listing of the function hierarchy

1. **Navigate**
 1.1. Prepare voyage
  1.1.1. Gather information
   1.1.1.1. Gather ship related information
   1.1.1.2. Gather navigational information
  1.1.2. Plan route
   1.1.2.1. Select routes
   1.1.2.2. Determine plan phases
   1.1.2.3. Determine route sections
   1.1.2.4. Select means and methods to navigate
   1.1.2.5. Assign watch-standers
 1.2. Conduct the passage
  1.2.1. Observe air and water
  1.2.2. Observe fairway and traffic
  1.2.3. Monitor heading, speed, position
 1.3. Monitor internal conditions
  1.3.1. Provide information in progress of travel
  1.3.2. Monitor time zones
  1.3.3. Monitor watch procedures
2. **Communicate**
 2.1. Visual communication
  2.1.1. Internal communication
  2.1.2. External communication
 2.2. Auditory communication
  2.2.1. Internal communication
  2.2.2. External communication
3. **Control ship's speed**
 3.1. Control propulsion
  3.1.1. Adjust propulsion direction
  3.1.2. Adjust propulsion due to speed
  3.1.3. Monitor travel progress due to speed
  3.1.4. Monitor speed adjustment with regard to safety and economy
 3.2. Monitor propulsion systems
  3.2.1. Anticipate incorrect use
  3.2.2. Anticipate disturbances

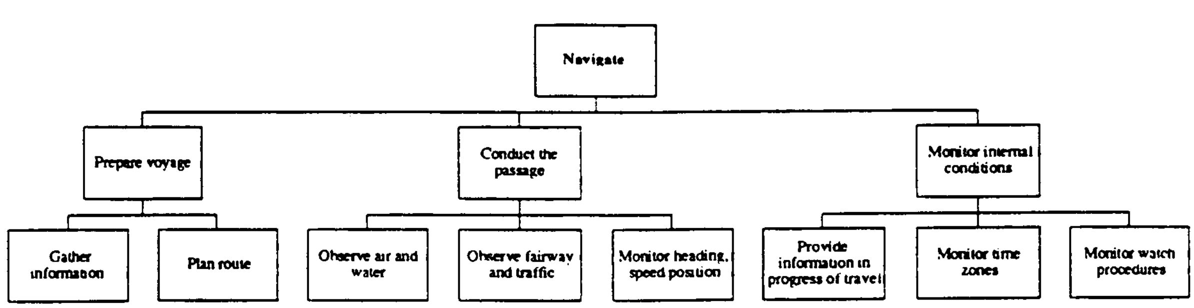
4. **Control ship's path**
   - 4.1. Control heading
     - 4.1.1. Adjust heading
     - 4.1.2. Monitor desired and actual heading
     - 4.1.3. Adjust rate
     - 4.1.4. Monitor desired and actual rate
   - 4.2. Monitor steering system
     - 4.2.1. Anticipate incorrect use
     - 4.2.2. Anticipate disturbance
5. **Control auxilliary power generating**
   - 5.1. Anticipate need
   - 5.2. Monitor supply
   - 5.3. Control supply
6. **Handle cargo**
   - 6.1. Monitor cargo
     - 6.1.1. Anticipate incorrect conditions
     - 6.1.2. Anticipate disturbance
   - 6.2. Control cargo conditions
7. **Monitor ship status**
   - 7.1. Monitor sea worthiness
   - 7.2. Monitor load and strength of hull and superstructure
   - 7.3. Monitor temperature and smoke detectors
   - 7.4. Monitor leakwater detectors

3.3.2.2. Diagrams of the function hierarchy

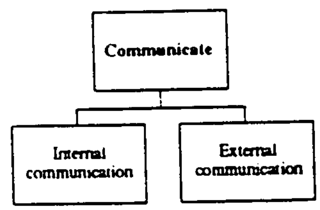
A. Upper hierarchy level



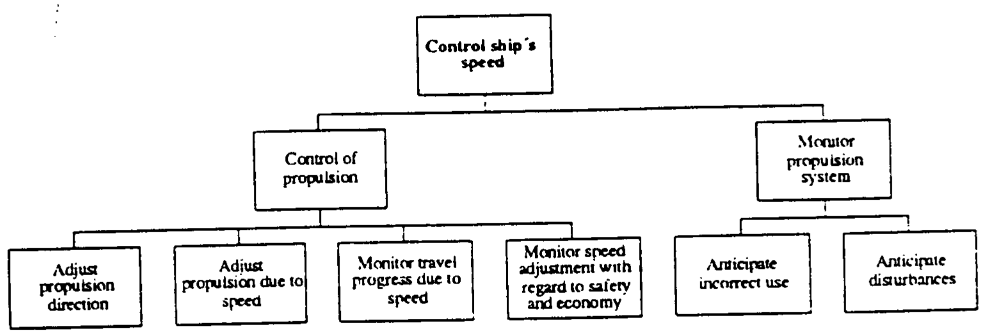
A.1. Hierarchy of the function "Navigate"



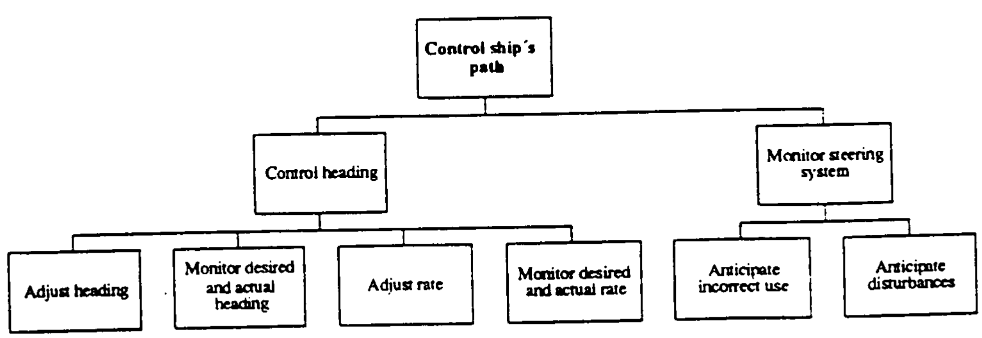
A.2. **Hierarchy of the function "Communicate"**



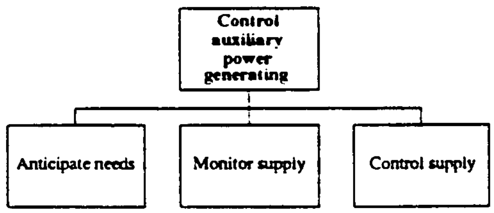
A.3. **Hierarchy of the function "Control ship's speed"**



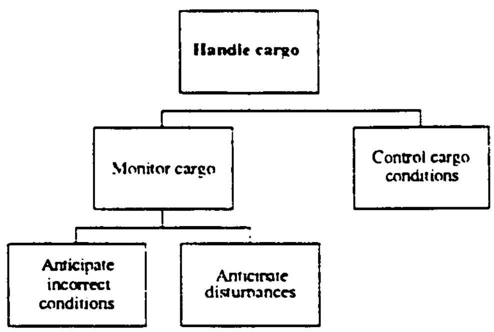
A.4. **Hierarchy of the function "Control ship's path"**



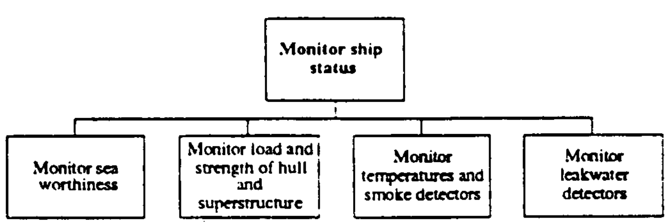
A.5. Hierarchy of the function "Control auxilliary power generation"



A.6. Hierarchy of the function "Handle cargo"

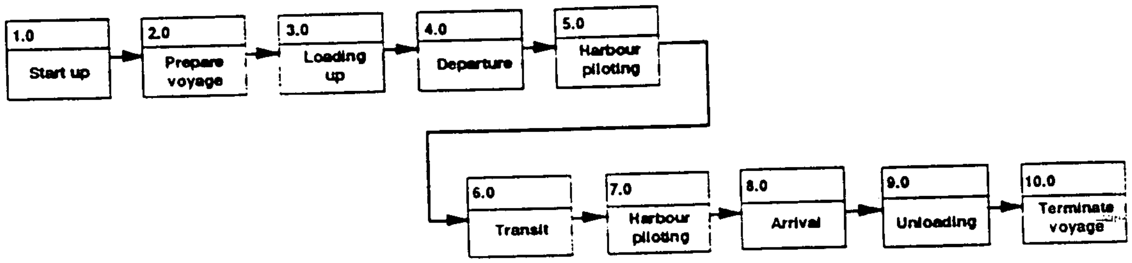


A.7. Hierarchy of the function "Monitor ship status"

