Cost And Schedule Analytical Techniques Development

Final Report

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NAS8-38784

Prepared for:
National Aeronautics and Space Administration
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I. INTRODUCTION

This Final Report summarizes the activities performed by Science Applications International Corporation (SAIC) and Applied Research, Inc. (ARI) (which was purchased by, and integrated into, SAIC in January 1994) under contract NAS8-38784 "Cost and Schedule Analytical Techniques Development Contract." This Final Report is in compliance with Attachment J-2, Paragraph B of the contract.

This contract provided technical services and products to the Marshall Space Flight Center's Engineering Cost Office (PP03) and the Program Plans and Requirements Office (PP02) for the period August 3, 1991 through November 30, 1994. Detailed Monthly Reports were submitted to MSFC which spelled out each month's specific work performed, deliverables submitted, major meetings conducted, and other pertinent information. Therefore, this Final Report will not repeat that level of detail, but rather, summarize the forty months of contract effort. An executive level summary of accomplishments is provided in **Table 1**.

REDSTAR Data Base
- Doubled document count from 8,000 to 16,000
- Developed state-of-art, FoxPro indexing system
- Installed extensive key word search capability
- Established seven Special Collections

NASCOM Hard Copy Data Base
- Increased contents by 50% to 90 aerospace projects
- Published 2 updates of data base
- Added new features: sample problems, data base averages, improved documentation

NASCOM Automated Data Base
- Conceived, developed, programmed in C++
- Delivered operational copies to all NASA Centers
- Developed and delivered User's Manual
- Provided training to NASA personnel

NASCOM Cost Model
- Totally restructured and programmed in C++
- Delivered initial NASCOM Cost Model
- Developed NASCOM Cost Model's User's Guide
- Contains many innovative features

Complexity Generators
- Eliminated subjective engineering judgment
- Provide traceable, repeatable, documented factors

Program Planning
- Wrote five Guideline papers
- Developed project implementation plans
- Prepared data requirements packages

Schedules
- Added 1,300 schedule documents to REDSTAR
- Established Schedule Notebooks
- Developed Schedule Template Evaluation Model (STEM)
- Developed STEM User's Manual
- Developed Schedule and Cost Optimization Model (SACOM)
- Developed SACOM User's Manual
- Developed schedule and logic networks

NASA Computer Connectivity
- On NASA network via T-1 line
- Became on-line with MSFC Repository
- Provided file transfer, and printing at NASA

Other Analytical Techniques
- Developed Microgravity Experiment Cost Model (MECM)
- Developed MECM User's Manual
- Developed Ground Operations Cost Model (GOCM)
- Developed GOCM User's Manual
- Developed PRICE System Technical Briefs

Special Project Support
- Space Station Redesign Study
- Access to Space Study
- New Ways of Doing Business (NWODB) Study
- Hundreds of Quick Response Actions for MSFC, NASA Headquarters, and other centers

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Table 1. Summary of Contract Accomplishments

II. BASIC CONTRACT ACCOMPLISHMENTS

The following sections are broken out by the three MSFC major statement of work task areas and provide insight into the work performed in each area over the life of this contract.

1.0 Task 1: REDSTAR Data Base SystemMaintenance and Expansion

During the course of this contract, the REDSTAR Data Base was reorganized, doubled in size, and upgraded to professional library standards. In addition to improvements to the expansion and maintenance of the REDSTAR Data Base, SAIC was instrumental in a major redesign and improvement of the NASCOM Data Base (NASCOM-DB). The hardcopy version of NASCOM-DB was greatly improved with the inclusion of example problems, data base averages, clear project programmatic and technical descriptions, and a step-by-step explanation of the NASCOM-Data Base normalization process. SAIC also conceived, designed, and developed the Automated NASCOM-DB (NASCOM-DB). This data base allows instant retrieval of any data in the NASCOM-DB and is available to all of NASA.

