

**TASK NETWORK MODELS IN THE PREDICTION OF WORKLOAD IMPOSED BY
EXTRAVEHICULAR ACTIVITIES DURING THE HUBBLE SPACE TELESCOPE
SERVICING MISSION**

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ABSTRACT

In a joint effort with Brooks A.F.B, Texas, the Flight Crew Support Division at Johnson Space Center has begun a computer simulation and performance modeling program directed at establishing the predictive validity of software tools for modeling human performance during spaceflight. This paper addresses the utility of task network modeling for predicting the workload that astronauts are likely to encounter in extravehicular activities during the Hubble Space Telescope (HST) repair mission. The intent of the study was to determine whether two EVA crewmembers and one intravehicular activity (IVA) crewmember could reasonably be expected to complete HST Wide Field/ Planetary Camera (WFPC) replacement in the allotted time.

Ultimately, examination of the points during HST servicing that may result in excessive workload will lead to recommendations to the HST Flight Systems and Servicing Project concerning (1) expectation of degraded performance, (2) the need to change task allocation across crewmembers, (3) the need to expand the timeline, or (4) the need to increase the number of EVA's.

INTRODUCTION

Future manned space missions will represent unprecedented expansion of civilization into the solar system. Space Station Freedom will permit crews to live and work in Earth orbit 90-day intervals, and perhaps longer. Lunar outposts will demand that crews work routinely in a harsh extraterrestrial environment, conducting scientific experiments and eventually supervising complex operations such as resource utilization. The proposed mission to Mars will involve outbound and return flights of a combined duration of one to three years, including time spent working on the planetary surface (Stocklosa, 1985). Clearly, as

spaceflight becomes increasingly complex and of longer duration astronauts are likely to encounter greater workload. However, human performance under various workload conditions, critical to the success of spaceflight, has only recently begun to be studied systematically (Stocklosa, 1985).

The need to assess workload becomes even more critical in a shuttle mission such as STS-61 which is scheduled to repair and service the Hubble Space Telescope in December, 1993. A committee review states that the mission is achievable but risky because of the growing workload, tight schedule and management complexity. The independent panel noted that the timeline for EVA is "very tight, having grown 25% in the period of our review, and continues to grow". Indeed, any additional component failures may require additional tasks to be added between now and the mission. The list of repairs has grown to fill an 11-day flight, with at least consecutive days of EVA's by alternative pairs of astronauts, making it by far the most ambitious shuttle EVA plan.

To date no attempts have been made to assess the workload imposed by tasks during intravehicular or extravehicular activities, and yet of all activities performed by humans in micro-gravity, those performed outside the pressurized modules are the most dangerous. Clearly, there is a requirement to develop methodologies for workload measurement and a need to identify points during a mission that may result in excessive workload.

This paper describes the current status of a program of investigation for assessing whether two EVA crewmembers and one IVA crewmember can reasonably be expected to complete WFPC replacement in the allotted time. Specifically, task network modeling and workload component scaling are discussed in detail as the suggested methodologies for predicting the amount of workload likely to be encountered when replacing the WFPC during the HST servicing mission. Ultimately, results will lead to the

parallax error, environmental influences and other cumulative errors. These cumulative errors, when removed from consideration would combine to further reduce the variability of the temperature and thus increase the probability of conformance. Figure 1 (see previous page) provides a pictorial representation of the capability analysis procedure, including the formula used to derive the capability analysis values in this application.

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formulation of recommendations to the HST Flight Systems and Servicing Project concerning EVA/IVA mission functions for which task re-allocation, expansion of the timeline, or increases in the number of EVA's, could be used as strategies for reducing mental and physical workload.

Task Network Modeling

Task network modeling is a methodology for investigating human performance in systems. It involves the breaking down of an operation or process into a series of subtasks, where relations among tasks are represented by the networks that connect them. Each node of the network represents a discrete subtask performed by the human and has associated parameters selected for their relevance to the analysis. Node parameters may include performance time, resources consumed, or potential errors. The network structure defines the order in which the operator performs the subtasks and can include branching pathways to denote decisions or alternatives. Loops are used to represent repetitions, the consequences of errors or the impact of environmental conditions (Laughery, 1985). Task network modeling permits in-depth analyses and quantification of human performance variability and is used primarily during initial system design where direct measures of crew performance are not available or are impractical. The overall process of task network modeling is depicted in Figure 1.