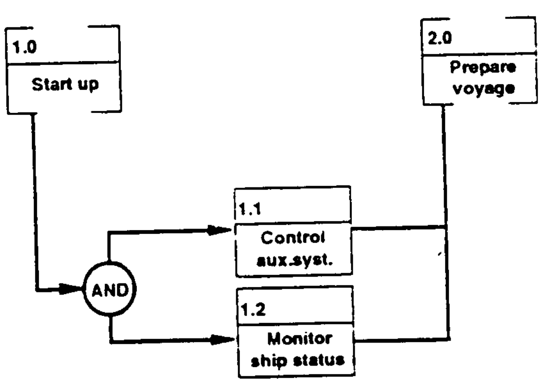


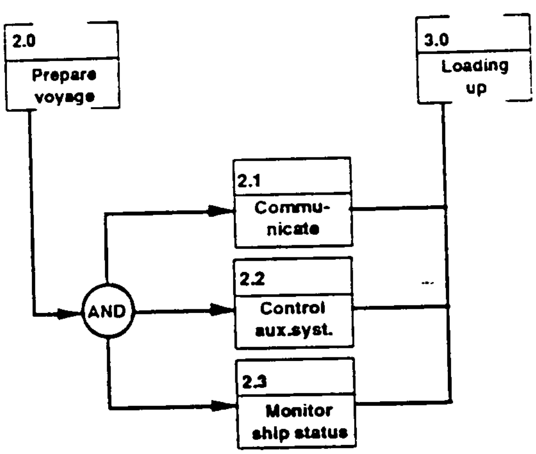
3.2.3. Function flow diagrams of the bridge system

A. Function flow diagram of the upper level functions

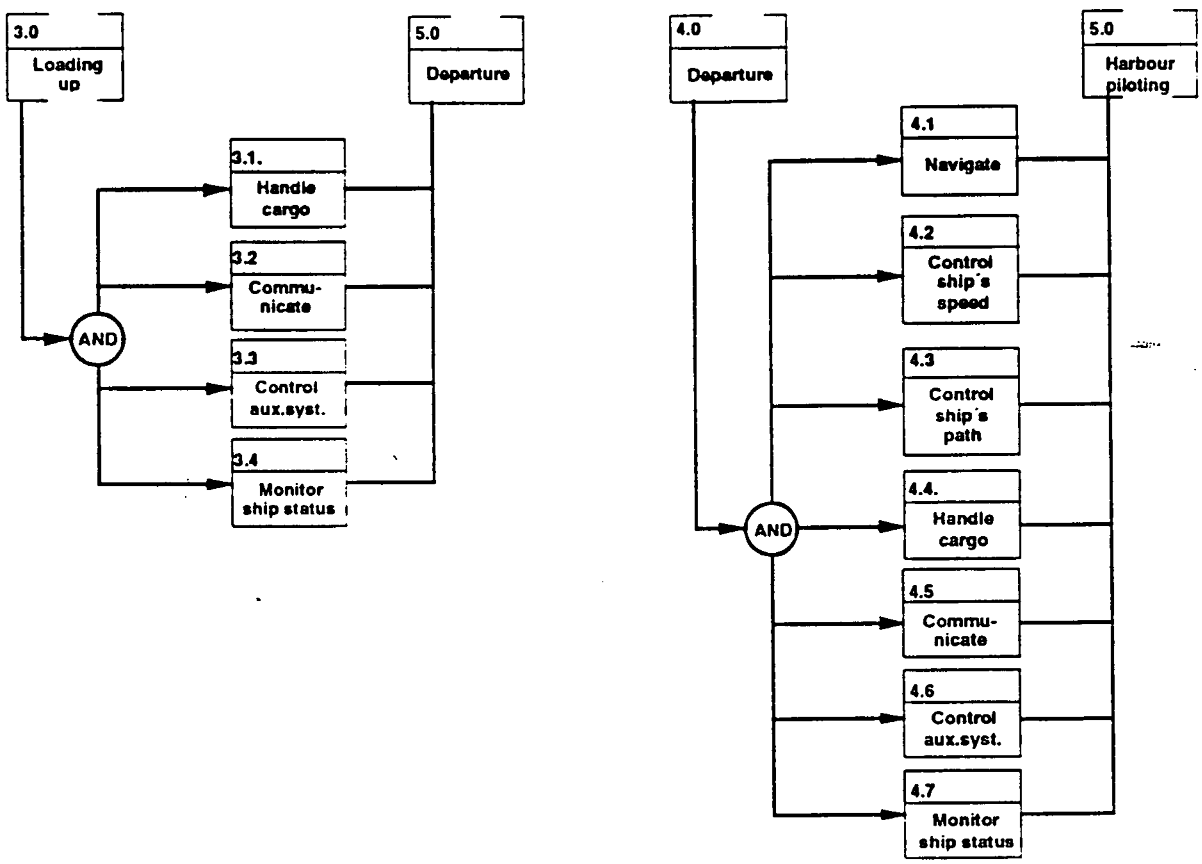


A.1. Function flow diagrams of the functions "Start up" and "Prepare voyage"





A.2. Function flow diagrams of the functions "Loading up" and "Departure"



The following upper level functions have the same subfunctions and function flow diagrams:

Departure (4.0)	= Habour piloting (5.0; 7.0), Transit (6.0), Arrival (8.0)
Loading up (3.0)	= Unloading (9.0)
Prepare voyage (2.0)	= Terminate voyage (10.0)

3.3.3. System hierarchy of a fast patrol boat (FPB)

3.3.3.1. Listing of the system hierarchy

Fast Patrol Boat

- I. **Sensor system**
  - A. Radar system
    1. Navigation radar
    2. Surveillance radar
    3. Tracking radar
  - B. **Optical electro optical system**
    1. Laser range finder
    2. IR-camera
    3. Optical sights
  - C. **Reference sensors**
    1. Navstar GPS
    2. Inertial platform
    3. EM Log
  - D. **ESM radar**
  - E. **ESM communication**
  - F. **ESM laser**
- II. **Radio Room**
  - A. **Link**
  - B. **Voice**
  - C. **RATT**
  - D. **Communication operator**
- III. **Top bridge**
  - A. **Fire controller**
- IV. **Bridge**
  - A. **Navigation station**
    1. Navigator
    2. Navigation console
  - B. **Officer of the watch**
- V. **Weapon system**
  - A. **SSM system**
    1. SSM
    2. SSM launcher
  - B. **Torpedo system**
    1. Torpedo
    2. Torpedo tube
  - C. **Gun system**
    1. Gun
    2. Ammunition transport
  - D. **SAM system**
    1. SAM
    2. SAM operator
    3. SAM launcher
  - E. **Jamming equipment**
  - F. **Chaff system**
  - G. **Flare system**

