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The Human Role In Space (THURIS) Applications Study

Final Briefing
in response to NAS8-36638
Data Requirement DR-2

McDonnell Douglas Astronautics Company
Huntsville Division

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To: NASA/George C. Marshall Space Flight Center
Attention: S. B. Hall, PD24
Building 4200
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In compliance with DR-2 of subject contract, the Final Study Briefing is hereby submitted. Fifteen copies are enclosed.

Should there be any questions concerning this transmittal, please contact the undersigned.

F. Savage
Business Manager

FS:cts

Enclosures

Copy to: Mr. T. P. Crabb, AP35-D/MSFC (without enclosure)

OCTOBER 1987 MDC W5125-2

The Human Role in Space (THURIS) Applications Study

Final Briefing
(DR-2)

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PREPARED FOR THE NASA GEORGE C. MARSHALL SPACE FLIGHT CENTER
UNDER CONTRACT NO. NAS8-36638, EFFECTIVE DATE: 9 DECEMBER 1986

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THURIS APPLICATIONS STUDY

FINAL BRIEFING
OCTOBER 1987

AGENDA

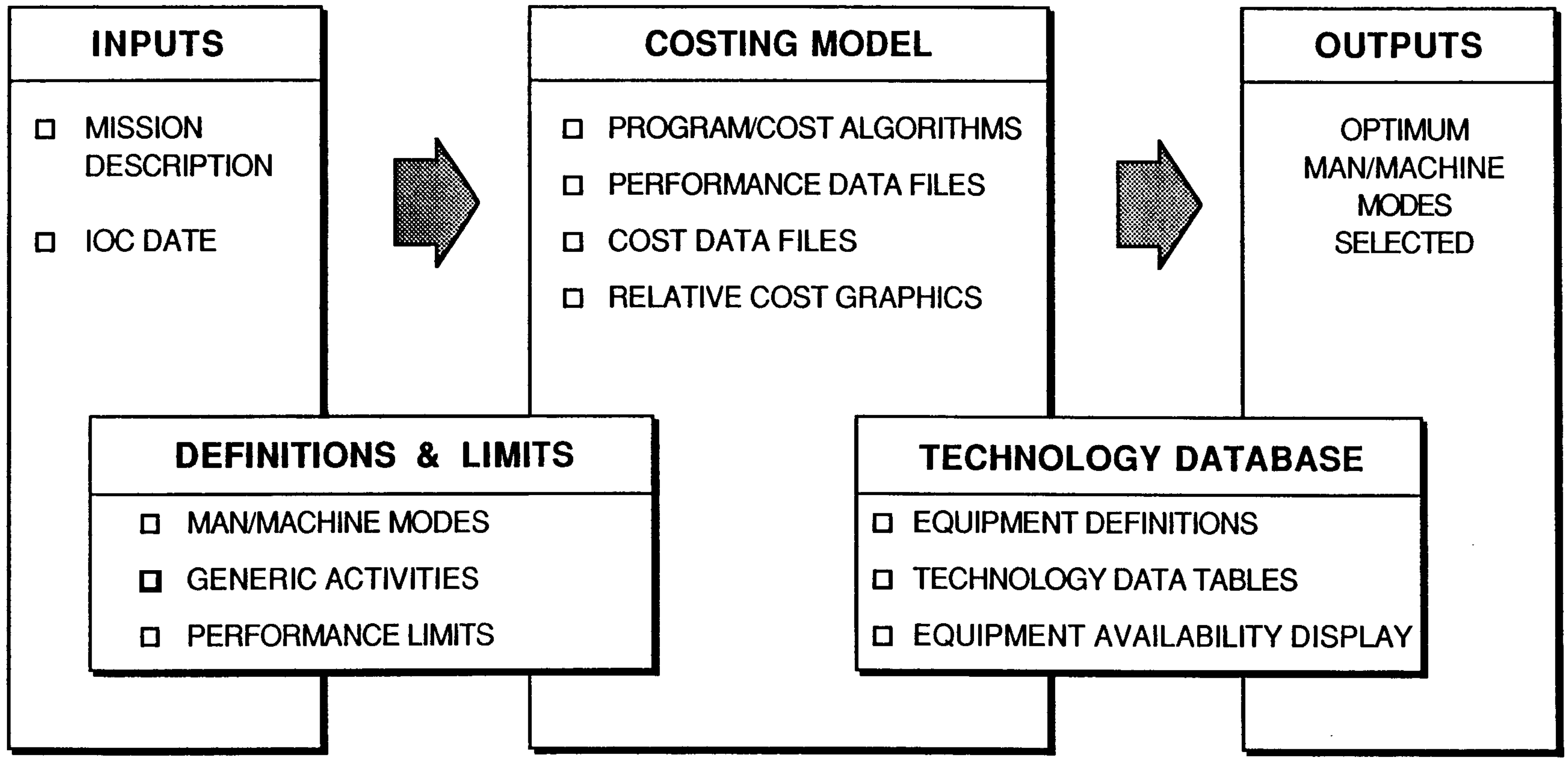
- Background, Objectives and Results .... George Maybee
- Methodology Enhancement and Sensitivity Analysis .... Dave Bergeson
- Technology Readiness Database .... George Maybee
- Concluding Remarks .... George Maybee

THURIS - A METHOD FOR OPTIMIZING THE HUMAN ROLE IN SPACE

THURIS application is an iterative process involving successive assessments of man/machine mixes in terms of performance, cost and technology to arrive at an optimum man/machine mode for the mission application. The process begins with user inputs which define the mission in terms of an event sequence and performance time requirements. The desired initial operational capability date is also an input requirement. THURIS terms and definitions (e.g., generic activities) are applied to the input data converting it into a form which can be analyzed using the THURIS cost model outputs. The cost model produces tabular and graphical outputs for determining the relative cost-effectiveness of a given man/machine mode and generic activity. A technology database is provided to enable assessment of support equipment availability for selected man/machine modes. If technology gaps exist for an application, the database contains information supportive of further investigation into the relevant technologies.

In the present study, we have concentrated on testing and enhancing the THURIS cost model and subordinate data files and developing a technology database which interfaces directly with the user via Technology Readiness displays. This effort has resulted in a more powerful, easy-to-use applications system for optimization of man/machine roles.

THURIS - A METHOD FOR OPTIMIZING THE HUMAN ROLE IN SPACE



ORIGINS OF THURIS

PHASE I - DEVELOPMENT: THURIS was developed to provide project managers with a unified, objective methodology for selecting man/machine roles for future space missions. Performance, cost and technology readiness were recognized as primary considerations in determining cost-effective man/machine allocations. THURIS was therefore constructed to bring these considerations to bear on specific mission requirements within the context of the complete NSTS/Space Station infrastructure.

The methodology contained a set of definitions which clearly related man/machine activities to performance, cost, and technology. In their original form, these definitions included 6 man/machine modes, 37 generic activities which could be combined to represent virtually any mission task, and 63 support equipment items assigned as required to support the man/machine modes appropriate for each generic activity. The relative cost of performing a generic activity in a given mode is calculated by the THURIS cost model. The model output is a graph showing relative cost as a function of the number of repetitions for the activity. These graphs provide for visual determination of cost-effective man/machine modes.

ORIGINS OF THURIS

PHASE I - DEVELOPMENT

- ☐ Developed methodology for space activity allocation based on three criteria:

    1. Performance requirements
    2. Cost of facilities and equipment
    3. Technology readiness

- ☐ Consolidated data from many space projects, studies and simulation programs.

- ☐ Defined man/machine modes and generic activities applicable to a broad spectrum of missions.

- ☐ Defined costing algorithms, support equipment requirements and analytical procedures.

- ☐ Concluded that the THURIS model is an effective tool which enables planners to optimize man/machine roles early in a program.

ORIGINS OF THURIS (CONT)

PHASE II - VALIDATION: The methodology developed in phase 1 was modified to permit analysis of missions in the conceptual phase of development when little detail is available concerning system design and operation. Modifications included (1) simplifying generalizations concerning support equipment allocations and costs, and (2) revisions of man/machine modes to combine the "supported" and "augmented" modes and add the ground-teleoperated mode. The modified model was validated by exercising it against nine mission scenarios different from those used in phase 1. These scenarios were based on operations involving the Orbital Maneuvering Vehicle (OMV), Orbital Transfer Vehicle (OTV), Space Station Research Laboratory Modules, and a GEO platform concept.

ORIGINS OF THURIS (cont'd)

PHASE I I - VALIDATION

- <u>Analyzed</u> nine mission scenarios using methodology developed in phase 1.

- <u>Applied</u> a fixed set of equipment allocations and costs to all missions.

- <u>Revised</u> methodology as follows:

  1. Developed simplified man/machine cost-effectiveness relationship and graphics

  2. Developed separate procedures for Phase A and Phase B levels of analysis

  3. Revised man/machine mode definitions

- <u>Concluded</u> further refinements of THURIS model required and applications be extended to progressive missions, e.g., Mars exploration.

MAJOR STUDY OBJECTIVES

The THURIS methodology and cost estimating model developed and validated in the earlier studies enables the user to arrive at logical, cost-effective choices for man/machine roles in a variety of missions. A question to be answered in the present study is "What are the effects of changes to groundrules and assumptions, implicit in the methodology, on the outcome of THURIS applications?" For example, what happens to the man/machine allocations for a Space Station mission if DDT&E costs are charged and the launch cost is doubled? Will the analyst reach different conclusions about role allocations? Will automated modes of operation become more attractive or less attractive?

Technology readiness, an important criterion in mapping future missions, was generalized in terms of estimated technology readiness levels in previous studies. In the present study, a major objective was to develop a broad-based, easily accessible technology database with information directly correlated with the THURIS support equipment complement. The database was to be computerized to provide a straight forward, easily maintainable and expandable technology readiness file for THURIS applications.