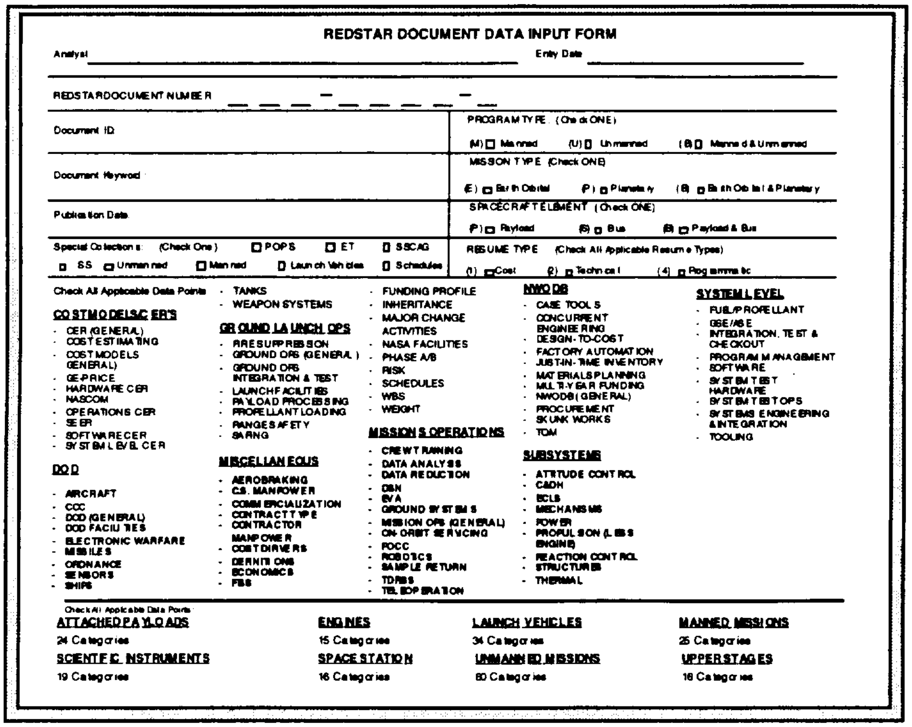
1.1 REDSTAR Data Base System Maintenance

SAIC provided approximately 1,000 square feet of floor space, 91 file cabinets, and 27 bookcases for the REDSTAR Data Base. The REDSTAR Data Base was under the management of a masters' degreed librarian who is listed in the current publication of *Who's Who Among National Technical Libraries*. Not only has the sheer volume of REDSTAR source documentation increased twofold in the last three years (average yearly document entry rate of nearly 2,700), but library organizational standards, document retrievability and accountability, and interfaces to nationwide document repositories are now on par with any professional library of this nature in the country.

The most valuable of historical documentation is worthless if it can not be retrieved from hard copy of automated filing systems. To this end, SAIC has instituted and maintained a high degree of professional library standards in its management of REDSTAR. When the data base was transitioned to SAIC, the Library Reference System (LRS) was non-standardized and in need of updating. The LRS, then coded in dBase III, could not be queried on document keywords, search routines required an in-depth knowledge of dBase code, and data characterization was incomplete in that only a limited number of NASA programs were on the existing data characterization form.

SAIC modernized the LRS and thus enhanced the utility of REDSTAR. The data characterization sheet or "cut sheet", which is the hard copy representation of the LRS's electronic query matrix, was greatly expanded. (See Figure 1-1 for portions of the updated "cut-sheet".) It now includes about 50 additional missions and attached payloads. A host of topics in the field of management and engineering efficiencies that are of current and future interest to NASA such as, NWODB, Skunkworks, total quality management, and concurrent engineering have also been added. Further, data can now characterized as pertaining to ground, launch or mission operations. These recent updates to the "cut sheet" provided a more comprehensive way to enter and retrieve data from REDSTAR. SAIC also established a keyword REDSTAR LRS search capability. This powerful tool is easily maintained and allows data retrieval by simply keying in a one-word topic. SAIC and NASA personnel were provided with a list of keywords that were standardized for use in the LRS routines.