H. **Decoy system**

VI. **Operation room**

A. **Tactical station**

1. Commanding officer
2. Tactical consol

B. **Sensor station**

1. Sensor operator
2. Sensor console

C. **Weapon station**

1. Weapon operator
2. Weapon console

VII. **NBC sensor system**

VIII. **NBC protection system**

IX. **Instrument room**

A. **Radar extractor**

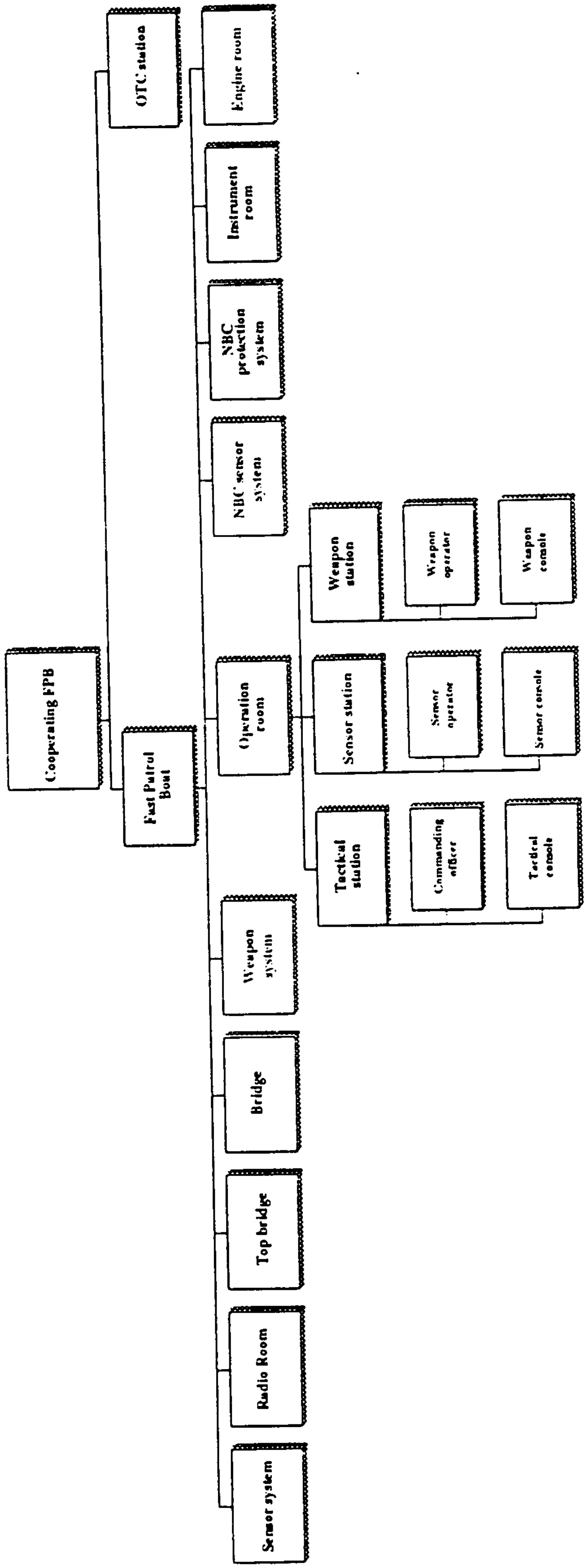
X. **Engine room**

XI. **OTC station**

A. **Officer in tactical command**

B. **OTC console**

3.3.3.2. Diagram of the FPB system hierarchy



3.3.4. Function hierarchy of a fast patrol boat (FPB)

Defence of FPB area

I. **Perform environment activities**
   A. **Incoming object function**
      1. **Non communicating object function**
         a) Reflect, emit, transmit indirect
         b) Reflect, emit, transmit direct
         c) Subject to FPB attack
         d) Attack FPB, use weapons
         e) Test exit from environment
         f) Exit from environment
      2. **Communicating object function**
         a) Transmit, emit reflect
         b) Send intelligence, object messages
         c) Exit
   B. **Incoming objects communication**
   C. **Land based installations function**

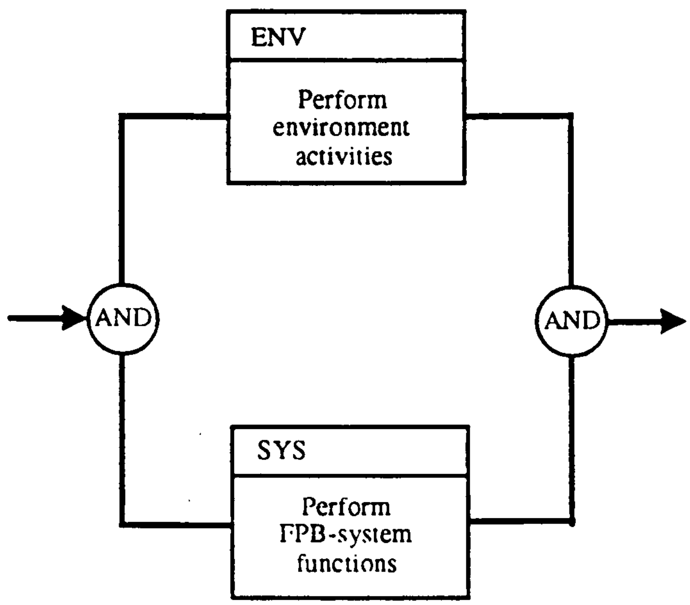
II. **Perform FPB-system functions**
   A. **Operate FPB**
      1. **Respond to incoming objects**
         a) Respond to one incoming object
            (1) Tracking and attack
            (2) Analyse
            (3) Attack
            (4) Surface defence
            (5) Air defence
            (6) Test exited/neutralised or continue
         b) Coordinate response
      2. **Respond to messages and detectables**
         a) NBC defence
            (1) Receive NBC detectables
            (2) Analyse NBC danger
            (3) Respond to NBC danger
            (4) Test all MEUs neutralised?
            (5) Receive NBC messages
         b) Respond to mine fields
            (1) Receive mine fields messages
            (2) Update mine fields info
         c) Respond to weather and visibillity
            (1) Monitor weather and visibility
            (2) Receive weather and visibility messages
            (3) Update weather and visibility info
         d) Respond to gun shells
            (1) Perform chaff engagement
            (2) Test all MEUs neutralised?
            (3) Detect and analyse gun shells threat
         e) Respond to situation reports
            (1) Receive situation reports
            (2) Update general situation
         f) Respond to logistics

(1) Receive logistics report
(2) Update logistics

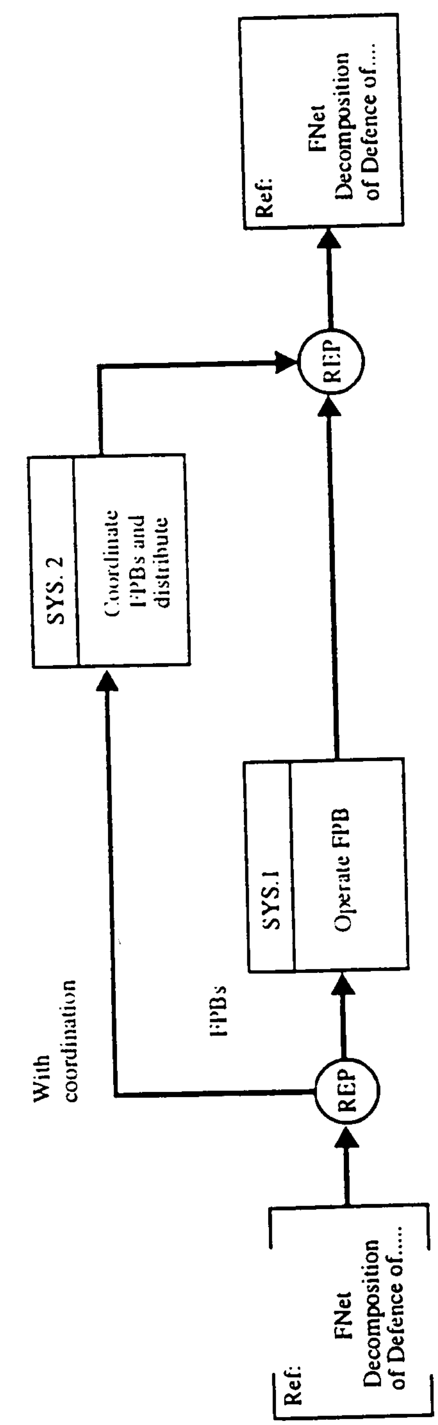
3. **Respond to orders**
   a) Sail FPB according to orders
      (1) Make/update sailing route
      (2) Positioning
      (3) Update course and speed
      (4) Steering and propulsion
   b) Respond to emcon orders
      (1) Test all MEUs neutralised?
      (2) Receive emcon orders
      (3) Respond to communication emcon
      (4) Respond to heat radiation emcon
      (5) Respond to light emcon
      (6) Respond to noise emcon
      (7) Respond to sensor emcon
      (8) Respond to smoke emcon
   c) Respond to Communication plan orders
      (1) Test all MEUs neutralised?
      (2) Receive communication orders
      (3) Execute communication orders
4. **Assess situation, monitor FPB status**
   a) Test all MEUs neutralised?
   b) Assess situation
   c) Monitor FPB status

B. **Coordinate FPBs and distribute**
1. **Coordinate FPBs**
   a) Preparation
      (1) Plan mission (preparation)
      (2) Coordinate preparation
   b) Approach
      (1) Plan mission (approach)
      (2) Coordinate approach
   c) Combat
      (1) Coordinate combat
   d) Post Combat
      (1) Plan mission (Post combat)
      (2) Coordinate post combat
2. **Distribute data between FPBs**