OBJECTIVES

- ☐ Analyze the sensitivity of THURIS-derived man/machine role recommendations to changing groundrules
  - Include/exclude DDT&E costs
  - $86M vs $200M launch cost
  - Space Station vs Shuttle sortie mission
- ☐ Develop a computerized technology data base for THURIS applications
  - Consolidate technology readiness data
  - Format information for easy access and maintenance

MAJOR STUDY GUIDELINES

Essential definitions derived in the initial THURIS study which are carried over* in the present study include:

(1) Thirty-seven generic activities based on a survey and analysis of a variety of space missions
(2) Nine cost factor categories developed for cost estimation
(3) Sixty-three support equipment items which are the basis for costing man/machine modes across the 37 generic activities
(4) Six man/machine categories including Manual, Augmented, Teleoperated, Ground-supervised, Orbit-supervised, and Independent

The THURIS Applications Study addresses Low-Earth-Orbit (LEO) missions and assumes operations and attendant systems and technologies projected through the year 2010.

*Subject to review and revision as part of a general THURIS critique to be performed early in the study

MAJOR STUDY GUIDELINES

GUIDELINES

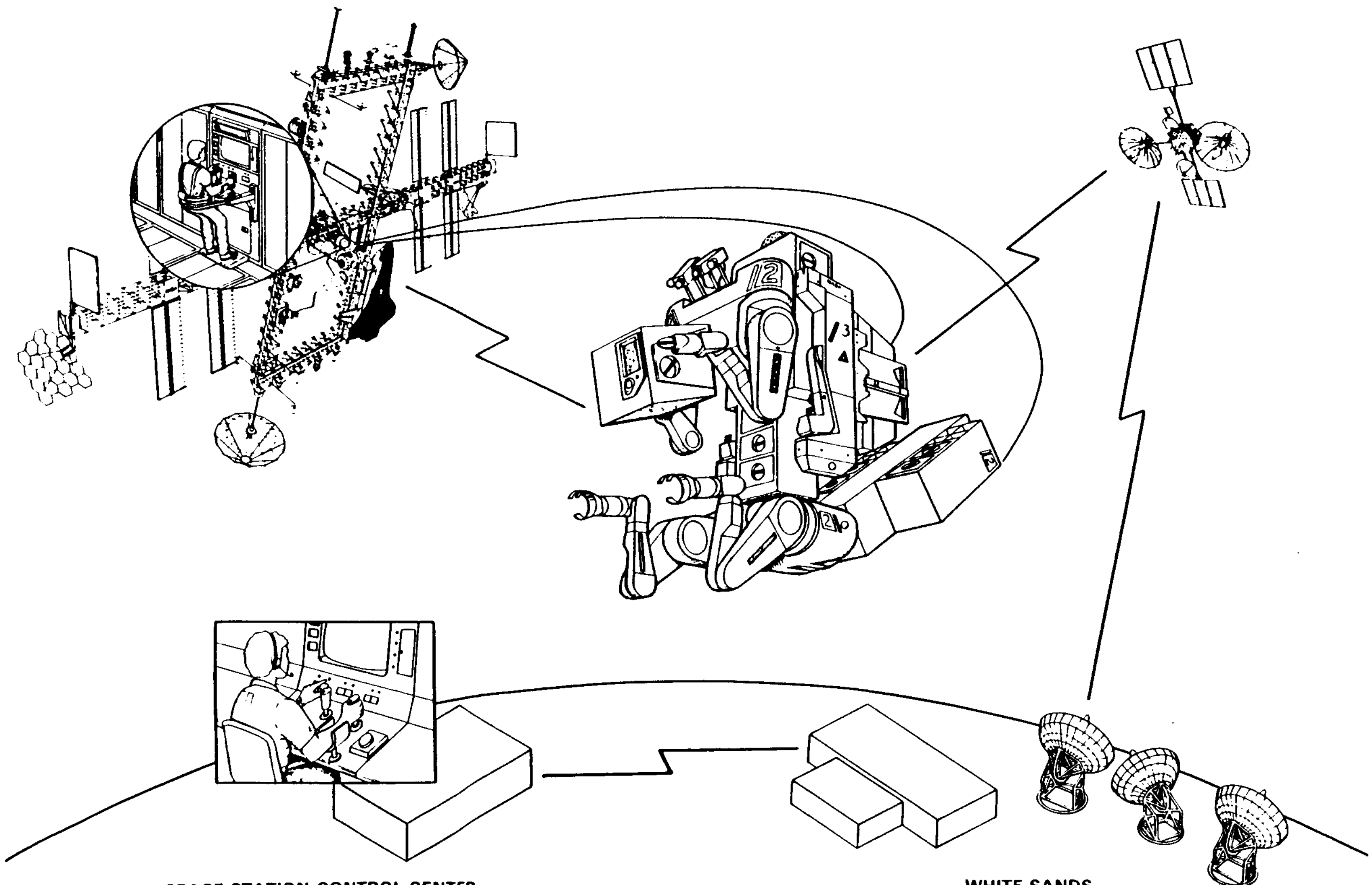
- Use terms and definitions developed in the first THURIS study
  - Generic activities
  - Cost factor categories
  - Support equipment definitions
- Use the man/machine categories developed in the second THURIS study
- Focus on data pertaining to 1986 to 2010 timeframe Space Station LEO applications

GROUND/ORBIT SUPERVISED ROBOT OPERATIONS

A Flight Telerobotic Servicer (FTS) is planned for early Space Station operations and is included in the THURIS support equipment complement. It will include capabilities such as dual arms, force, torque and position sensors, and stereo cameras. A man-in-the-loop control station will provide for telerobotic operations. The FTS will be capable of functioning as a dexterous manipulator within the Space Station payload servicing facility, and as a smart front end on the Space Station OMV. It is planned that control of the telerobot be exercised through the NSTS Orbiter during the Space Station assembly phase. Later it will be controlled from the core Space Station and from the ground.

A McDonnell Douglas Generic Space Robot (GSR) concept, shown in the illustration, exemplifies general robotic applications for Space Station. It would use artificial intelligence and its own guidance and tracking system to do repair and maintenance tasks on or around the Space Station. Growth would advance the capability from teleoperations through telepresence and ultimately to a supervised autonomous robot which could act independently within prescribed limits. Functions performed by the robot would include payload maintenance, servicing or repair of platforms, unpressurized ORU retrieval, module manipulation, satellite servicing, and hazardous operations such as OMV propellant reservicing.

GROUND/ORBIT SUPERVISED ROBOT OPERATIONS



APPLICATIONS STUDY TASK APPROACH

TASK 1 - SENSITIVITY ANALYSIS. This task included five subtasks which covered the review and enhancement of THURIS methodology, a comparative analysis of THURIS-generated cost-effectiveness curves based on a set of options for Space Station and Shuttle sortie mission costing, and an evaluation of the impact of model sensitivities on man/machine role selections. Fundamental elements of THURIS methodology, including man/machine mode and generic activity definition, equipment allocations, costs and costing algorithms were evaluated and modified as required to enhance the model. The effects of changes to basic input variables and underlying groundrules and assumptions were investigated. New programs were written to support this activity. The total effort was focused on challenging the stability of the model and ultimately demonstrating its responsiveness to a variety of applications and attendant assumptions.

TASK 1: SENSITIVITY ANALYSIS

- ☐ Critique THURIS methodology and cost model
- ☐ Enhance and update model as required
- ☐ Compare THURIS outputs for alternative mission/launch cost options
- ☐ Analyze cost impact of technology readiness
- ☐ Identify impact of cost on man/machine role allocations

APPLICATIONS STUDY TASK APPROACH (CONT)

TASK 2 - TECHNOLOGY DATA BASE DEVELOPMENT. The approach to this task involved determining an effective, practical method of incorporating specific technology readiness information into the THURIS decision making process and creating a computer database to implement the method. It was decided that the most direct, top-level connection between THURIS cost and performance data and technology data is the support equipment availability date. The database was therefore dedicated to that premise. The development effort included a review and updating of the THURIS support equipment complement, review of technology readiness display options, development of a user-friendly technology database with NASA approved operating software and formats, and entry of technology data into the system. The database was documented and delivered, ready for immediate use in THURIS applications.

TASK 2: TECHNOLOGY DATABASE DEVELOPMENT

- ☐ Review and update hardware/software element for generic activities
- ☐ Review technology modeling efforts for THURIS applications
- ☐ Develop options for consolidating technology data to directly support THURIS
- ☐ Develop, load and demonstrate a technology database using NASA approved formats
- ☐ Deliver database documentation and software

STUDY RESULTS SUMMARY

METHODOLOGY REVIEW AND ENHANCEMENT. An analysis of the 37 generic activities was conducted with the objective of consolidating activities. On the basis of equipment commonality, it was initially thought that some activities could be combined. However, a deeper look at performance limitations associated with these activities led to the conclusion that they should remain as originally defined. Support equipment added to the model included a baseline Spacelab facility and an IVA robot, providing a more complete basis for mission applications. The ground-teleoperated mode was added to provide for the ultimate operation of systems such as the Flight Telerobotic Servicer from ground stations. The algorithm for computing operating system software costs was modified to distribute costs uniformly across the expected user population. The THURIS cost model programs were transposed from PASCAL to BASIC language to permit integration with the MSFC THURIS operating system. A program was also written to automate the calculation of man/machine mode intersection points which are used to measure the shift in cost-effectiveness zones.

METHODOLOGY REVIEW AND ENHANCEMENT

- Generic Activities --- Considered consolidating activities; no change made
- Support Equipment --- Added seven, deleted five; total now 65 items
- Man/Machine Modes --- Added ground-teleoperated mode
- Costing Algorithms --- Modified operating system software computational base
- Programs ------------ Transposed cost model programs from PASCAL to BASIC; developed program for calculating Man/Machine mode intersections

STUDY RESULTS SUMMARY (CONT)

MAN/MACHINE ALLOCATION SENSITIVITY. The sensitivity of the THURIS cost model and resultant man/machine role allocations were evaluated in three ways: (1) input parameters such as performance time and equipment life cycle were varied and the resultant outputs analyzed, (2) a complete set of cost curves, embracing all man/machine modes and generic activities, was generated and analyzed for eight mission configuration/launch cost options, and (3) an OTV engine exchange mission was analyzed to determine the effects of configuration/launch cost options on a specific application. In each of these assessments it was demonstrated, as would be expected, that the model is indeed sensitive to variations in the system parameters and that the resulting outputs are altered in a logical and consistent manner.