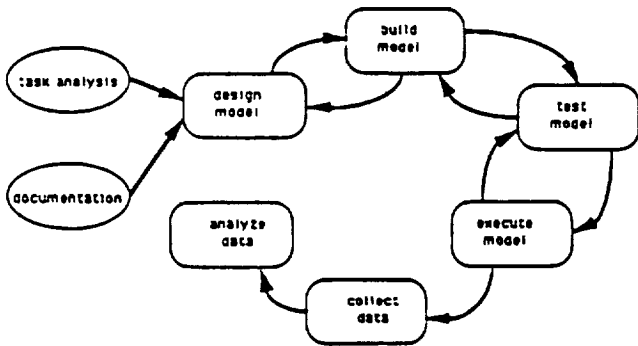


Figure 1. Task Network Modeling Process (from Laughery, 1989)

Figure 2 depicts a proposed task network for dialing a telephone. As can be seen, one picks up the receiver, determines whether a long distance call is to be made, and dials the number. Such a task network would easily permit exploration of the effect of using a touch tone or rotary telephone on error and call completion time. A parametric experiment testing the effect of telephone type could then easily be conducted (see Naylor, 1969).

Workload Component Scaling

Task network modeling is not designed specifically as a workload assessment tool. The only output provided is time required to accomplish the task and the sequence

in which tasks are performed (Laughery, 1989). Task network modeling was made more usable for the assessment of workload in the current study by augmenting it with a set of workload constructs. The approach was a modification of the procedure developed by Aldridge and Szabo (1984) and implemented by Laughery (1989), where each operator activity in a task network is characterized by the workload demand in each of four channels: auditory, visual, mediational and motor.

METHOD

The methodology was developed in a three-phase program of investigation that included development of a workload component scale used to produce computer-generated estimates of workload during Extravehicular activity (EVA) mission segments.

Phase I -- Task Network Modeling

It is important to note that the HST servicing mission was comprised of five major tasks, including the replacement of the (1) two Solar Arrays, (2) High Speed Photometer with the Correcting Optics Space Telescope Axial Replacement, (3) WFPC (4) two Rate Sensor Units and (5) Electronics Control Unit. Replacement of the WFPC was selected for this analysis because it was believed that it represented an EVA timeline estimate too optimistic.

During this phase, a complete, descriptive task listing of the wide field/planetary camera replacement task was compiled. The task listing was developed as a static series of flow diagrams that portray the HST servicing mission as a paper flowchart, illustrating the steps that crewmembers must accomplish to complete the task. The first step in the static model development involved examination of flight data files in order to decompose the task into its component behaviors. The task was decomposed into a consistent sequence of sub-tasks which supported performance of the task. A subtask was defined as a statement of activity, work, or action to be performed in support of the task.

During this phase, the static flow diagram developed previously was translated into a dynamic task network model depicting the flow of decisions and actions performed in support of WFPC replacement as a computer simulation.

Apparatus. Two simulators were employed to gather the required data. The Systems Engineering Simulator provides a high fidelity dynamic simulation of the shuttle AFT flight deck. It is a standard trainer for RMS tasks. The Air-Bearing Floor Facility provides a two-dimensional simulation of microgravity. In addition, the Weightless Environment Test Facility (WEFT) provides a three-dimensional simulation of microgravity through the attainment neutral buoyancy.