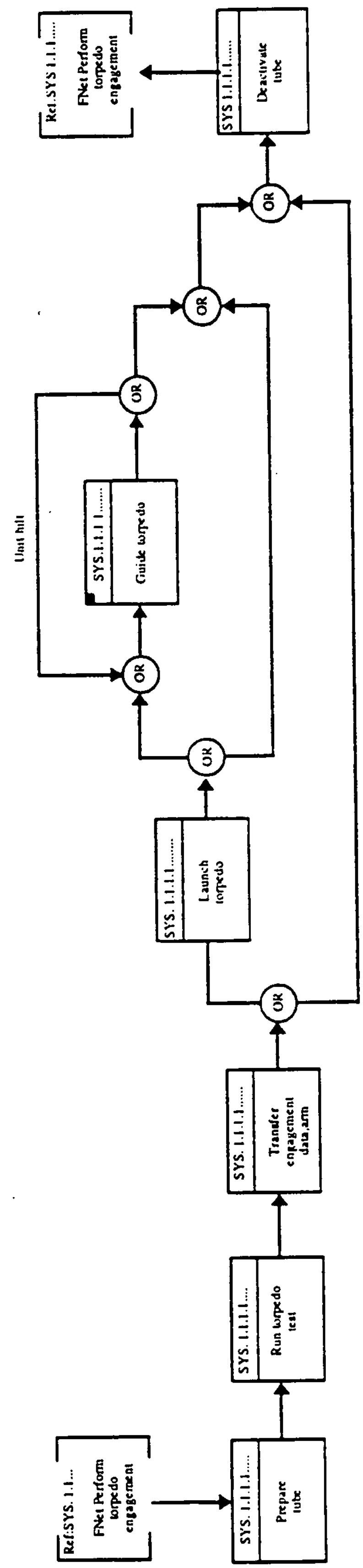
3.3.5. **Function flow diagrams of a fast patrol boat (FPB) (in part)**



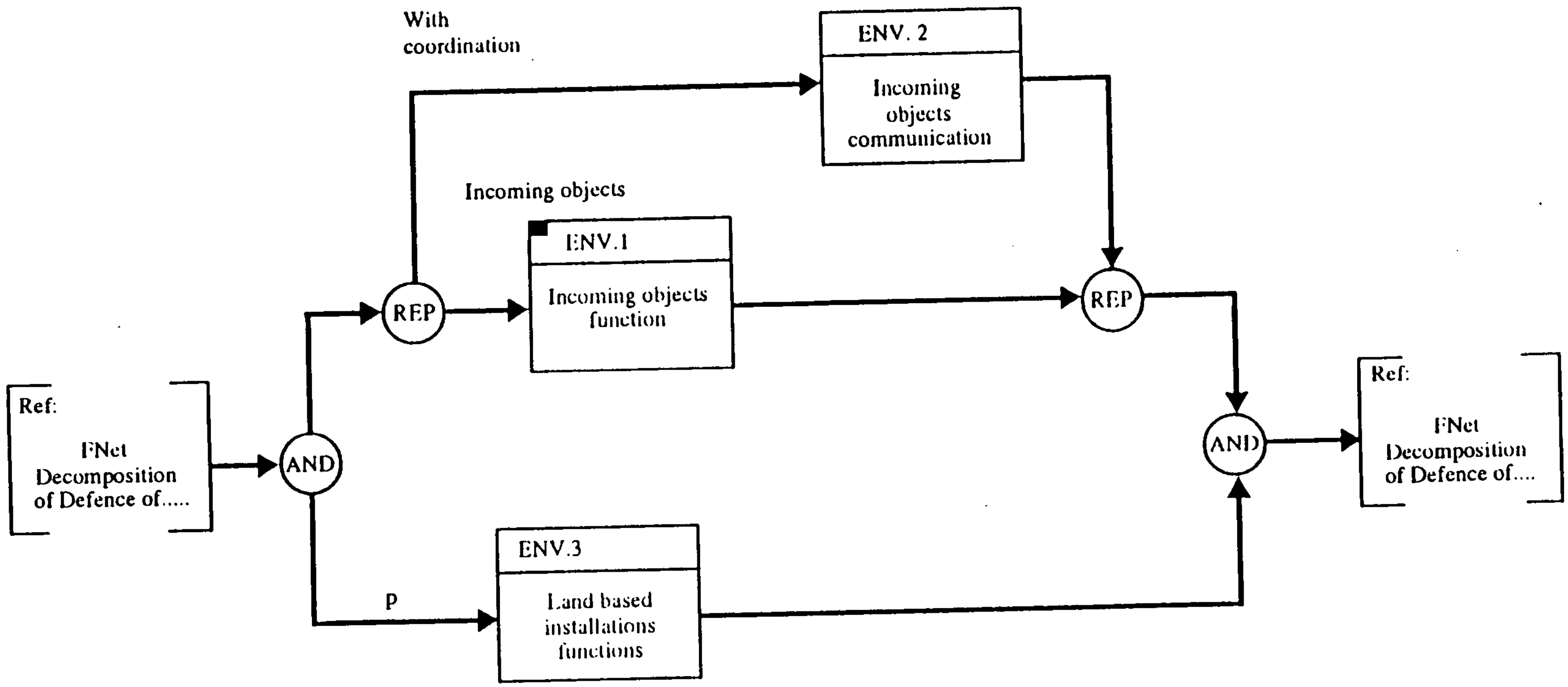
A.1. Perform FPB system functions



A.1.1. Perform single torpedo engagement



A.2. Perform environment activities



3.3.6. Function hierarchy of a ship engine control centre

I. Control propulsion subsystems (PSS)

A. Execute PSS requests of the bridge

1. Execute diesel requests

a) Start diesel

(1) Acknowledge start diesel request
(2) Check start readiness
(3) Activate start
(4) Monitor start
(5) Report start completion
(6) Identify start unreadiness cause
(7) Report start unreadiness
(8) Identify start failure
(9) Report start failure

b) Stop diesel

(1) Acknowledge stop diesel request
(2) Check stop readiness
(3) Activate stop
(4) Monitor stop
(5) Report stop completion
(6) Identify stop unreadiness cause
(7) Report stop unreadiness
(8) Identify stop failure
(9) Report stop failure

c) Change over to diesel

(1) Acknowledge change over to diesel request
(2) Check change over readiness
(3) Activate change over
(4) Monitor change over
(5) Report change over completion
(6) Identify change over unreadiness cause
(7) Report change over unreadiness
(8) Identify change over failure
(9) Report change over failure

2. Execute hydaulic clutch requests

a) Fill hydraulic clutch

(1) Acknowledge fill request
(2) Check fill readiness
(3) Activate fill
(4) Monitor fill
(5) Report fill completion
(6) Identify fill unreadiness cause
(7) Report fill unreadiness
(8) Identify fill failure
(9) Report fill failure

b) Empty hydraulic clutch

(1) Acknowledge empty request
(2) Check empty readiness

(3) Activate empty
(4) Monitor empty
(5) Report empty completion
(6) Identify empty unreadiness cause
(7) Report empty unreadiness
(8) Identify empty failure
(9) Report empty failure

3. Execute gas turbine requests

a) Start gas turbine

(1) Acknowledge start request
(2) Check start readiness
(3) Activate start
(4) Monitor start
(5) Report start completion
(6) Identify start unreadiness cause
(7) Report start unreadiness
(8) Identify start failure
(9) Report start failure

b) Stop gas turbine

(1) Acknowledge stop request
(2) Check stop readiness
(3) Activate stop
(4) Monitor stop
(5) Report stop completion
(6) Identify stop unreadiness cause
(7) Report stop unreadiness
(8) Identify stop failure
(9) Report stop failure

c) Change over to gas turbine

(1) Acknowledge change over request
(2) Check change over readiness
(3) Activate change over
(4) Monitor change over
(5) Report change over completion
(6) Identify change over unreadiness cause
(7) Report change over unreadiness
(8) Identify change over failure
(9) Report change over failure

4. Execute speed change requests

a) Acknowledge speed change request
b) Check speed change readiness
c) Activate speed change
d) Monitor speed change
e) Report speed change completion
f) Identify speed change unreadiness cause
g) Report speed change unreadiness
h) Identify speed change failure
i) Report speed change failure

5. **Execute mode change requests**
    a) Acknowledge mode change request
    b) Check mode change readiness
    c) Activate mode change
    d) Monitor mode change
    e) Report mode change completion
    f) Identify mode change unreadiness cause
    g) Report mode change unreadiness
    h) Identify mode change failure
    i) Report mode change failure