TECHNOLOGY DATABASE. The technology readiness database was developed using R:base 5000 software. It is designed to provide clear and direct support to the THURIS process. This is accomplished by keying the technological information to equipment support items and generic activities. In addition to the database, a BASIC program and ASCII file were prepared to provide for the generation of technology readiness displays in the MSFC THURIS operating system. A menu system is provided with the technology database to permit user-friendly maintenance.

STUDY RESULTS SUMMARY (cont'd)

MAN/MACHINE ALLOCATION SENSITIVITY

- ☐ Sensitivity Factor Analysis ---- Demonstrated effects of changing input variables on cost model outputs
- ☐ Comparative Analysis - Demonstrated effects of changing major groundrules/assumptions on cost model outputs
- ☐ Mission Analysis ------ Demonstrated man/machine allocation sensitivity for OTV mission as a function of mission/launch cost options

TECHNOLOGY READINESS DATABASE

- ☐ Information Tables ---- Developed EQUIPDAT and TECHDAT tables in R:base 5000
- ☐ Technology Display---- Developed programs for equipment availability display

AGENDA

Background, Objectives and Results .... George Maybee

Methodology Enhancement and Sensitivity Analysis .... Dave Bergeson

Technology Readiness Database .... George Maybee

Concluding Remarks .... George Maybee

THURIS SENSITIVITY ANALYSIS

The previous THURIS studies developed a methodology for performing man/machine allocation. The objective of this study task was to review and test the assumptions of that methodology in order to enhance both the model and the overall THURIS approach. Analyses performed included a comparison of THURIS results based on variances in facility costing methods, impact of technology readiness on costs, and impact of changing costs on allocation of man/machine roles

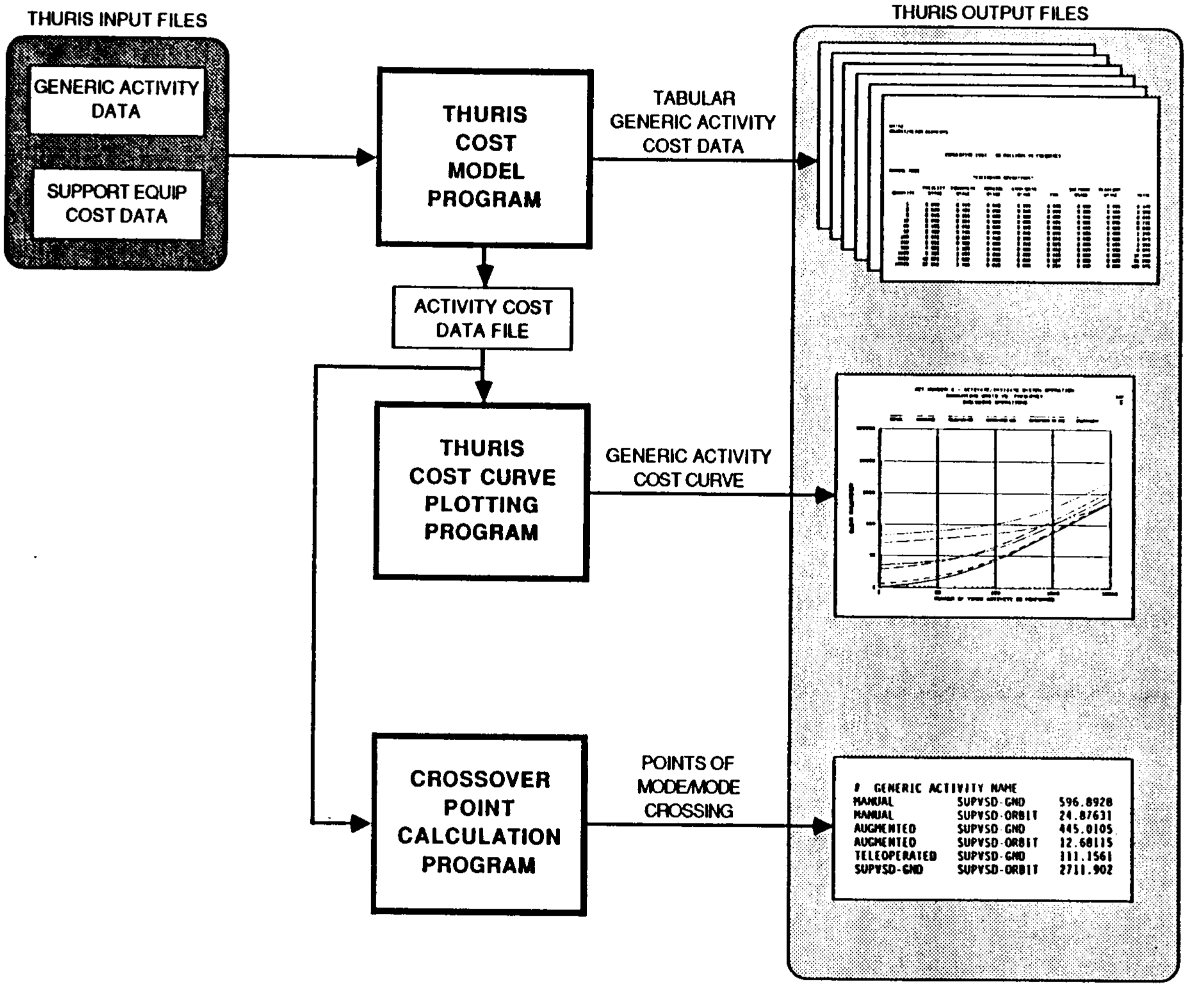
THURIS SENSITIVITY ANALYSIS

- ☐ Review of Data and Assumptions
- ☐ Enhancement on THURIS Approach
- ☐ Comparative Cost Analysis
- ☐ Analysis of Cost Impact of Technology Readiness
- ☐ Analysis of Cost Impact on Man/Machine Role Allocations

THURIS MODEL SOFTWARE

Three distinct programs make up the THURIS model software. These programs are written in BASIC language and the software is accessed using a personal computer workstation. The THURIS cost model program uses generic activity data and equipment cost inputs to tabulate costs for performing the activity in various modes. The THURIS cost curve plotting program provides a graphical view of the generic activity cost data on a log/log scale. The crossover point calculation program calculates intersection points of the plotted curves in order to provide accuracy in analysis of curve movement.

THURIS MODEL SOFTWARE



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THURIS REVIEW ISSUES

In reviewing THURIS assumptions, various issues were identified and evaluated for potential impact on the THURIS cost model. Concerns which were found to have impact were closed based on modification to methodology or assumptions.

THURIS REVIEW ISSUES

NO.	ISSUES	REMARKS
1	10 Year Life	User Selects Scenario
2	Learning Curve Application	Learning Curve Option Included in Model
3	Training Facilities Excluded	Hardware Design Labs Also Not Included
4	High EVA Availability	EVA Availability Adjustment
5	No Pre-EVA Activities	Included in Mission Event Planning
6	Facility Usage Not Costed for Independent Modes	Logistics Costs Included. Power Was Insignificant Cost Driver
7	Software Cost Allocation	Enhancement to Software Methodology

SENSITIVITY ANALYSIS FACTORS

Various inputs to the THURIS cost model process were altered as a means of testing the sensitivity and stability of the model. Such factors included activity performance times, costs of support equipment items, the assignment of support equipment to the generic activity modes, crew time available to perform EVA functions, and equipment life used in amortization of equipment production cost.