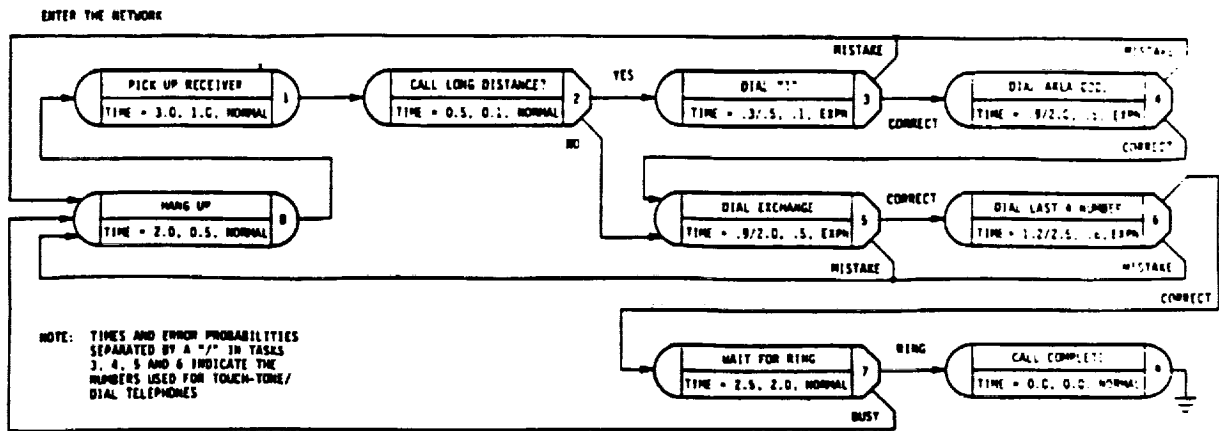


Figure 2. Task Network for Dialing a Phone

Procedures. Analysis of the WFPC replacement was based informally on the Structured Analysis and Design Technique (SADT). SADT provides a structured discipline for the task analyst to use in decomposing a system into a hierarchy of functions. Decomposition of the WFPC replacement task using the IDEF concept involved in-depth examination of the task in terms of the following types of functions: control, resources, input, and output. Control functions determine the constraints under which a particular subtask operates. For the WFPC replacement task, the only control function identified was the flight data file timeline. Resource functions denote the mechanisms that are the major contributors essential to the transformation of input functions to output functions. Analysis of the WFPC replacement task resulted in the identification of the following resource functions: Pilot, Mission Specialist 1, and the STS-61 Flight Data File checklist. Input functions represent the entities that are to be transformed into output, such as hand controller inputs which result in the movement of the Remote Manipulator System.

The static model representation of WFPC replacement was further analyzed during the Systems Engineering Simulator, WETF and Air-Bearing Floor Facility training sessions. A total of 4 STS-61 WETF training sessions were monitored. These sessions provided information concerning the nature of crew coordination, subtask performance times and the use of direct views, camera views, and checklists. They served to identify additional subtasks not readily apparent from the flight data files or from subject matter experts.

Phase II -- Workload Component Scaling

Identification of EVA/IVA Tasks. Scaling of workload components required identification of tasks specific to EVA/IVA activities. Each of these tasks was classified according to one of four workload channels: motor, visual, auditory, cognitive and psychomotor.

Content Validation. A total of four astronauts participated in the content validation effort. Two had prior EVA experience. Content validation sought to assess the degree to which the EVA/IVA tasks identified previously accurately reflected those activities performed during a mission.

Scale Development. Aldridge and Szabo (1984) developed an ordinal scale for determining the demand required in each of the four channels noted above. In the current study, several methods were considered for generating interval scales. An interval scale was selected because there was a desire to reflect equal magnitude differences in workload between corresponding tasks. Magnitude estimation was the method of choice. O'Donnel and Eggemeier (1986) found that magnitude estimation more closely achieved interval scale measures than did ranking. Further, magnitude estimation also appears to be less subject to fatigue effects than pair comparisons, especially when a large number of stimuli must be judged. It also has high convergent validity (O'Donnel et al. 1986). More importantly, magnitude estimation tends to be more reliable than other scaling methods because there is no need to resort to theory (e.g., distributions of discriminial dispersions) to generate them. In addition, O'Donnel et al. (1986) indicated that magnitude estimation provided a sensitive measure of perceive task difficulty and effort.