B. **Monitor PSS**
1. **Monitor diesel and its auxilliary systems**
    a) Select check point
    b) Compare desired/actual state
    c) Decide subsystem OK
2. **Monitor gas turbine and its auxilliary systems**
    a) Select check point
    b) Compare desired/actual state
    c) Decide subsystem OK

3. **Monitor energy transfer systems**
    a) Select check point
    b) Compare desired/actual state
    c) Decide subsystem OK

C. **Handle PSS failures**
1. **Handle failures of diesel and its auxilliary systems**
    a) Detect failure
    b) Identify failed system
    c) Evaluate failure consequences
    d) Decide compensation required
    e) Compensate failure
        (1) Identify alternative actions for compensating
        (2) Evaluate alternative actions
        (3) Select appropriate action
        (4) Execute selected action
    f) Find disturbed component
        (1) Select check point
        (2) Compare desired/actual state
        (3) Decide failure found
        (4) Identify disturbed component
    g) Eliminate failure cause
        (1) Identify alternative actions for eliminating
        (2) Evaluate alternative actions
        (3) Select appropriate action
        (4) Execute selected action

2. **Handle failures of gas turbine and its auxilliary systems**
    a) Detect failure

b) Identify failed system
c) Evaluate failure consequences
d) Decide compensation required
e) Compensate failure
    (1) Identify alternative actions for compensating
    (2) Evaluate alternative actions
    (3) Select appropriate action
    (4) Execute selected action
f) Find disturbed component
    (1) Select check point
    (2) Compare desired/actual state
    (3) Decide failure found
    (4) Identify disturbed component
g) Eliminate failure cause
    (1) Identify alternative actions for eliminating
    (2) Evaluate alternative actions
    (3) Select appropriate action
    (4) Execute selected action

3. Handle failures of energy transfer systems

a) Detect failure
b) Identify failed system
c) Evaluate failure consequences
d) Decide compensation required
e) Compensate failure
    (1) Identify alternative actions for compensating
    (2) Evaluate alternative actions
    (3) Select appropriate action
    (4) Execute selected action
f) Find disturbed component
    (1) Select check point
    (2) Compare desired/actual state
    (3) Decide failure found
    (4) Identify disturbed component
g) Eliminate failure cause
    (1) Identify alternative actions for eliminating
    (2) Evaluate alternative actions
    (3) Select appropriate action
    (4) Execute selected action

II. Manage energy supply

III. Manage ship safety

ANNEX I: GLOSSARY OF TERMS AND ACRONYMS

allocation of functions – The process of deciding how system functions shall be implemented, by human, by equipment, or by both, and assigning them accordingly.

analysis – the resolution of anything complex into its simple elements.

ANEP – Allied Naval Engineering Publication.

CAD – Computer Aided Design.

CALS – Computer aided Acquisition and Logistics Support. A US DoD and industry initiative to transfer the design process from one based on paper to one based on computer data by developing data exchange standards and data bases for design, reliability, and maintenance information.

CASE – Computer Aided Software Engineering.

C^3I – Command, Control, Communications and Information. A command and control system.

cognitive behaviour – All aspects of knowledge, including perceiving, remembering, imagining, conceiving, judging, and reasoning.

cohesion – A term used in structured analysis/design approaches to software development referring to the extent to which a software module deals with a single, well-defined activity.

contractor – An organization, usually in industry, which contracts to perform engineering activities to develop and build a system or equipment.

CORE – Controlled Requirements Expression. A proprietary technique for identifying system requirements through structured decomposition.

coupling – A term used in structured analysis/design approaches to software development referring to the extent to which the software modules are related to one another.

critical task – A task which, if not accomplished in accordance with system requirements, will have adverse effects on cost, system reliability, efficiency, effectiveness, or safety (after US MIL-H-46855B).

demonstrator – Equipment built to illustrate future trends and possibilities in design. Demonstrators may resemble the real-life counterpart dynamically. Operationally, a demonstrator may range from a functioning laboratory set-up to a complete system.

designer – One who designs or plans or makes patterns for manufacture.

Design and Development – The phase of an equipment programme which calls for design engineering work aimed at full validation of the technical approach and ensures complete system integration to the point where production contract action can be taken (NATO PAPS).
DoD – US Department of Defense

duty – A set of operationally related tasks within a job, e.g, communicating, navigating, system monitoring (NATO STANAG 3994/1). Duties may be divided into primary and secondary duties.

equipment – All non-expendable items needed to outfit/equip an individual or organization (NATO Glossary).

ergonomics – The systematic study of the relation between the human, machine, tools, and environment, and the application of anatomical, physiological. and psychological, knowledge to the problems arising therefrom: Synonymous with Human Factors.

feasibility study – A study carried out by industry or government agencies or a combination of both, with the object of providing a technical appraisal of the feasibility of developing and producing an equipment with the performance required by the NATO Staff Target (NATO PAPS).

front end analysis – Analyses conducted at the earliest stages of system design and concerned with a system's personnel, training and logistics requirements (U.K. DEF STAN 00-25).

function – A broad category of activity performed by a system, usually expressed as a verb + noun phrase, e.g., "control air-vehicle," "update way-point" (NATO STANAG3994/1). A function is a logical unit of behaviour of a system.

functional analysis – An analysis of system functions describing broad activities which may be implemented by personnel, and/or hardware and/or software.

GENSAW - The user assisted GENeric Systems Analyst Workstation being developed by the USAF to support human engineering analyses from mission & scenario decomposition to performance prediction (workload simulation using SAINT).

Gantt charts – Charts used for project planning and control which show the necessary project activities listed in a column against horizontal lines showing the dates and duration of each activity.

HARDMAN – A US Navy programme for the integration of issues of manpower, personnel and training with the weapon system acquisition process.

human engineering (HE) – The area of human factors which applies scientific knowledge to the design of items to achieve effective human-machine integration (after US MIL-H-46855B). Human engineering includes developmental test and evaluation activities.

human factors (HF) – A body of scientific facts about human capabilities and limitations. It includes principles and applications of human engineering, personnel selection, training, life support, job performance aids, and human performance evaluation: Synonymous with Ergonomics.

human-machine interface – An imaginary surface across which information and energy are exchanged between the human and machine components of a system. The interface is defined by the displays and controls used by the operator/maintainer to control, monitor or otherwise interact with the system.

human-machine system – A composite of equipment, related facilities, material, software and personnel required for an intended operational role.

human systems integration (HSI) – The technical process of integrating the human operator with a materiel system to ensure safe, effective operability and supportability.

IDEA – Integrated Decision Engineering Aid. A proprietary software program which provides an integrated set of tools and data files to keep track of front-end human engineering analyses within the framework of the US Army's MANPRINT approach.

IDEF – (ICAM (Integrated Computer Aided Manufacturing Office) DEFinition) A US Air Force developed tool for building descriptive models of system functions and data, commercialised as SADT™.

ILS – Integrated Logistics Support. A method of assuring that a system can be supported effectively and economically, so as to conform to specified operational requirements, within the resources of available personnel sub-system logistic support and maintenance, for its programmed life cycle. It considers jointly all resources needed, namely supplies, maintenance, humans and equipment, transportation, facilities and cost (CAN DND-ENG STD-3).

IMPACTS – A US Air Force programme for the integration of manpower, personnel, and training issues with the weapon system acquisition process.

interval scale – A scale of measurement which has the characteristics of an ordinal scale, and, in addition, uses equal intervals without reference to a true zero value, e.g. the Centigrade scale of temperature does not refer to absolute zero.

job – The combination of all human performance required for operation and maintenance of one personnel position in a system, e.g., navigator (NATO STANAG 3994/1).

link analysis – A technique for representing and attempting to optimise the interactions between an operator or operators and equipment or between multiple operators.

Liveware – A US term for the human component of systems (operators and maintainers) which complements the system hardware and software.

maintainer – An individual responsible for retaining a defence system in, or restoring it to, a specified condition.

manpower – The demand for human resources in terms of numbers and organization.

manpower, personnel, training and safety (MPTS) – The human dimension of the complete weapon system. The term MPTS also encompasses the disciplines of human engineering and health hazard prevention.