SENSITIVITY ANALYSIS FACTORS

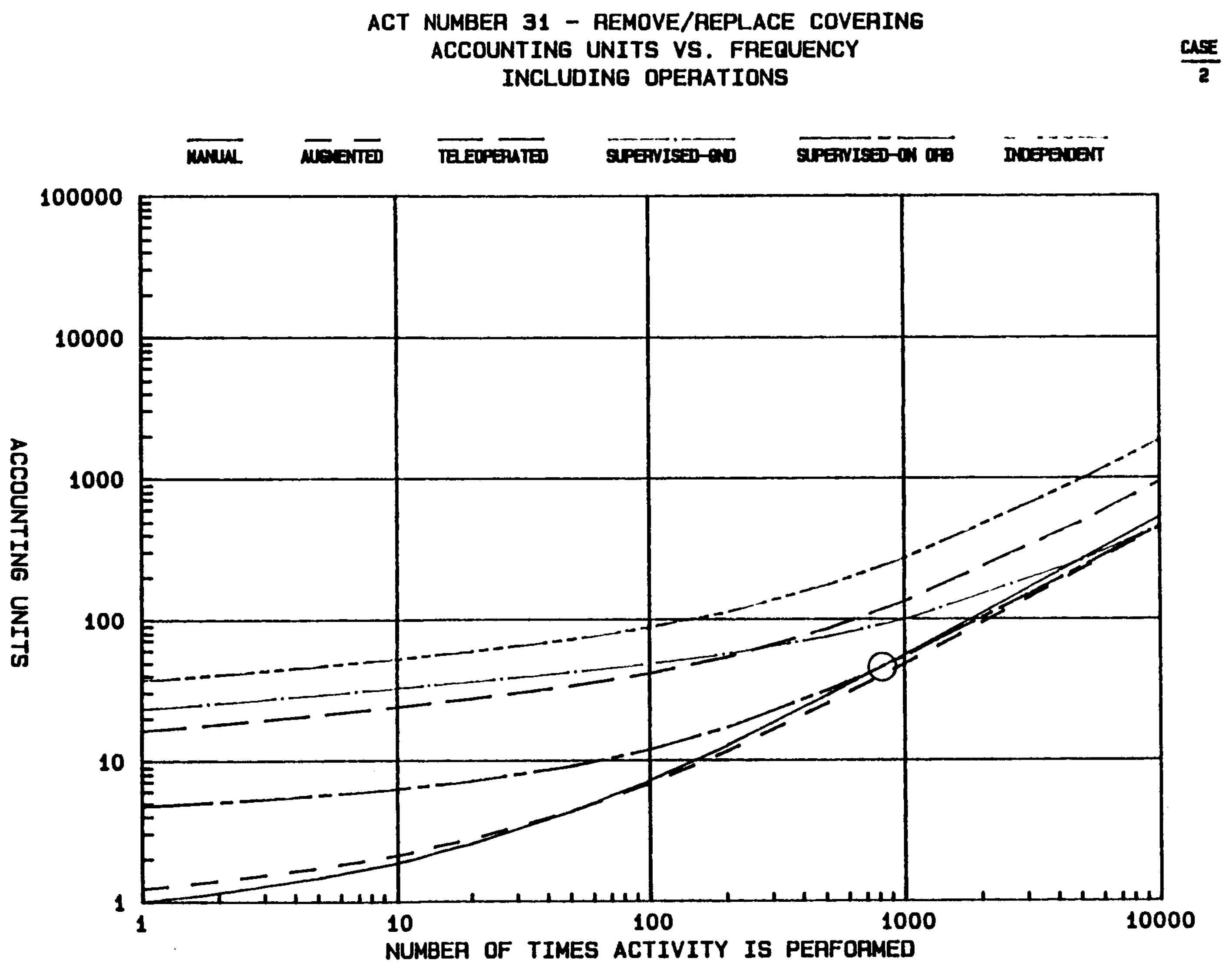
	Model Sensitivity
☐ Performance Time	✓
☐ Support Equipment Costs	✓
☐ Support Equipment Assignment	✓
☐ Crew Availability for EVA	✓
☐ Equipment Life Amortization Factor	✓

SENSITIVITY ANALYSIS FACTORS

FULL MISSION STATION - 86M LAUNCH CROSSOVER POINTS

An example of THURIS cost versus frequency curves for Activity 31, remove/replace covering is shown in this chart. The circled point represents the crossover point between the manual mode and the supervised orbit mode. At approximately 800 repetitions the two modes had the same cumulative costs. The relative starting points along the left axis of the graph represent the increasing costs of support items added as the degree of automation is increased. The movements of these crossover points were studied for response to the various sensitivity analysis factors.

FULL MISSION STATION - 86M LAUNCH CROSSOVER POINTS



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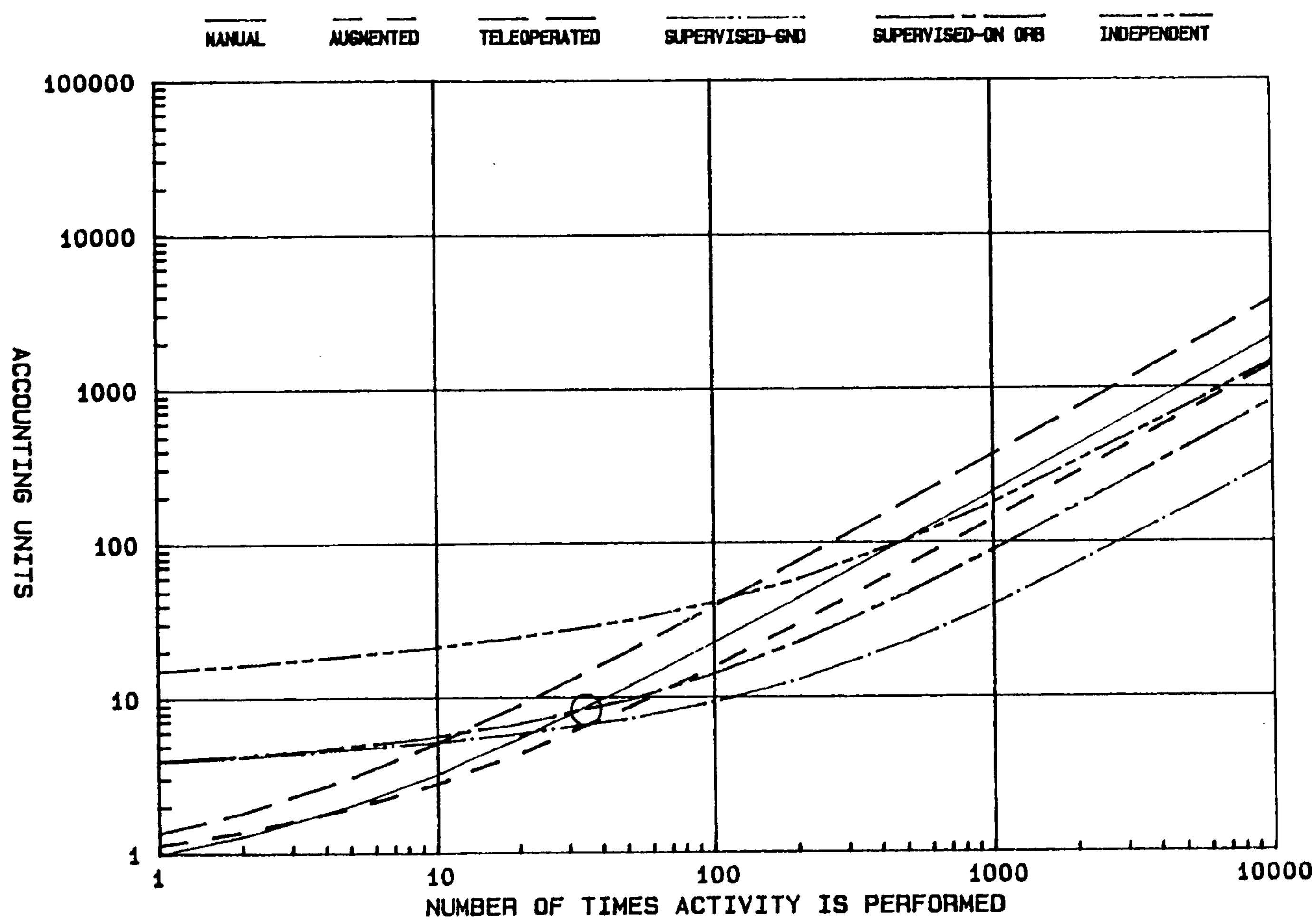
SHUTTLE SORTIE 86M LAUNCH CROSSOVER POINTS

This example also shows the cost/frequency curves for Activity 31, remove/replace covering, but the case here is for the shuttle sortie case with 86 million used for launch costs. The circled point again shows that the supervised orbit cumulative costs equal manual mode costs at approximately 30 repetitions. The relative cost differences, as shown along the left axis of the chart, show that the initial repetitions in the more automated modes are relatively less expensive than for the Space Station case previously shown. The movements of these crossover points were studied and compared for response to the sensitivity factors.