The updated LRS was programmed in the FoxPro data base application. Because FoxPro operates in the Windows environment, REDSTAR's LRS search and retrieval commands are now "point and click" with search times nearly instantaneous. Typing in dBase code and waiting up to 3 minutes for search results are a thing of the past. This dynamic increase in search speed is even more important when one considers the rate at which the size of the REDSTAR Data Base is increasing. Another library service that SAIC has introduced to this contract is the use of both local and national information centers as sources of aerospace information. For example, we have established working relationships with the historians and archivist at MSFC, JPL, Goddard Space Flight Center (GSFC), the University of Alabama in Huntsville, and the Air University Air Command and Staff College at Maxwell Air Force Base. Through these sources, as well as the Redstone Scientific Information Center (RSIC) and MSFC Repository, we have obtained much valuable historical data in support of the CSATD contract. We are on-line with the MSFC Repository's automated data retrieval system and developed search strategies of this large information center from the 486 PC in REDSTAR.



REDSTAR DOCUMENT DATA INPUT FORM

Analyst ____ Entry Date ____

REDSTAR DOCUMENT NUMBER ___ ___ ___ – ___ ___ ___ ___ – ___

Document ID

PROGRAM TYPE (Check ONE) (M) Manned (U) Unmanned (B) Manned & Unmanned

Document Keyword

MISSION TYPE (Check ONE) (E) Earth Orbital (P) Planetary (B) Earth Orbital & Planetary

Publication Date

SPACECRAFT ELEMENT (Check ONE) (P) Payload (S) Bus (B) Payload & Bus

Special Collections: (Check One) POPS ET SSCAG SS Unmanned Manned Launch Vehicles Schedules

RESUME TYPE (Check All Applicable Resume Types) (1) Cost (2) Technical (4) Programmatic

Check All Applicable Data Points

COST MODELS/CER'S
- CER (GENERAL)
- COST ESTIMATING
- COST MODELS (GENERAL)
- GE-PRICE
- HARDWARE CER
- NASCOM
- OPERATIONS CER
- SEER
- SOFTWARE CER
- SYSTEM LEVEL CER

DOD
- AIRCRAFT
- CCC
- DOD (GENERAL)
- DOD FACILITIES
- ELECTRONIC WARFARE
- MISSILES
- ORDNANCE
- SENSORS
- SHIPS
- TANKS
- WEAPON SYSTEMS

GROUND LAUNCH OPS
- FIRE SUPPRESSION
- GROUND OPS (GENERAL)
- GROUND OPS INTEGRATION & TEST
- LAUNCH FACILITIES
- PAYLOAD PROCESSING
- PROPELLANT LOADING
- RANGE SAFETY
- SAFING

MISCELLANEOUS
- AEROBRAKING
- C.S. MANPOWER
- COMMERCIALIZATION
- CONTRACT TYPE
- CONTRACTOR MANPOWER
- COST DRIVERS
- DEFINITIONS
- ECONOMICS
- FBS
- FUNDING PROFILE
- INHERITANCE
- MAJOR CHANGE ACTIVITIES
- NASA FACILITIES
- PHASE A/B
- RISK
- SCHEDULES
- WBS
- WEIGHT

MISSIONS OPERATIONS
- CREW TRAINING
- DATA ANALYSIS
- DATA REDUCTION
- DSN
- EVA
- GROUND SYSTEMS
- MISSION OPS (GENERAL)
- ON-ORBIT SERVICING
- POCC
- ROBOTICS
- SAMPLE RETURN
- TDRSS
- TELEOPERATION

NWODB
- CASE TOOLS
- CONCURRENT ENGINEERING
- DESIGN-TO-COST
- FACTORY AUTOMATION
- JUST-IN-TIME INVENTORY
- MATERIALS PLANNING
- MULTI-YEAR FUNDING
- NWODB (GENERAL)
- PROCUREMENT
- SKUNK WORKS
- TQM

SUBSYSTEMS
- ATTITUDE CONTROL
- C&DH
- ECLS
- MECHANISMS
- POWER
- PROPULSION (LESS ENGINE)
- REACTION CONTROL
- STRUCTURES
- THERMAL

SYSTEM LEVEL
- FUEL/PROPELLANT
- GSE/ASE
- INTEGRATION, TEST & CHECKOUT
- PROGRAM MANAGEMENT
- SOFTWARE
- SYSTEM TEST HARDWARE
- SYSTEM TEST OPS
- SYSTEMS ENGINEERING & INTEGRATION
- TOOLING