MANPRINT – The US Army Manpower and Personnel Integration programme for the integration of six areas of manpower, personnel, training, systems safety, health hazards analysis, and human factors engineering into the systems acquisition process.

methodology – The study of method, usually taken to mean an integrated set of methods and rules applicable to some goal.

mission – What a human-machine system is supposed to accomplish, in response to a stated operational requirement (NATO STANAG 3994/1).

mission analysis – A process to determine the operational capabilities of military forces that are required to carry out assigned missions, roles, and tasks in the face of the existing and/or postulated threat with an acceptable degree of risk (NATO PAPS).

mission need document – In NATO, a statement based on a mission analysis, identifying in broad outline a quantitative or qualitative operational deficiency that cannot be solved satisfactorily with existing of planned forces and/or equipment (NATO PAPS).

mock-up – A model, built to scale, of a machine, apparatus, or weapon, used in studying the construction of, and in testing a new development, or in teaching personnel how to operate the actual machine, apparatus or weapon (NATO Glossary of Terms). A three-dimensional, full-scale replica of the physical characteristics of a system or sub-system (U.K. DEF STAN 00-25).

moding analysis – The analysis of the different modes of operation of multi-function systems. For example, a multi-function radar can be operated using different search patterns, track-while-scan or other modes. These modes are usually selected through a "tree" of control options, which includes "modes."

MoD PE – U.K. Ministry of Defence Procurement Executive.

Monte Carlo simulation – A method used in mathematics, statistics, and operations research to resolve problems by the use of random sampling. The behaviour of a system is simulated by feeding in values of the system variables, and repeating the operation over different sets of values so as to explore the system under a variety of conditions.

nominal scale – A scale of measurement which distinguishes only characteristics without regard to order , e.g. the membership of sets.

OOW – Officer of the Watch (of a ship).

operator – An individual primarily responsible for using a system, or enabling a system to function, as designed.

ordinal scale – A scale of measurement which implies some ordering of the values, e.g. more/less relationships. Most subjective ratings are ordinal scale.

PAPS – Phased Armaments Programming System. A systematic and coherent set of procedures and milestones for promoting co-operative armaments programmes in NATO.

PC – Personal Computer.

personnel – The definition of manpower in terms of trade, skill, experience levels, and physical attributes.

ratio scale – A scale of measurement which has the characteristics of an interval scale, and in addition has a true zero point as its origin, e.g., length, mass, the Kelvin temperature scale.

RDD – Requirements Driven Development. A proprietary technique for deriving the requirements for complex systems through the systematic decomposition descriptions of system functional relationships.

reliability – The probability that an item will perform its intended function for a specified interval under stated conditions (CAN DND ENG-STD-3).

RSG – Research Study Group. A group sponsored by one of the NATO Defence Research Group Panels to carry out research on a specific topic.

SADT – Structured Analysis and Design Technique™. A proprietary means of identifying system requirements through a structured decomposition.

safety – Freedom from those conditions that can cause death or injury to personnel, damage to or loss of equipment or property, or damage to the environment.

SAINT – Systems Analysis by Integrated Networks of Tasks. Software which supports network simulation and Monte-Carlo modelling of systems.

SAT diagrams – Sequence and timing diagrams. A variety of function flow diagram showing the sequence of functions performance by sub-systems.

span of control – A term used in structured analysis/design approaches to software development referring to the number of lower-level modules which are called, or controlled, by one module.

specification – The document which prescribes in detail the requirements to which ... supplies or services must conform. NOTE: It may refer to drawings, patterns, or other relevant documents and may indicate the means and criteria whereby conformance can be checked (AGARD Multilingual Dictionary).

– A document intended primarily for use in procurements which clearly and accurately describes the essential and technical requirements for items, materials, or services, including procedures by which it can be determined that the requirements have been met (CAN A-LP-005-000/AG-006).

staff requirement – A detailed statement of the required design parameters and operational performance of the equipment or weapon system. This document represents the specification of the system upon which project definition is based (NATO PAPS).

staff target – A broad outline of the function and desired performance of new equipment or weapon system(s), before the feasibility or the method of meeting the requirement, or other implications have been fully assessed (NATO PAPS).

STANAG – A NATO standardization agreement.

standard – An exact value, a physical entity, or an abstract concept, established and defined by authority, custom, or common consent to serve as a reference, model, or rule in measuring quantities, establishing practices or procedures, or evaluating results. A fixed quantity or quality (NATO Glossary of Terms and Definitions).

– A document that establishes engineering and technical limitations and applications for, items, materials, processes, methods, designs, and engineering practices (CAN A-LP-005-000/AG-006).

statement of requirement (SOR) – A statement of the capability required of a new system, to meet an existing or postulated threat, synonymous with NATO Staff Target. In the U.K. it includes estimated costs and technical factors.

sub-task – Activities (perceptions, decisions, and responses) which fulfill a portion of the immediate purpose within a task, e.g., "key in latitude."

system – In general a set or arrangement of things so related or connected as to form a unity or organic whole (Webster's New World Dictionary of the American Language, 2nd College Edition, 1970. The Publishing Company).

system design – The preparation of an assembly of methods, procedures, and techniques united by regulated iterations to form an an organized whole (NATO Glossary of Terms).

system effectiveness – The probability that the system will provide, in terms of resources required, and as specified, either:

a. the maximum operational performance within the total cost prescribed, or
b. the required value at lowest cost. (CAN DND-ENG-STD-3).

system(s) engineering – A basic tool for systematically defining the equipment, personnel, facilities and procedural data required to meet system objectives (US MIL-H-46855B).

system requirements analysis – An analysis of what is required of a system to identify those characteristics which the system (both personnel and equipment) must have to satisfy the purposes of the system (after U.K. DEF STAN 00-25).

task – A composite of related operator or maintainer activities (perceptions, decisions, and responses) performed for an immediate purpose, e.g., "insert aircraft position" (after NATO STANAG 3994/1).

task analysis – A time oriented description of personnel-equipment-software interactions brought about by an operator, controller or maintainer in accomplishing a unit of work with a system or item of equipment. It shows the sequential and simultaneous manual and intellectual activities of personnel operating, maintaining, or controlling equipment (US MIL-H-46855B).

task description – A listing of tasks, usually in tabular form, arising from the results of a system description/analysis (U.K. DEF STAN 00-25).

task element – The smallest logically and reasonably defined unit of behaviour required in completing a task or sub-task, e.g., "key in digits."

task synthesis – The process of creating or putting together the tasks which compose a system function (after U.K. DEF STAN 00-25).

technique – A mechanical, or formal, approach to doing something.

Test and Evaluation (T&E) – A comprehensive programme of test activities, conducted throughout the system hierarchy and over the system life cycle, to:

a. assess system performance,
b. verify conformance to system requirements,
c. determine system acceptability.

time line – a representation of actions, activities or tasks in the temporal domain using a horizontal line or bar.

training – The process by which trainees acquire or enhance specific skills, knowledge, and attitudes required to accomplish military tasks.

UIMS – User Interface Management System

weapon system – a combination of one or more weapons with all related equipment, materials, services, personnel and means of delivery and deployment (if applicable) required for self-sufficiency (NATO Glossary of Terms).

work breakdown structure (WBS) – A matrix of sub-systems and design/development team activities used for project management.

workload – The level of activity or effort required of an operator to meet performance requirements or criteria (Glossary of Ergonomics).

workplace – The complete working environment within which all the operators and equipment are arranged to function as a unit (U.K. DEF STAN 00-25).

workspace – The geometrical space required to perform a job, duties, or task, including the details of display and control location, the physical relationship between different displays and controls, and the standing/seating arrangement of the operators/maintainers.

WSAP – The weapon system acquisition process.

ANNEX II

DIRECTORY OF SUBJECT MATTER EXPERTS

This annex provides contact addresses for the organizations that deal with human factors/ human engineering problems in each country, so that potential users can ask for assistance and guidance. Where appropriate, separate contacts have been provided for each of the three services.

An attempt has been made to give contacts for four classes of activity: general research; general applications; research-specific subjects and applications-specific subjects. In most countries, it has not been possible to provide separate contacts for all of these, due to national differences in the structuring of human factors research and development. In these cases, more general points of contact have been listed.

It has not always been possible to give a post rather than a named person. For Example at NDRE Norway, the work is organized into time-limited projects, not all of which cover man-machine aspects. Because of this, relevant Project Managers are named.