SHUTTLE SORTIE - 86M LAUNCH CROSSOVER POINTS

ACT NUMBER 31 - REMOVE/REPLACE COVERING
ACCOUNTING UNITS VS. FREQUENCY
INCLUDING OPERATIONS

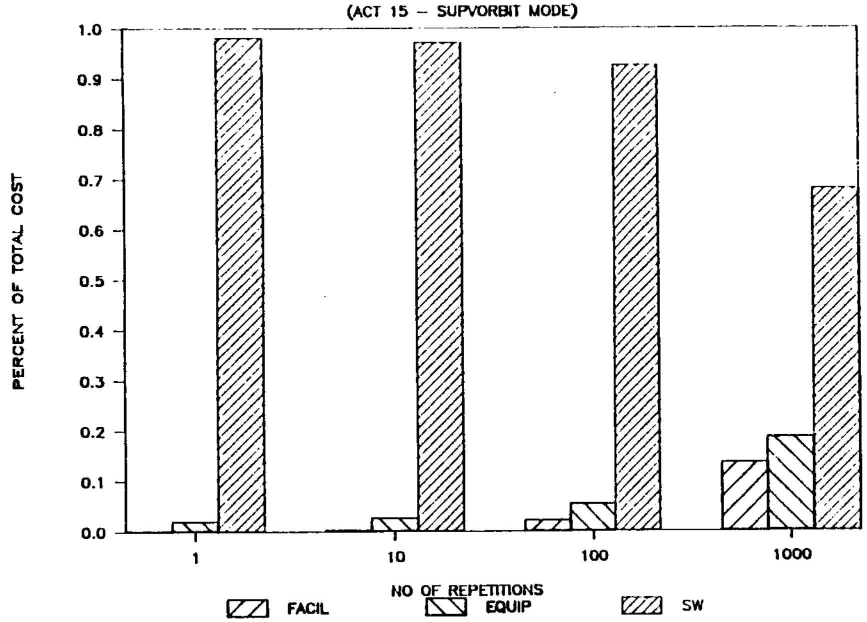
CASE 6

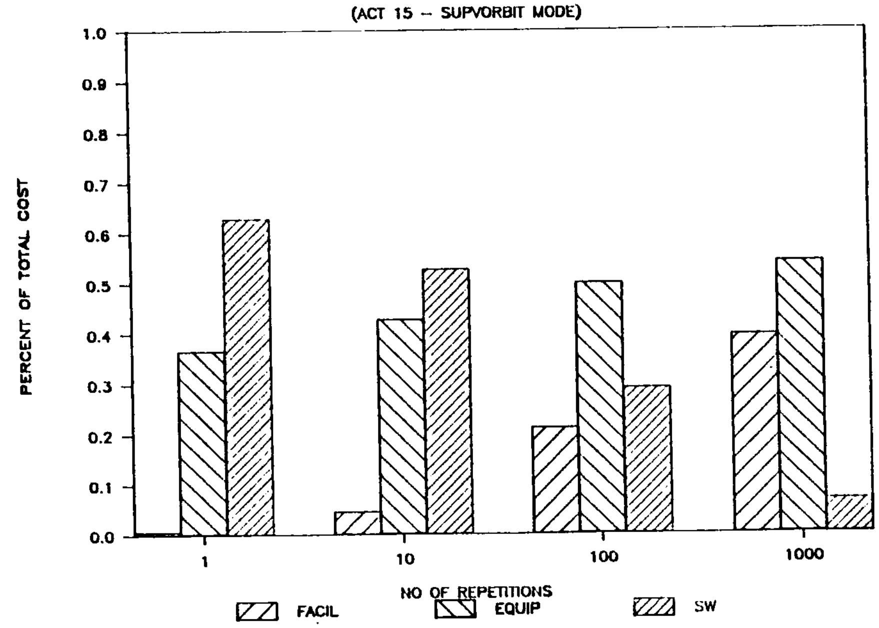


ENHANCEMENT OF SOFTWARE COST METHODOLOGY

Pareto diagrams were constructed from THURIS cost model data to identify dominant cost drivers for various man/machine modes of generic activities. The analysis indicated the dominant cost driver for the more automated modes was software. The cost allocation assumptions for the software category were scrutinized and it was determined that the dominance of the software costs was due to a methodology which allocated development cost of software operating systems as if it were a production cost and derived an operating cost based on the number of uses for the operating system. An alternative methodology was devised to spread the operating and development costs evenly across each of the thirty users identified in the Microgravity and Materials Processing Facility (MMPF) Study.

ENHANCEMENT OF SOFTWARE COST METHODOLOGY





COST ELEMENT	COST COMPUTATIONAL BASE
Operating Systems Software - Original Methodology	$\frac{\text{Software Development Cost (C)}}{\text{Number of Activity Repetitions (N)}} + \frac{0.55\ C}{N^{0.848}}$
Operating Systems Software - Revised Methodology	$\left[\frac{\text{Software Development Cost (C)}}{\text{Number of Activity Repetitions (N)}} + \frac{0.55\ C}{N^{0.848}}\right]\left[\frac{1}{30}\right]$

COMPARATIVE COST ANALYSIS CASES

The comparative cost analysis task was performed to determine what the changes of mission groundrules do to the model results.. The analysis was begun using a "delta mission" case defined by the previous THURIS study. With each case developed for the analysis a change in groundrules occurred. These included shifts from low to high launch cost, differences between delta mission and full capability mission, the inclusion of design and development costs, and the replacement of the Space Station facility with a Spacelab facility. It is noted that the facility assumes a higher cost with the addition of each case.

COMPARATIVE COST ANALYSIS CASES

FACILITY TYPE	LAUNCH COST	
	$86M	$200M
DELTA STATION EXCLUDING DDT&E	CASE 0	CASE 1
FULL STATION EXCLUDING DDT&E	CASE 2	CASE 3
FULL STATION INCLUDING DDT&E	CASE 4	CASE 5
SHUTTLE SORTIE	CASE 6	CASE 7

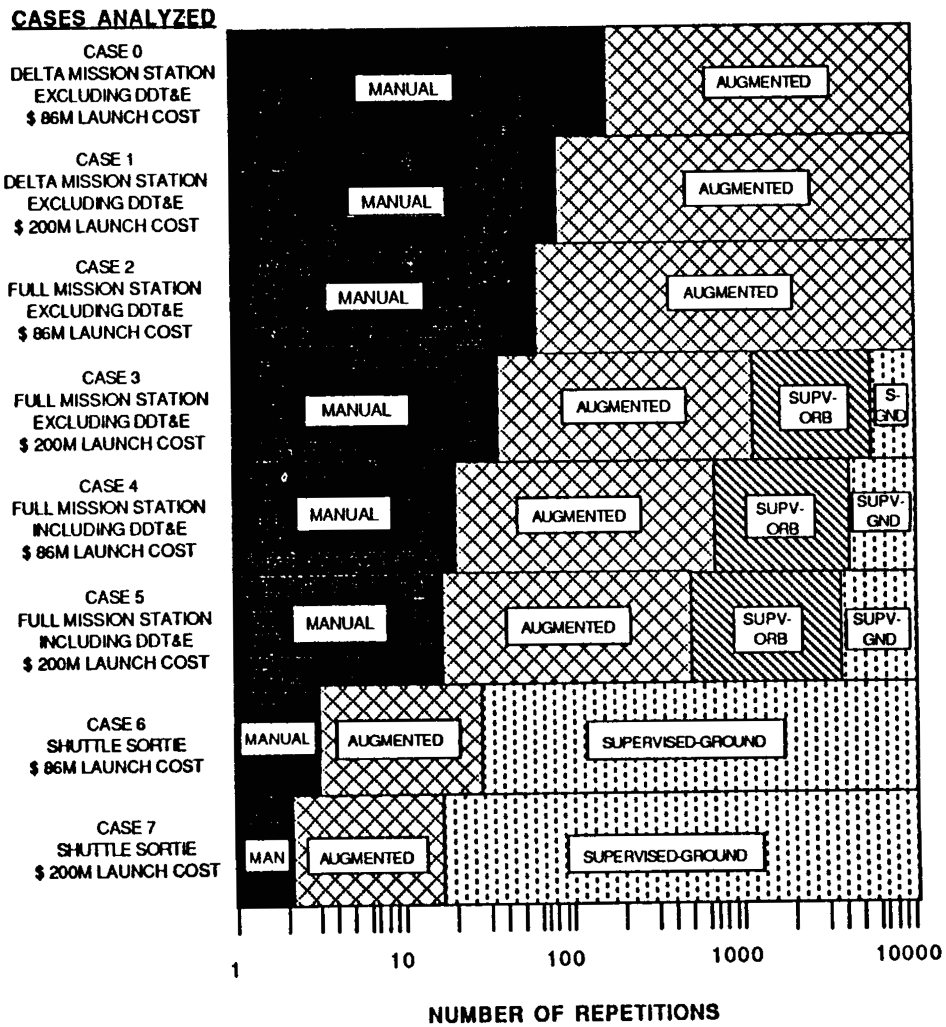
TRENDS IN OPTIMUM COST MODES

In general it was noted that the increase to the facility cost in the comparative cost analysis cases caused the curves to shift such that more automated (machine) modes became cost effective at a lower activity repetition point. This is due to the fact that the increase in facility cost adds to the total costs of the more manual modes which utilize the facility, thus increasing the cost of crew time. The figure shows how tradeoffs of the most cost effective mode occur. In the shuttle sortie cases, the automated modes dominate the optimum cost zone. This is due to the fact that the high shuttle sortie facility costs are driven by less crew availability, full launch cost allocation, and high cost per unit time for ground control facilities.

Through the comparative cost analyses performed, it was determined that the model is sensitive to changes in overall facility groundrules, potentially impacting the selection of the optimum cost mode. However, a consistency was recognized in the reaction of the model to the cases analyzed and the model was observed to be flexible, easily accommodating variances in groundrules through minor manipulations to the THURIS cost model input data.

TRENDS IN OPTIMUM COST MODES

Example - Act 31 Remove/Replace Covering



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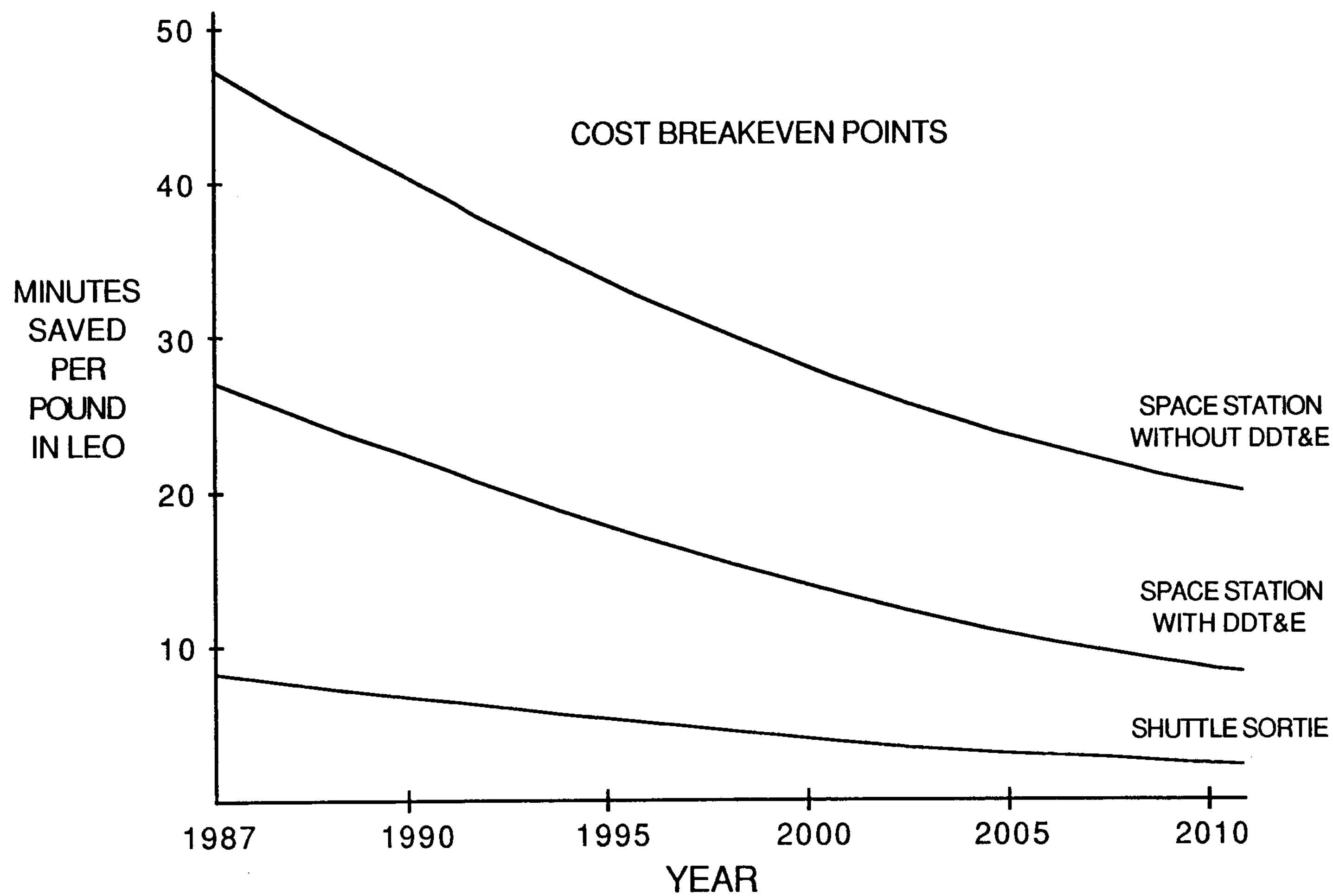
RELATIVE COST EFFECTS OF TECHNOLOGY READINESS IMPACTS