Check All Applicable Data Points

ATTACHED PAYLOADS 24 Categories
ENGINES 15 Categories
LAUNCH VEHICLES 34 Categories
MANNED MISSIONS 25 Categories
SCIENTIFIC INSTRUMENTS 19 Categories
SPACE STATION 16 Categories
UNMANNED MISSIONS 60 Categories
UPPERSTAGES 18 Categories

Figure 1-1 "Cut Sheet" Provides Comprehensive Data Point Characterization

Also coded in FoxPro was the REDSTAR document checkout program. Checkout procedures were standardized and implemented. The REDSTAR document number, document title, the borrower's name, and the date of checkout were input into the electronic file. When documents were returned, the date of return was input into the checkout routine.

The REDSTAR inventory was used to ensure document accountability, to restructure the contents of each filing cabinet to make room for future documents, and to assess the feasibility of creating new special collections for data of the same subject. On completion of each end of the year REDSTAR inventory, a complete to-date listing of the contents of REDSTAR was published and sent to resource and planning groups throughout NASA.

1.2 REDSTAR Data Base System Expansion

In the past three years, the REDSTAR document count has increased from about 8,000 to nearly 16,000. This statistic is astounding when one considers that SAIC has managed REDSTAR only 3 of its 23-year existence.

For each new data collection effort, in-house sources were reviewed and contacts made to likely NASA and industry sources for information and leads to relevant data. This approach has worked well for SAIC over the past three years. For example, our collection of Space Station Freedom, CRRES and Orbital Maneuvering Vehicle (OMV) project data was obtained through our established relationships with personnel in these NASA project offices. Approximately 500 documents pertaining to these 3 projects were obtained before the project offices were closed or relocated. **Figure 1-2** contains a listing of some of the data collection contacts made for MSFC in the past three years.

Still other data was obtained by consulting the LRS, RSIC, the MSFC library and repository, DIALOG Information Services, NASA Scientific and Technical Aerospace Reports, the Defense Technical Information Center, the National Technical Information Center, the National Space Science Data Center and other available data bases.

In the past three years we made numerous data collection trips including those to GSFC, JPL, KSC, JSC, NASA Headquarters, Reston, Crystal City and El Segundo, California. These trips were fruitful in that we obtained over 25 mission costs and technical data packages in sufficient detail to include them in the NASCOM-Data Base and associated cost models.

REDSTAR Special Collections, established by SAIC, allowed the analyst to conveniently peruse data of the same subject matter. This allows a REDSTAR user to go to one or two file cabinets that contain the majority of the REDSTAR data on a specific subject. Special collections were set up for NASCOM-Data Base data points, schedules, Program Operating Plans (POPs), Space Station, launch vehicles, solid rocket motor, Shuttle projects, unmanned spacecraft, manned spacecraft, and the External Tank.