FRANCE

	AIR FORCE	ARMY	NAVY
GENERAL RESEARCH		Direction des Recherches, et Etudes Technique (DRET) de la Direction Générale, pour l'Armement (DGA) Service des Recherches. Group 9. Biologie et Facteurs Humains Cité de l'air 26 Boulevard Victor 75015 PARIS	
		DGA/DRET/SDI/G9	
GENERAL APPLICATION	DGA/Direction des Constructions Aeronautiques (DCAé) LAMAS BRETIGNY	DGA/Direction des Armements Terrestes DAT Service Facteurs Humains Establishment Techniques D'Angers (ETAS)	DGA/Direction des Constructions Navals Centre d'Etudes et de Recherches Technique sous Marin (CERTSM) Service Facteurs Humains Toulon
RESEARCH - SPECIFIC SUBJECT	Centre d' Etude et de Recherches de Médecin Aerospatiale (CERMA) BRETIGNY	Centre de Recherches du Service de Santé des Armées (CRSSA) GRENOBLE	Centre d' Etude et de Rescherches en Biologie (CERB) Hopital Saint Anne TOULON
		DGA/DRET/Etablissement Centrale Technique de l'Armements (ETCA) Centre d' Études des Bouchet (CEB) (N.B.C. problems)	
APPLICATIONS - SPECIFIC SUBJECT	Centre d' Etude et de Recherches en Psychologie Air (CERPAIR) St Cyr l'école	Section Technique de l'Armée de Terre STAT Groupement Ergonomique et Facteurs Humains. SATORY	Commissions d'Etudes Pratiques TOULON
		- Centre d' Etude de la Selection Psychologique de l'Armee de Terre (CESPAT) COMPIENGNE	- Centre d' Etudes Psychologique de la Marine. PARIS
		Centre des Relations Humains Ecole Militaire (CRH).	

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GERMANY

	AIR FORCE	ARMY	NAVY
GENERAL RESEARCH	Director Research Institute for Human Engineering (FAT) Neuenahrer Str 20 5307 Uachtberg-Werthoven		
GENERAL APPLICATIONS	Bundesamt fur Wehrtechnik und Beschaffung Dezernat AT II 4 Postfach 73 60 5400 Koblenz		
RESEARCH - SPECIFIC SUBJECT	Director Research Institute for Human Engineering (FAT) Neuenahrer Str 20 5307 Wachtberg-Uerthhoven		
APPLICATIONS - SPECIFIC SUBJECT	Luftwaffenamt Abteilung LW Rust IC Postfach 90 25 O0 - 501 - 14 5000 Koln 90	Heeresamt Abteilung III (1) Bruhler Strasse 300 500 Koln 51	Marineamt Abteilung Rustung 1 H Marineanlage Bordum Anton-Dohrn-Weg 59 2940 Wilhelmshaven

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THE NETHERLANDS

	AIR FORCE	ARMY	NAVY
GENERAL RESEARCH	Director National Defence Research Organisation Schoemakerstraat 97 2628 VK DELFT		
GENERAL APPLICATIONS	Head Scientific Research Airforce Ministry of Defense Binckhorstlaan 135 2516 BA DEN HAAG	Head Scientific Research Army Ministry of Defense V.d. Burchlaan 31 2597 PC DEN HAAG	Head Scientific Research Navy Ministry of Defense V.d. Burchlaan 31 2597 PC DEN HAAG
RESEARCH - SPECIFIC SUBJECT	(Human Factor Research) Director Institute for Perception TNO (IZF-TNO) Kampweg 5 PO Box 23 3769 ZG SOESTERBERG		
APPLICATIONS - SPECIFIC SUBJECT	Head Research Groups (IZF-TNO)	Perception Information Processing Skilled Behaviour Work Environment	

Techniques, regarding man-machine system design, are used in the latter three groups, and are related to nearly all types of military man-machine vehicles and associated systems, with emphasis on task-analysis, workload and performance prediction.

NORWAY

	AIR FORCE	ARMY	NAVY
GENERAL RESEARCH	Norwegian Defense Research Establishment (NDRE) 2007 Kjeller Attention: Frode Fonnum		
GENERAL APPLICATIONS	Air Material Command 2007 Kjeller	Army Material Command 0580 Oslo	Navy Material Command Project Section or Technology Section 5078 Haakonavern
RESEARCH - SPECIFIC SUBJECT	Psychology, Physiology, Performance and stress: NDRE, Department of Toxicology, Attention: Frode Fronnum Human engineering, systems integration: NDRE, Department of Electronics Attention: Johan Aas Karsten Bråthen Erik Nordø		
APPLICATIONS - SPECIFIC SUBJECT	Command and Weapon Control Systems: NDRE, Dep of Electronics Attn: Arne Sjøvik	Command and Weapon Control Systems: NDRE, Dep of Electronics Attn: Kjell Rose	Command and Weapon Control Systems: NDRE, Dep of Electronics Attn: Johan Aas Karsten Bråthen Erik Nordø

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UNITED KINGDOM

	AIR FORCE	ARMY	NAVY
GENERAL RESEARCH	Institute of Aviation Medicine Farnborough, Hants GU14 6SZ Attention: Head/Psychology Division DRA Aerospace Division (RAE) Farnborough, Hants GU14 6TD Attention: Head/Flight Systems Dept	Army Personnel Research Establishment Farnborough, Hants GU14 6TD Attention: Assistant Director/Operator Performance Division	DRA Maritime Division (ARE) Portsdown, Portsmouth Hants P06 4AA Attention: Head/Human Factors Group, MCO Division Ministry of Defence Main Building Whitehall, London SWIA 2HB Attention: RTHF, DOR(SEA)
GENERAL APPLICATIONS	Institute of Aviation Medicine Attention: Head/Psychology Division DRA Aerospace Division (RAE) Attention: Head/Flight Systems Dept	Army Personnel Research Establishment Attention: Assistant Director/Operator Performance Division	DRA Maritime Division (ARE) Attention: Head/Human Factors Group, MCO Division Ministry of Defence Attention: RTHF, DOR(SEA)
RESEARCH - SPECIFIC SUBJECT	Institute of Aviation Medicine Attention: Head/Psychology Division DRA Aerospace Division (RAE) Attention: Head/Flight Systems Dept	Army Personnel Research Establishment Attention: Assistant Director/Operator Performance Division	DRA Maritime Division (ARE) Attention: Head/Human Factors Group, MCO Division Ministry of Defence Attention: RTHF, DOR(SEA)
APPLICATIONS - SPECIFIC SUBJECT	Institute of Aviation Medicine Attention: Head/Psychology Division DRA Aerospace Division (RAE) Attention: Head/Flight Systems Dept	Army Personnel Research Establishment Attention: Assistant Director/Operator Performance Division	DRA Maritime Division (ARE) Attention: Head/Human Factors Group, MCO Division Attention: RTHF, DOR(SEA)

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UNITED STATES

	AIR FORCE	ARMY	NAVY
GENERAL RESEARCH	Secretary of the Air Force CODE AQT The Pentagon Washington D.C. 20330	Director, MANPRINT Department of the Army Chief, Research Studies and Analyses DAPE-MR The Pentagon Washington D.C. 20310	Office of Advanced Technology Office of Naval Research Code 33 800 N. Quincy Street Arlington, VA 22217
GENERAL APPLICATIONS	Secretary of the Air Force CODE AQX The Pentagon Washington D.C. 20330	Director, MANPRINT Department of the Army Chief, Acquisition DAPE-MR The Pentagon Washington D.C. 20310	Assistant Secretary of the Navy Manpower and Reserve Affairs Special Assistant Manpower Requirements The Pentagon Washington D.C. 20350
RESEARCH - SPECIFIC SUBJECT	USAF Armstrong Laboratory Code CA Brooks AFB Texas 78235	Technical Director Army Research Institute US Army 5001 Eisenhower Avenue Alexandria VA 22015	Deputy Chief of Naval Operations Code IIIK Arlington Annex Arlington VA 20370
APPLICATIONS - SPECIFIC SUBJECT	USAF Human Systems Division Code YA Brooks AFB Texas 78235	Director US Army Human Engineering Labs Attn: SLCHE Aberdeen Proving Ground MD 21005	Deputy Chief of Naval Operations Code IIID Arlington Annex Arlington VA 20370

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ANNEX III

HUMAN ENGINEERING REGULATORY DOCUMENTS IN USE IN RSG.14 MEMBER NATIONS

This annex lists the standards, specifications, guidelines, handbooks and directives that deal with human factors/ human engineering which are in use in various countries. The documents are listed by country of origin. As shown in Appendix A to Chapter 5 of Volume 1, some of those documents are used in several nations, others are used in only one.

1. STANDARDS

NATO STANAGS (All published by NATO Military Agency for Standardization - Aircraft Instrument Panel (MAS-AIP), Brussels).