The various support items have been assembled into the technology readiness data base provided as a part of this study. Those items presently available have been identified as such. The RCA-PRICE (Parametric Review of Information for Costing and Evaluation) model was used to predict future costs for typical automation hardware and to construct a general case display of the economic break-even point for the hardware for the period from 1987 to 2010. The hardware costs for development and production were compared with flight crew cost factors for the Space Station with and without DDT&E costs, and the shuttle sortie cases. The resulting chart shows the trend over the period of interest for how much flight crew time automation hardware must save to equal the cost effectiveness of manned modes.

RELATIVE COST EFFECTS OF TECHNOLOGY READINESS IMPACTS



COST IMPACTS OF MAN/MACHINE ROLE ALLOCATION

The various generic activity cost curves for the various mission scenarios and man/machine modes were studied for trends or general observations about the nature of behavior of the optimum cost modes. Observations concerning the Space Station and shuttle mission scenarios, the supervised-ground mode, the supervised-orbit mode, and the independent mode were apparent.

COST IMPACTS OF MAN/MACHINE ROLE ALLOCATIONS

- ☐ Space Station cases favor the manual mode by a factor of 3 to 5 with respect to the Shuttle Sortie cases
- ☐ Shuttle sortie cases favored supervised ground modes for activities with more than 20 - 50 repetitions
- ☐ The supervised orbit mode did not consistently become cost effective in any repetition range
- ☐ Advancing technology in software could cause supervised and independent modes to become cost effective in the 100 to 500 repetition range in the mid 1990's

AGENDA

Background, Objectives and Results .... George Maybee

Methodology Enhancement and Sensitivity Analysis .... Dave Bergeson

Technology Readiness Database .... George Maybee

Concluding Remarks .... George Maybee

TECHNOLOGY READINESS TASK OBJECTIVES

The objective of this task was to provide an efficient, user-friendly means of organizing and utilizing technology information in the THURIS decision-making process, minimizing subjective judgement and maximizing the correlation between technology readiness data and the selection of man/machine roles. This objective was to be met by developing a computerized database and entering data into it from appropriate technology data sources. It was also an objective to develop the software and instructions necessary to operate the database in parallel with the THURIS cost model program.

TECHNOLOGY READINESS TASK OBJECTIVES

OBJECTIVES

- ☐ Define a direct, objective method for accessing and utilizing technology readiness data in THURIS applications.
- ☐ Implement the technology data utilization method with an efficient, user-friendly system
- ☐ Design system for growth, maintenance, and interfacing with other THURIS elements.

TECHNOLOGY READINESS TASK APPROACH

Data base content and format were derived from review of technology data sources and discussions involving our study team and the MSFC study manager. Options for the database were developed and presented to the study manager for review and approval. The selected option was subsequently developed and documented. Data was entered into the system and the completed database was delivered as the final product of the task.

APPROACH

- ☐ Review technology models and data sources for application to THURIS.
- ☐ Identify appropriate content and format for technology data.
- ☐ Define options for MSFC review and approval
- ☐ Develop databasing system for MSFC approved options.
- ☐ Acquire and enter data into the database.

DATABASE GROUNDRULES

The THURIS support equipment items are the basis for bringing technology information into the decision making process. Two aspects of the equipment items are particularly important in shaping the scope and content of the DATABASE: (1) equipment capability and (2) equipment availability. A relatively general description of equipment capability, together with the year of availability, enables the user to quickly establish a position on the technology readiness of any given item and identify any technology gaps which may exist. As a measure of technology readiness, the criterion of equipment availability helps eliminate some of the subjectivity inherent in the process of estimating technology readiness levels. The original THURIS methodology includes a process for estimating technology readiness levels and deciding on that basis whether the degree of technological risk associated with a particular activity is acceptable. R:base 5000 data basing software was selected because it is relatively easy to use and allows for expansion of the database as new and more extensive data becomes available.

DATABASE GROUNDRULES

GROUNDRULES

- Consolidate technology data directly with THURIS support equipment items.
  - Discontinue use of estimated technology readiness levels.
  - Use equipment availability date as direct measure of technology readiness.
- Use R:base 5000 databasing software.
- Design database derivatives to be compatible with IBM operating system.

DATABASE ASSUMPTIONS

It is assumed that assignment of equipment to the various man/machine modes and generic activities will often be tailored by the user to fit the application according to mission-specific requirements. To simplify this process and reduce the amount of data in the database, a single set of equipment item definitions and technologies is assumed to be adequate for all generic activities, i.e., one equipment item/mode description applies to all 37 activities. A technology readiness level of seven (engineering model tested in space) is assumed for all available hardware and software.

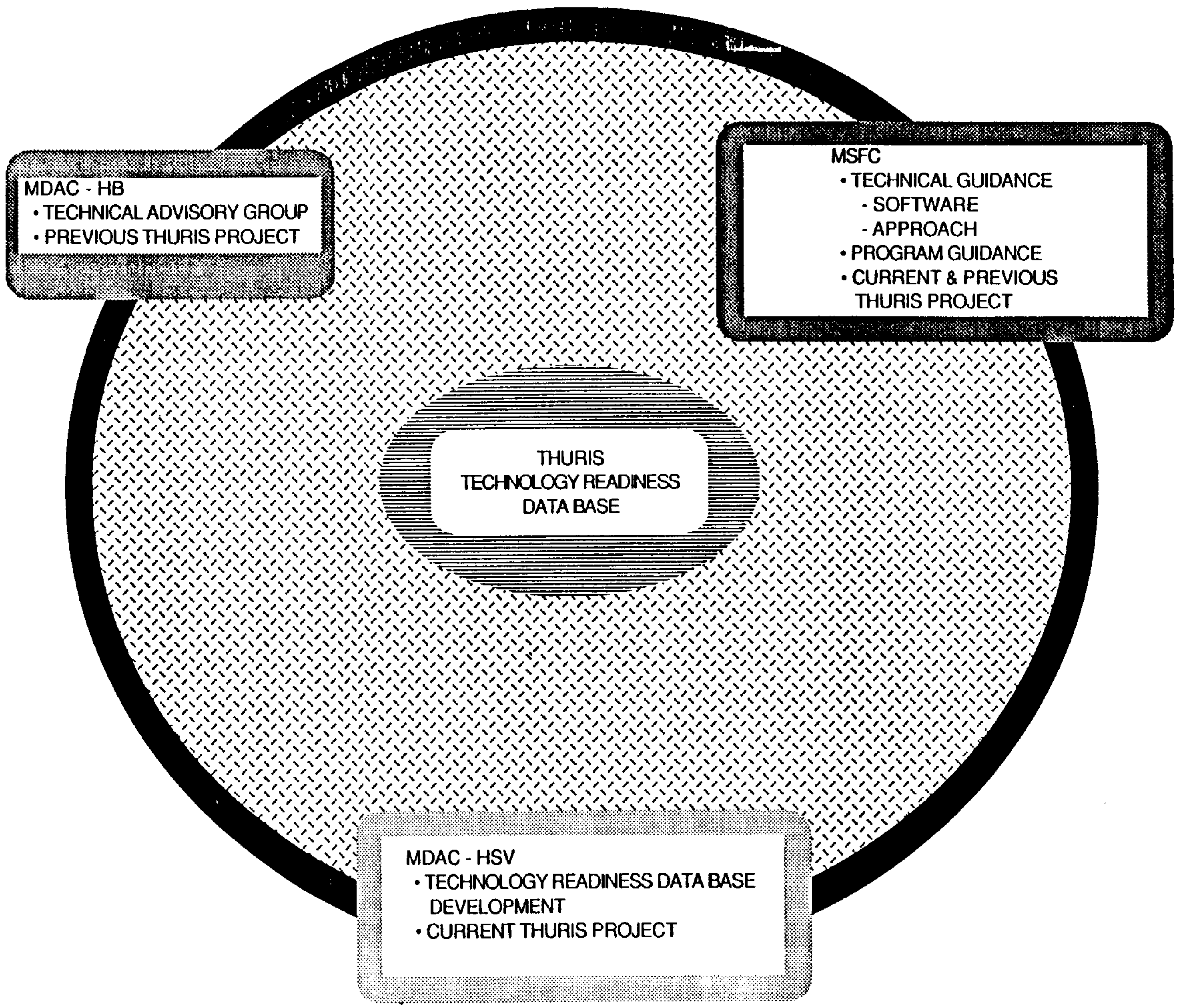
ASSUMPTIONS

- Equipment item capabilities reflect state-of-the-art technology.
- Equipment item complements will be assigned by the user for specific applications.
- Off-the-shelf hardware performance is equivalent to a technology readiness level of seven.
- A single set of equipment item definitions and associated technologies applies to all generic activities.