A total of 10 subjects from the aerospace community were presented each with a description of an EVA/IVA task twice in random order for each of the four workload channels. For each task, subjects assigned a numerical estimate that reflected the amount of workload likely to be imposed by the task. Similar estimates were than made for subsequent tasks. Workload was defined in terms of the mental and/or physical effort required to complete the task. Subjects were asked to assign numbers so the they were proportional to the amount of workload imposed by each tasks. Thus, ratios assigned to the different tasks were intended to correspond with the ratios between the workload imposed by the different tasks.

Mean logarithms were used as the scale values once inter-individual sources of variability were removed from the data in accordance with the procedures developed by Lane, Catania and Stevens (1961). According to these authors, use of magnitude estimation results in a source of variation attributed to the fact that different observers may prefer to work in different number ranges. According to Lane, et al. (1961), a transformation is needed which leaves invariant the individual slopes and intercepts, while partialing out variability due individual differences. The resulting workload scales are presented in Table 1.

Ideally, the derived scale would have been further evaluated to determine whether it conformed to a power function to assess whether the response magnitudes provided by the subjects were proportional to the stimulus intensity raised to power. However, because in the current study the nature of the stimuli (i.e., EVA/IVA tasks) precluded quantification in terms of intensity, degree of conformance to a power function could not be determined.

Phase -- III Tabulation of Workload Demands

As of this writing Phases I and II have been completed. Current work on the tabulation of workload demands has begun. Execution of the model will permit estimation of total attentional demands across all tasks during any part of the simulation. It will also permit characterization of the crewmember's attentional requirements graphically.

All tasks comprising WFPC replacement have been organized into five major segments (1) removal WFPC I from HST, (2) installation of WFPC I into temporary parking fixture, (3) removal of WFPC II FROM SIPE, (4) installation of WFPC II into HST, (5) removal of WFPC I from temporary parking fixture, and (6) installation of WFPC II into SIPE. The time estimates for subtasks comprising each segment have been used to construct timelines with 30-second intervals. Total demand placed on each astronaut has been estimated by summing across concurrent entries for each modality.

Summation of all concurrent entries within each modality (i.e., visual, mediational, motor and auditory) for each astronaut will provide an estimate of workload.

RESULTS

Although the preliminary results of Phase III were quite rudimentary in nature, it is believed that the methodology described provides an objective approach for evaluating the workload that astronauts are likely to encounter in extravehicular activities. It also provided a first-iteration estimate of the amount imposed within each information processing channel across each of the six HST repair activities.

Table 1. Workload Component Scales

Scale Value	Task
<u>Motor Processes</u>	
0.18	Discrete activation
0.49	Translation without equipment
0.52	Ingress/Egress
0.60	Restrained Manipulation of ORU's
0.65	Compensatory Tracking
0.69	Translation with equipment
1.10	Unrestrained Manipulation of ORU's
<u>Visual Processes</u>	
0.28	Confirmation
0.30	Discrimination/Identification
0.47	Comprehension
0.49	Status Monitoring
0.61	Alignment and Orientation
<u>Mediation Processes</u>	
0.24	Alternative Selection
0.49	Estimation/calculation
0.65	Plan Formulation
0.78	Problem solving
<u>Auditory Processes</u>	
0.53	Comprehension
0.58	Discrimination

Initial execution of the preliminary model suggested that installation of WFPC II may be particularly demanding due to the frequency and duration of activities requiring manipulation of WFPC II.

A detailed description of the results will be presented in a report to be released to the HST Flight Systems and Servicing Project in December, 1993.

FUTURE STUDIES

Ultimately, the methodology developed during this program of investigation will lead to a number of products that will be applied to future task network simulations of the workload likely to be experienced during future EVA activities, including:

- task analyses that provide indications estimates of workload components.

- validated workload component scales for rating the visual, auditory, motor and mediation components of workload.
- methods for evaluation of the workload imposed by concurrent EVA tasks.
- measures for identifying overload conditions.
- strategies for reducing workload during EVA.

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