STANAG 3216 AI: Layout of flight data in pilots displays
STANAG 3217 AI: Operation of controls and switches at aircrew stations
STANAG 3218 AI: Location, actuation and shape of engine controls and switches in fixed wing aircraft
STANAG 3219 AI: Location and grouping of electrical switches in aircraft
STANAG 3220 AI: Location, actuation and shape of airframe controls for fixed wing aircraft
STANAG 3221 AI: Automatic flight control system (AFCS) in aircraft - design standards and location of controls
STANAG 3224 AI: Aircrew station lighting
STANAG 3225 AI: Location, actuation and shape of airframe controls for rotary wing aircraft
STANAG 3229 AI: Numerals and letters in aircrew stations
STANAG 3341 AI: Emergency control colour schemes
STANAG 3359 AI: Location and arrangement of engine displays in aircraft
STANAG 3370 AI: Aircrew station warning, cautionary and advisory signals
STANAG 3436 AI: Colours and markings used to denote operating ranges in aircraft instruments
STANAG 3593 AI: Numbering of engines and their associated controls and displays in aircraft
STANAG 3622 AI: External vision from aircrew stations
STANAG 3639 AI: Aircrew station dimensional design factors
STANAG 3648 AI: Electronically and/or optically generated aircraft displays for fixed wing aircraft
STANAG 3692 AI: Location and actuation of thrust vector controls for VSTOL aircraft other than rotary wing aircraft
STANAG 3705 AI: Principles of presentation for information in aircrew stations
STANAG 3800 AI: Night vision goggle lighting compatible design criteria
STANAG 3870 AI: Emergency escape/evacuation lighting
STANAG 3994 AI : Application of human engineering to advanced aircraft systems.

FRG DIN Standards:

Several DIN standards are in use which regulate health hazards or environmental factors, or deal with specific aspects of equipment design in the same way as AIP STANAGs

UK Defence standards and British standards:

DEF STD 00 12: Climate environmental conditions affecting the design of material for use by NATO forces in a ground role. London: Ministry of Defence
DEF STD 00 25: Human factors for designers of equipment: Parts 1-12. London: Ministry of Defence

DEF STD 00 27: Acceptable limits for exposure to impulse noise from military weapons, explosives and pyrotechnics. London: Ministry of Defence

BS 6841: British standard guide to measurements and evaluation of human exposures to whole-body mechanical vibration and repeated shock. London: British Standards Institute

US

MIL-STD-250D: Aircrew station controls and displays for rotary wing aircraft. Department of Defense, Washington D.C

MIL-STD-850B: Aircrew station vision requirements for military aircraft. Department of Defense, Washington D.C

MIL-STD-133B: Aircrew station geometry for military aircraft. Department of Defense, Washington D.C

MIL-STD-1472D: Human engineering design criteria for military systems, equipment and facilities.Department of Defense, Washington D.C.

MIL-STD-1478: Task performance analysis. Department of Defense, Washington D.C.

MIL-STD-1800: Human engineering performance requirements for systems. Department of Defense, Washington D.C.

ASTM F1166-88: Standard of practice for human engineering design for marine facilities, systems and equipment. Philadelphia: American Society for Testing and Materials

NASA STD 3000: Man-systems integration standards

2. SPECIFICATIONS

US

MIL-H-46855B: Human engineering requirements for military systems, equipment, and facilities. Washington D.C.: US Army Missile R&D Command.

DI-DFAC-80740: Human engineering program plan. Washington D.C.: Department of Defense

DI-HFAC-80741: Human engineering progress report.Washington D.C: Department of Defense

DI-HFAC-80742: Human engineering dynamic simulation plan. Washington D.C.: Department of Defense

DI-HFAC-80743: Human engineering test plan. Washington D.C.: Department of Defense

DI-HFAC-80744: Human engineering test report. Washington D.C.: Department of Defense

DI-HFAC-80745: Human engineering system analysis report. Washington D.C.: Department of Defense

DI-HFAC-80746: Human engineering design approach document - operator. Washington D.C.: Department of Defense

DI-HFAC-80747: Human engineering design approach document - maintainer. Washington D.C:. Department of Defense

DI-HFAC-81197: Task performance analysis report. Washington D.C.: Department of Defense

3. GUIDELINES AND HANDBOOKS

NATO

DS/A/DR(82)350: Ergonomic design guide-lines. Brussels: NATO AC/243 Panel-8 (English translation of Part C of FRG Handbuch der ergonomie)

NATO NNAG IEG/6 (All published by the NATO Naval Armaments Group, Brussels).

ANEP 20: Human factors/ergonomics in the development and acquisition of ship weapon systems.
ANEP 21: Procedure for ships manning for NATO surface ships.
ANEP 22: Human factors considerations for the determination of automation policy.
ANEP 23: The influence of maintenance on manning.
ANEP 24: Guidelines for shipboard habitability requirements for combatant surface ships.
ANEP 25: Guidelines for environmental factors in NATO surface ships.
ANEP 26: Ergonomics data for shipboard space design in NATO surface ships.
ANEP 27: Human factor guidelines for the design of man/machine interfaces in operational rooms.
ANEP 28: Guidelines for the development of Operational Stations Book (OSB) for NATO naval vessels.

France

DGA/AQ 902: Manuel des methodes de conduite de programme (Guide of methods for conducting weapons programmes). Paris: Ministère de la défense.

DEN/CMQ No. 88610: Guide de mise en oeuvre de l'analyse fonctionnelle (Guide for performing functional analysis). Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament,

DGA/AQ 4114: Guide pour la prise en compte des facteurs humains (Human factors guide). Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament, Mission assurance de la qualité.

DGA Ergonomie et conception: Les trent questions qu'il faut se poser. (Thirty questions to ask). Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament, Direction des Armements Terrestres.

DGA L'Ergonomie de conception d'un produit (Design ergonomics). Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament, Direction des Armements Terrestres.

Ergodata:. Paris: Anthropologie Appliquée.

FRG

Handbuch der ergonomie.(Handbook of ergonomics) 2nd. Edition. Munich & Vienna: Carl Hanser Verlag.

Design and construction guidelines: ships. Koblenz: Bundesamt für Wehrtechnik, BWB SG.

UK

Human factors guidelines for the design of computer-based systems. Volumes 1-6. London: Ministry of Defence (Procurement Executive) and Department of Trade and Industry.

US

DoD-HDBK-761: Human engineering guidelines for management information systems.
DoD-HDBK-763: Human engineering procedures guide. US Army Missile Command, Redstone Arsenal.
MIL-HDBK-759A: Human factors engineering design for army materiel. Alabama: US Army Missile Command, Redstone Arsenal.
Engineering data compendium: human perception and performance. Volumes. 1-3. New York: John Wiley & Sons. 1987
Directory of design support methods. San Diego, CA: US Department of Defense, Manpower and training Research Information System. 1990
Advanced HFE tool technologies. Tech. Memo. 2-88. Maryland, Aberdeen Proving Ground: US Army Human Engineering Laboratory. 1987.

4. MISCELLANEOUS DOCUMENTS

France

AFNOR X35-001: Conception des systèmes de travail. (The design of work systems). Paris: Association Française de Normalisation
AFNOR: Ergonomie receuil de normes Francaises. (Collection of french ergonomic standards). Paris: Association Française de Normalisation
Directive IMN 01514:
Instruction sur la conduite des programmes d'armament de l'Armée de l'air. Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament
DGA/DPA 60 800 Instruction sur la conduite des programmes d'armament de l'Armée de terre. Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament
Instruction sur la conduite des programmes d'armament Navals. Paris-Armées: Ministère de la défense, Délègation Générale pour l'Armament

FRG

Directive: ergonomics in the Federal Armed Forces. Bonn: Bundesministerium der Verteidigung, BMVg Org.
General ergonomic requirements. Koblenz: Bundesamt für Wehrtechnik, BWB AT.
Checklist BWB AT II. Koblenz: Bundesamt für Wehrtechnik und Beschaffung, BWB AT.

AWT 341: Job instruction : Engineering.Koblenz: Bundesamt für Wehrtechnik und Beschaffung, BWB AT.
Navy requirement No. 8. Wilhelmshaven: Marineamt. MarARüst 1H.

UK

EH 40/91: Health and safety (toxicity: occupational exposure limits. London: Health and Safety Executive.

DRG DOCUMENT CENTRES

NATO does not hold stocks of DRG publications for general distribution. NATO initiates distribution of all DRG documents from its Central Registry. Nations then send the documents through their national NATO registries, sub-registries, and control points. One may sometimes obtain additional copies from these registries. The DRG Document Centres listed below can supply copies of previously issued technical DRG publications upon request.

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