DEVELOPMENT TEAM

The technology readiness database was developed through the efforts of our study and advisory groups and the MSFC study manager. The work was accomplished during the first ten months of the study. Our MDAC-HSV team developed the database structure and content, performed the data entry, and documented the system. MDAC-HB personnel, who developed the original THURIS methodology, participated as technical advisors for the project. Guidance in the selection of software and data basing approach was provided by the MSFC study manager.

DEVELOPMENT TEAM



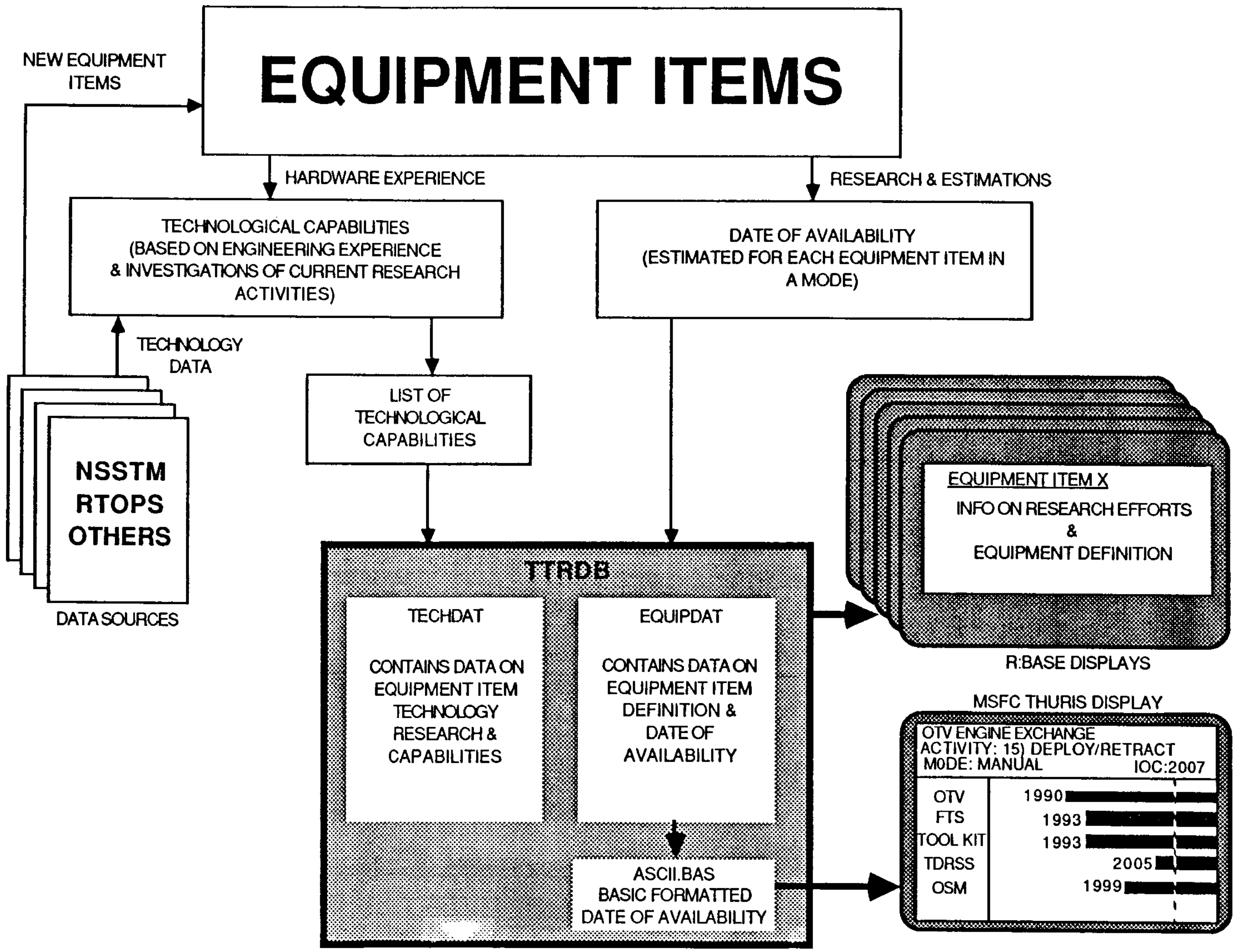
TECHNOLOGY READINESS DATABASE SYSTEM

THURIS support equipment items are described in terms of capability and year of availability. The primary source for technology capabilities is the NASA Space Systems Technology Model (NSSTM), 6th Edition (NASA TM 88176, June 1985). This model provides key technologies associated with different systems and trends technological capability up to the turn of the century. The Research and Technology Objectives and Plans (RTOPS) for FY 1987 were used to derive new equipment items and evaluate technology research. Other sources, such as professional society papers and in-house experience and expertise, were also utilized to derive new equipment items and compile pertinent information on technology research.

These data are archived in a database using R:base 5000 software and reside in a stand-alone model on an IBM PC. R:base 5000 is a state-of-the-art data basing system developed by Microim, Inc. This system contains a procedural language that is used to enter, edit, and manipulate data.

Information contained in the database can be viewed via standardized formats in R:base 5000. Also, data on equipment availability can be accessed (via BASICA file ASCII.BAS) by a stand-alone BASICA program and displayed in a graphical format for clear, quick identification of individual equipment item availability data.

TECHNOLOGY READINESS DATABASE SYSTEM



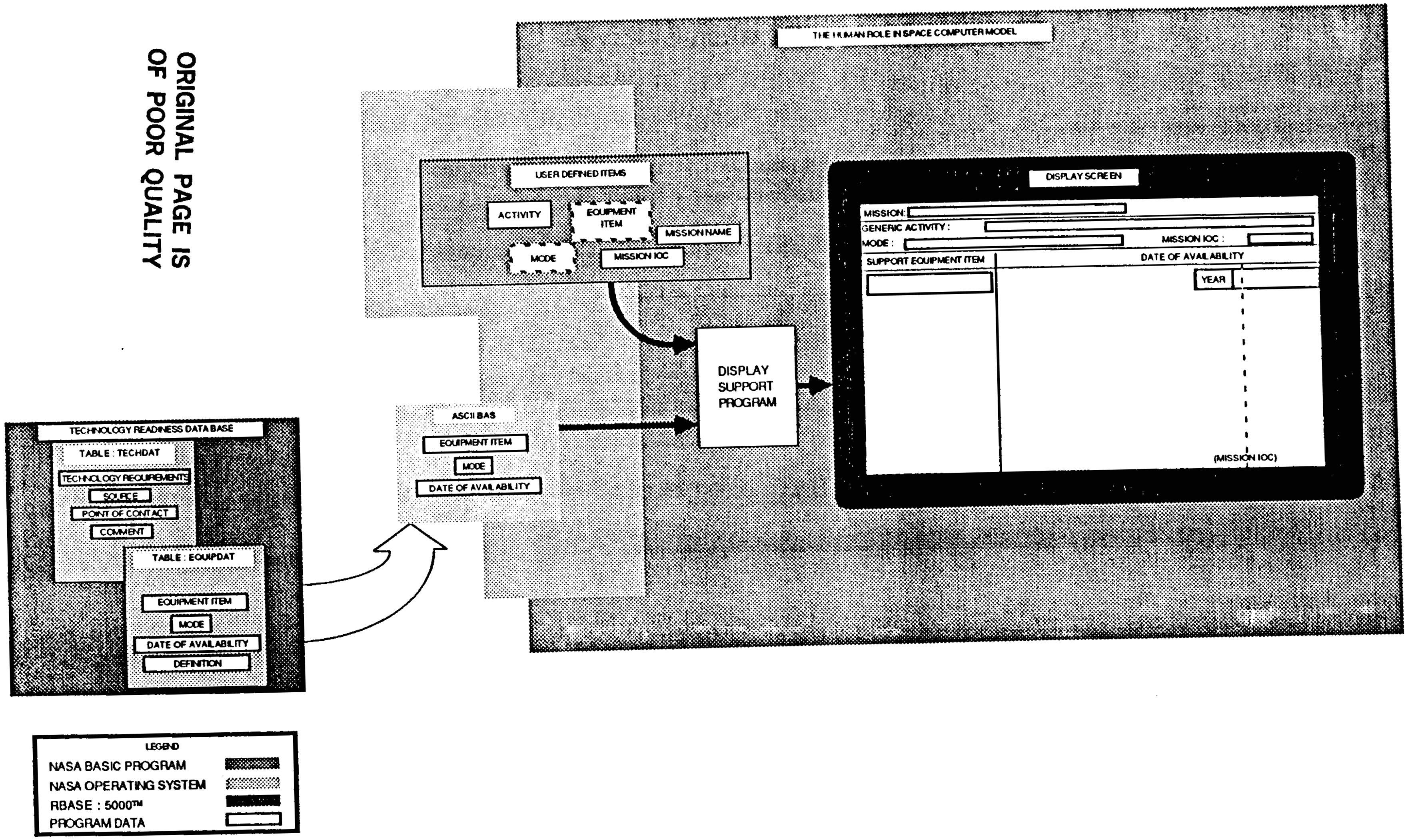
TECHNOLOGY READINESS INTERFACE TO MSFC THURIS MODEL

The Technology Readiness Data Base is designed to interface with an automated THURIS methodology computer system which is under development at MSFC. This system is programmed in BASICA and will allow the user to perform many of the routine steps of the THURIS process by computer, including presentation of selected data in the database.

A display support program was written for the MSFC system to provide for the generation of a display showing equipment availability. Equipment availability dates are automatically extracted from the Technology Readiness Data Base to create a BASIC data file, ASCII.BAS. The display support program utilizes this file to generate the equipment availability display. The display is activated by requesting the equipment items and man/machine modes of interest.