Company, Contact, Data Requested
Aero Astro, Inc., Melanie Horn, ALEXIS & HETE
Aero Astro, Inc., Richard Warner, ALEXIS & HETE
Aero Astro, Inc., Richard Warner, ALEXIS & HETE, 2
BMDO Edwards Airforce Base, Jason Feige, MSTI
Boeing Marketing, Seattle, Barbara Murphy, Boeing 777
Boeing, Diane Copenhaver, IUS launch cost
Boeing, Roy Berg, Minuteman II cost
Fairchild Aircraft, Don Johnson, Geowarn question
Fairchild Space, Bob Bartlett, EUVE
Fairchild Space, Tom Moser, EUVE
General Dynamics, John Silverstein, Titan IV Centaur launch costs
General Electric, Dave Lane, Engine cost data
GSFC Historian, Keith Koehler, document info
GSFC, Bill Tragesar, EUVE & XTE
GSFC, Bob Melis, TOMS
GSFC, George Barth, TRDS
GSFC, Jim Barrowman, EUVE & XTE
GSFC, Jim Manion, EOS
GSFC, Mike Weiland, GOES
GSFC, Mildred Saari, UARS
GSFC, Paul Caruso, ISTP
GSFC, Steve Dobroseilski, METSAT
GSFC, Vicki Corey, get on mailing list of GSFC document
Honeywell Library, Linda Tabor, EOS computer costs
Honeywell, Inc., Don Lee, FEWS
Hughes Aircraft, Uldis Lapins, HS-376 info
Hughes Space & Communications Group, Ed Limburgh, UFO
Hughes Space & Communications Group, Jerry Adams, UFO
IBM, Mark Michrana, Shuttle & SSF On-Board Processing
Innotech Aviation, Larry Neily, Geowarn question
Jet Propulsion Laboratory, Robert Metzger, MSTI
JPL Archives, Julie Reiz, JPL spacecraft document lists
JSC History Office, Joey Kuhlman, POP s document info
JSC Lambda Point Office, Joe Malloy, get on mailing list for document
Lockheed Research & Development Division, Don Bane, CRSS
Lockheed Research & Development Division, Dr. Ralph Kuiper, CRSS
MacDonald Douglas, Fred Tolley, F-15E landing gear cost
MacDonald Douglas, Jim Meyers, PAM, Delta Stage II launch cost
Martin Marietta Astro Space, Don Brown, Milstar
Martin Marietta Astro Space, Jerry Miranda, Satellite Processing
Martin Marietta Astro Space, Marvin Kravitz, DSCS-3
Martin Marietta Astro Space, Walt Woessner, DSCS-3
Martin Marrieta, Larry Price, Transtage launch cost
Morton Thiokol, Don Wilson, Castor nozzle cost
Morton Thiokol, Jack McCommons, STAR 30E, 48B cost
Morton Thiokol, Jack McCommons, Star 48, 37 motor cost
Morton Thiokol,Dennis Walstrum, Star 17 motor cost
MSFC, Gerry Hall, EASE costs
MSFC, Keith Hefner, AXAF
NASA Chief Historian, Dr. Launius
OSC, Chris Schade, Pegasus & Taurus cost
OSC, Jeff Campbell, TOS launch cost
Phillips Laboratory, Jim McClellan, MSTI
Pratt & Whitney, Mark Sullivan, Engine cost data
Pratt & Whitney, Nancy Colaguori, RL10-A-4
Rolls-Royce, Robert Stangarone, Engine cost data
Spectrum Astro, Ray Rew, MSTI
Tecolote, Mike Mahoney, Conestago cost
Teledyne Systems Co., Roger Gilreath, Milstar
TRW Space & Electronics Group, Susan Brough, DSP
U. S. Navy, Dick Coffman, UFO
U. S. Navy, Steve Archer, UFO
US Navy Research Lab, Paul Regeon, Clementine

Figure 1-2 SAIC Has Many Data Collection Contacts Across the Country

SAIC placed great emphasis on quick and accurate responses to sudden data needs and requests by MSFC. We efficiently provided rapid response data and analyses for studies such as: New Ways of Doing Business (NWODB), Space Station Freedom Redesign, Access to Space (including single and two-stage-to-orbit configurations), Spartan conversion project, small launch vehicle data collection, and National Launch System (NLS). These quick turnaround responses consisted of data set formulation, CER development, cost comparisons and trends, spreadsheet development, cost driver identification, and generation of hardware estimates.

1.3 NASCOM Data Base Development and Expansion

The NASCOM-DB consisted of 62 spacecraft project cost and technical analyses when SAIC was awarded the CSATD contract. SAIC has analyzed 42 projects for the NASCOM-DB, including new analysis for 28 projects and the re-analysis of 14 of the original data points to provide component level visibility. In three years SAIC was responsible for 42 of the 90 total NASCOM-DB projects or 47%.

The NASCOM-DB is essentially the very best and most complete aerospace project cost, technical and programmatic data from the REDSTAR Data Base. SAIC published Version 2.0, in January of 1993, and Version 2.1, in December 1993 and distributed them to all NASA centers.

Enhancement of the NASCOM-DB was a dynamic process at SAIC. We ensured that the consensus opinion PP03 as to the proper ground rules and process have adhered to in our effort to continually improve the NASCOM-DB. Individual study efforts including verification, modification, alternatives presentation, and joint working sessions with PP03 have consumed approximately 2,000 manhours of analytical effort. This entire effort was extremely successful, producing a consistent, standardized NASCOM-DB methodology.

The NASCOM-DB "data was normalized to a consistent set of ground rules and assumptions that govern the presentation of three separate and distinct sets of cost analyses ("As Reported", "Modeled" and "Synthetic Wraps Applied"). All historical cost data within the NASCOM-DB were analyzed for inclusions and exclusions and then converted to a standard constant year dollar from real year dollar project cost reports. All technical data was normalized to consistent terms and units.

The WBS for all NASCOM-DB projects included the actual project WBS at lower levels, yet applied generic accumulators at the subsystem and system level. This WBS normalization approach affords the MSFC cost engineer the option of using specific analogies or more generic elements when developing subsystem data sets for cost estimates. Component, subsystem, and system level mass properties which are all converted to pounds, conform to the same WBS.

The design approach for all NASCOM-DB data points is either prototype or protoflight. This distinction has predictable impact on project cost and is reported as such in the "As Reported" data. Consistent handling and normalization for the cost associated with the dedicated test article (prototype approach) versus all cost associated with test and refurbishment of the protoflight article was strictly maintained in the SAIC-produced NASCOM-DB.

Stratification of the NASCOM-DB was by mission or project type, i.e., manned spacecraft, unmanned spacecraft, and launch vehicle stages and liquid rocket engines. Also separately included were scientific instruments grouped by classes based on the specific function of each.

The final step in the NASCOM-DB methodology was the calculation of first pound costs. In NASCOM-DB terminology, first pound costs are the cost for the first pound of hardware. Statistically, first pound costs are the y-intercept values for a power curve equation, defined by the formula: y = ax^b, where y equals costs, x equals weight, b equals the slope of the curve, and a equals the y-intercept or the first pound cost. This formula requires that the b-value be known before the equation can be algebraically transformed and exercised. B-value determination is relative to the type of aerospace hardware, and mechanical/electrical composition. SAIC introduced subsystem unique b-values in the publication of NASCOM-DB Version 2.0 after exhaustive study and research. These unique b-values now reflect a logical and verifiable impact on a-value calculation, attributable to the degree to which economies of scale are exhibited. Technical, contractual, and programmatic resumes containing cost driving parameters, major milestone, known inheritance and hardware compatibility, and major programmatic influences were established (if required) or reverified and maintained for each data point in the NASCOM-DB. These resumes were presented in project and subsystem form, and follow the NASCOM-DB cost and weight WBS.

SAIC created an innovative new tool with which all NASCOM-DB information can be electronically retrieved. The Automated NASCOM-DB (NASCOM-ADB) is a user friendly data retrieval tool that operates in the Microsoft Windows environment and is coded in C++. The NASCOM-ADB allows users to electronically search, filter, and retrieve cost and technical data at any level presented in the hardcopy NASCOM-DB. The data level selection screen from the NASCOM-ADB is shown in Figure 1-7. The data contained in the NASCOM-ADB is consistent with the data contained in the NASCOM-DB, Version 2.1. NASCOM-ADB was distributed to all NASA Centers in December 1993.

The NASCOM-ADB was segregated into eight data base files including: Structures; Electrical Power; Command, Command, Communication and Data Handling; Attitude Control; Environmental Control and Life Support; systems Level; and, Miscellaneous. These data files include over 135 different fields of information for searching and filtering including 11 cost, 3 weight, and 121 performance, technical and programmatic fields.

Numerous special features contained in the NASCOM-ADB combine to make it a very convenient and useful tool for establishing cost estimating data sets. Search results can be saved and reopened to append or delete data points. Data can be easily copied and pasted into other Windows applications. Data can be printed to any printer. Font styles and sizes of the data can be changed. Columns and rows of data can be hidden from view or from being printed. The mission field and the WBS item field can be "frozen" on the screen to be viewed at all times while scrolling through the data outside the display boundary. A "Filter Reporter" shows what filters were used to complete the search. A Help Index is provided to supply information about any data point (program) of interest.

2.0 Task 2: Development of Cost Estimating Techniques

While this task is of equal importance to the REDSTAR Data Base maintenance and expansion task, the work performed on the cost estimating task has a more profound and visible effect on the cost analysis results produced by the Engineering Cost Office. SAIC's experience in developing innovative and defensible cost estimating techniques for NASA was directly applied to completing the initial version of the NASCOM Cost Model.