TECHNOLOGY READINESS INTERFACE TO MSFC THURIS MODEL

ORIGINAL PAGE IS
OF POOR QUALITY



MDAC

TECHNOLOGY READINESS DISPLAY

The BASICA display provides a record of the mission, generic activity, mode, and IOC date pertinent to the availability data presented on a complement of equipment items. These items, specified by the user, are assigned a date of availability in a given mode. These data are specified according to a technical definition documented in the R:base table EQUIPDAT and can be accessed for review and/or revision via the database menu system. The year equipment will be available is presented on the left hand side of a bar scaled in one year increments. Items not found are indicated by a zero. Items defined as not able to be used in the specified mode are indicated by the message "***MODE NOT APPLICABLE***" When no data is available in the data file on an item, the display generates a message "***DATA NOT AVAILABLE***." An option is provided for repeated runs at the bottom of the display.

TECHNOLOGY READINESS DISPLAY

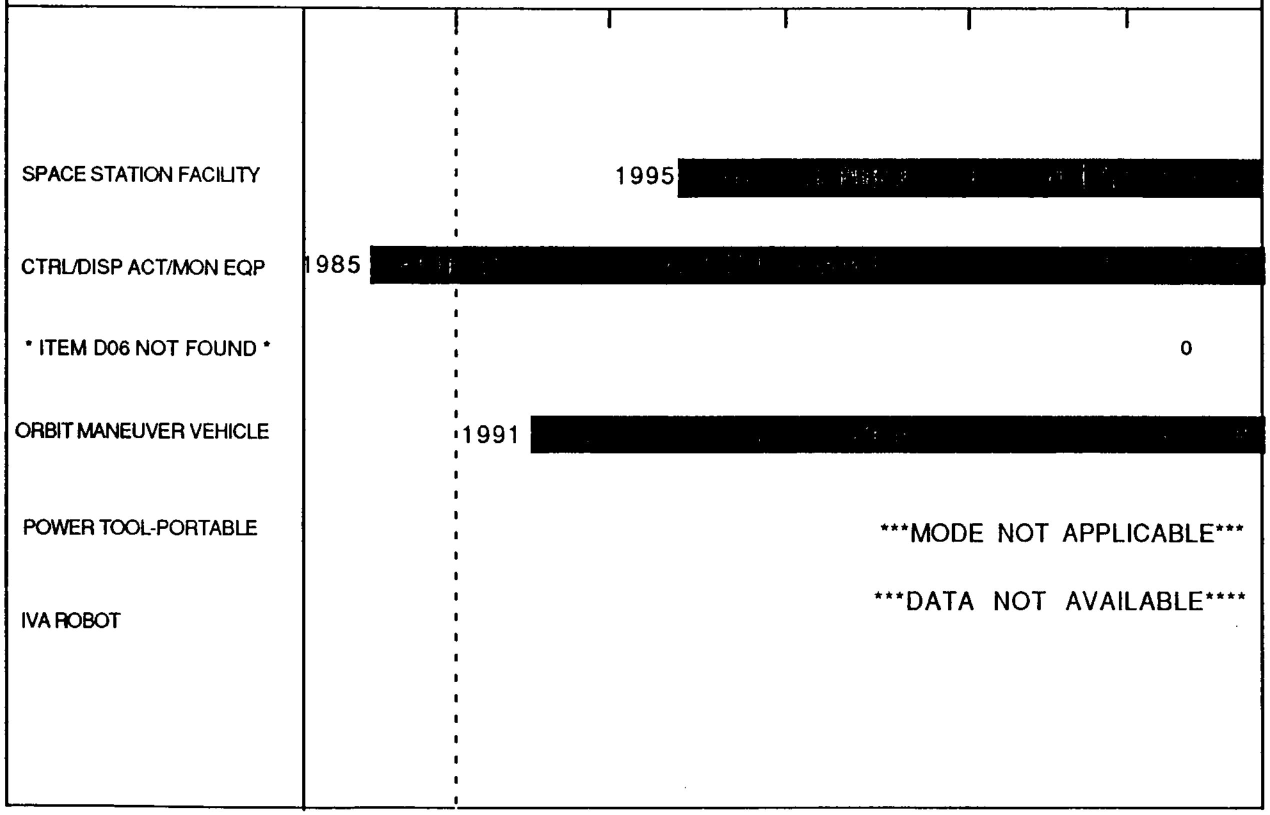
DISPLAY EXAMPLE

MISSION: OMV TV INSPECTION

GENERIC ACTIVITY: 16) DETECT CHANGE IN STATE OR CONDITION

MODE: TELEOPERATED ON-ORBIT

MISSION IOC: 1990



RUN AGAIN (Y/N)? ■

MDAC

DEFINITION DATA FORMAT

Data on equipment definitions can be reviewed in the format shown here. The equipment code and name is provided in the upper portion of the format. Other data include the date when the definition was last updated, the applicable mode (using a standardized abbreviation), the definition, the date of availability, and the source of this information.

```
THURIS TECHNOLOGY READINESS DATA BASE
EQUIPMENT ITEM DEFINTION SUMMARY
==========================================================================
EQUIPMENT ITEM: E03) FLIGHT TELEROBOTIC SERVICER (FTS)
--------------------------------------------------------------------------
LAST UPDATE ON 07/02/87
MODE: SO

DEFINITION: ORBITAL ROBOTIC SYSTEM INCLUDING ON-ORBIT WORK STATION, END
            EFFECTORS, SOFTWARE, AND FLIGHT SUPPORT EQUIPMENT DESIGNED TO
            AUGMENT OR REPLACE EVA CREWMEMBERS WITH LIMITED HUMAN
            INTERVENTION.


DATE AVAILABLE:       1993
SOURCE OF INFORMATION: GSFC RFP5-11381/228
--------------------------------------------------------------------------
```

TECHNOLOGY AND RESEARCH DATA FORMAT

This format provides data on research activities associated with an equipment item. It includes equipment code and name, a brief description of the capability, a paragraph describing the activity, information source, a point of contact, and the date on which the information was last updated.

THE HUMAN ROLE IN SPACE — EQUIPMENT TECHNOLOGY CAPABILITY SUMMARY

EQUIPMENT ITEM: E03) FLIGHT TELEROBOTIC SERVICER

CAPABILITY	COMMENT
ON-ORBIT TELEOPERATION & ROBOTIC SERVICING	ACTIVITY TO PROVIDE MANIPULATOR, MOBILITY, SENSING, & ACTUATION TECHNOLOGY FOR APPLICATIONS SUCH AS SATELLITE SERVICING, STRUCTURAL ASSEMBLY, & SPACE MANUFACTURING. INCLUDES CONCEPTUALIZATION, EVALUATION, & VERIFICATION OF ALGORITHMS, SENSORS, ACTUATORS, SOFTWARE, & SYSTEM ARCHITECTURE. INVESTIGATION OF COOPERATIVE HUMAN/MACHINE CONTROL TECHNOLOGY TO PROVIDE OPERATOR SUPERVISORY CONTROL.

SOURCE: RTOP (23) 549-01

POINT OF CONTACT: J. F. CREEDON,
LaRC, HAMPTON, VA.
804-865-4915

LAST UPDATE ON 07/27/87

AGENDA

Background, Objectives and Results .... George Maybee

Methodology Enhancement and Sensitivity Analysis .... Dave Bergeson

Technology Readiness Database .... George Maybee

Concluding Remarks .... George Maybee

CONCLUSIONS

It was found that the cost model is sensitive to changes in the following variables: activity performance time, support equipment cost and man/machine mode assignment, support equipment life cycles, Shuttle launch cost and Space Station cost. It was shown that changes in these parameters produce significant shifts in cost-effectiveness zones. It was demonstrated that increases in Space Station cost shift the THURIS outputs in favor of the more automated man/machine modes. It is important therefore, that for a given application, the most current, complete and accurate cost, performance and technology data be loaded in the model. Given the appropriate front-end loading, it is concluded that the model will be effective over a wide range of possible groundrules and assumptions.

The technology readiness database has been designed to facilitate the THURIS applications process and provide for growth. The configuration and content of the database rests on the conclusion that equipment availability dates and definitions, directly linked with man/machine modes and generic activities, effectively integrates the technology readiness criterion into the THURIS decision making process.

CONCLUSIONS

- The THURIS cost model output is sensitive to every variable investigated
  - Sensitivity is logical and consistent from case to case
  - Sensitivity produces shifts in cost-effective zones and therefore affects choices in man/machine modes
- The THURIS methodology is sound and flexible
  - Groundrules tailored to specific mission requirements are acceptable
  - The cost model and files may be loaded for settings other than LEO
- The Technology Readiness Database is an effective, easily used element of the THURIS man/machine role selection process.

RECOMMENDATIONS

The extension of THURIS applications to other settings, e.g., GEO, Lunar and Martian, is recommended as a natural and necessary progression in the development of the process. This extension, as well as maintenance of the LEO applications capability, requires periodic updating and expansion of the technology readiness database. The hooks for a ground-teleoperated man/machine mode have been established in the present study. It is recommended that additional performance data for that mode be obtained and entered into the cost model data files.

Optimum cost zone charts were prepared to demonstrate how the cost-effectiveness on man/machine modes shifts as a function of the costing basis. It is recommended that a program be written to automate the generation of this type of data presentation for use in future THURIS applications.

It has been shown that the model is sensitive to changes in the input variables such that one can arrive at different conclusions depending on the applications groundrules and assumptions. It is recommended that THURIS applications be conducted using a range of initial conditions, i.e., different sets of costs, equipment assignments, etc., to provide the best basis for selecting a baseline man/machine mode.

CONCLUDING REMARKS

RECOMMENDATIONS

- Develop THURIS applications packages for settings beyond LEO, e.g., GEO, Lunar and Mars
- Maintain and expand the Technology Readiness Database periodically
- Develop additional performance data for input to THURIS files for full implementation of the ground-teleoperated mode.
- Incorporate man/machine performance data from sources such as the MSFC Neutral Buoyancy and Teleoperator and Robotics Evaluation Facilities into THURIS data files.
- Perform rigorous applications of THURIS to selected LEO missions, e.g., Materials Development, Life Sciences, Satellite Servicing.