SAIC's cost estimating techniques development efforts for other NASA customers increased our NASA experience and understanding and provided synergistic efforts that benefited the Engineering Cost Office and the Program Plans and Requirements Office. For example, the SAIC development of the Microgravity Experiments Cost Model (MECM) led to three cost effective innovations for PP02 and PP03. The synergistic MECM activities are: (1) The shell of the MECM model was used to develop the NASCOM-Lite program in slightly over a month. To develop this powerful tool from scratch would have taken many months. (2) The development of the schedule estimating portion of MECM using microgravity schedule templates was the precursor for the Schedule Template Evaluation Model (STEM). (3) The cost and schedule integration techniques used in the MECM were used in the development of the Schedule and Cost Optimization Model.

2.1 Extensions and Improvements To NASCOM

The NASCOM Cost Model is an automated cost model that provides computer access to the NASCOM-DB to allow cost engineers to select most analogous data points for estimating DDT&E, flight unit cost, and integration cost elements. The NASCOM Cost Model relates the technical and programmatic aspects of a space or ground based element to its estimated cost. The model is capable of estimating cost at any level of definition (Phase A through Phase C/D), and at any level of detail (total project to component level).

As a place-holder until the NASCOM Cost Model was on line, SAIC developed and delivered a precursor model called NASCOM-Lite. This model was completed in May 1994 and training provided to MSFC users at that time. In August 1994, an updated User's Manual was delivered to NASA and a training class was provided by SAIC to NASA Headquarters Comptroller Office personnel in Washington. NASCOM Lite is versatile, automated, user friendly, and data backed. It was Microsoft Excel based for use on Macintosh or PC computers. The model allows component or subsystem level cost estimating based on the NASCOM Data Base and using either data base averages or a specific data point (analogy estimating). This model, unlike the NASCOM Cost Model, requires user-defined complexity factors as inputs. It contains a thru-put option for D&D, system test hardware, and/or flight unit cost which may be exercised if appropriate. NASCOM Lite automatically calculates system level or "wraps" costs. It includes a schedule estimating capability and shows results in real or user-defined fixed year funding spreads.

At completion of the current contract the automated NASCOM Cost Model Windows-based shell was completed and delivered to MSFC. Many of the NASCOM Complexity Generators were also completed and delivered to MSFC. The automated NASCOM Cost Model provides the capabilities shown in **Table 2-1.**

SAIC's innovative concept of NASCOM Complexity Generators brings MSFC's cost modeling capabilities on par with any commercially available cost model (i.e. PRICE and SEER). The major advantages of this approach over the commercial models are (1) the data base used to develop the NASCOM Complexity Generators is known and consists strictly of NASA and Air Force aerospace hardware (unlike commercial models whose data bases and methodologies consists of little space hardware and many non-government programs); (2) the difficult, uncertain, time consuming, and costly process of calibrating the commercial models is built into the NASCOM Complexity Generator design; and (3) the knowledge that the MSFC cost engineers have about the programs in the NASCOM-DB can be directly applied to the use of Complexity Generators.

- On-line access to all NASCOM-DB data
- Integrated and operational Complexity Generators (subsystem and component levels)
- User defined production quantity and quantity next higher assembly
- Automatic or user defined application of integration costs
- The ability to throughput costs, enter user defined CERs, or percentage cost down to a lower WBS level
- A user defined WBS with an unlimited number of levels
- Automated generation of output reports

Table 2-1 NASCOM Capabilities

The Complexity Generator was smoothly integrated into the NASCOM Cost Model estimating process by simply being an alternative to the use of engineering judgment in developing complexity factors. The MSFC engineer may choose to use a Complexity Generator or a user defined complexity for each CER used in an estimate at the subsystem or component level. If the user chooses to use a Complexity Generator, a screen similar to the one shown in **Figure 2-1** will be shown. The top half of the screen will display the performance parameters that are included in the generator. The middle section of the screen displays the programmatic parameters that have been normalized from the data base. The bottom portion of the complexity Generator screen shows the Design and Development (D&D) and flight unit complexity values derived from the performance and programmatic inputs.

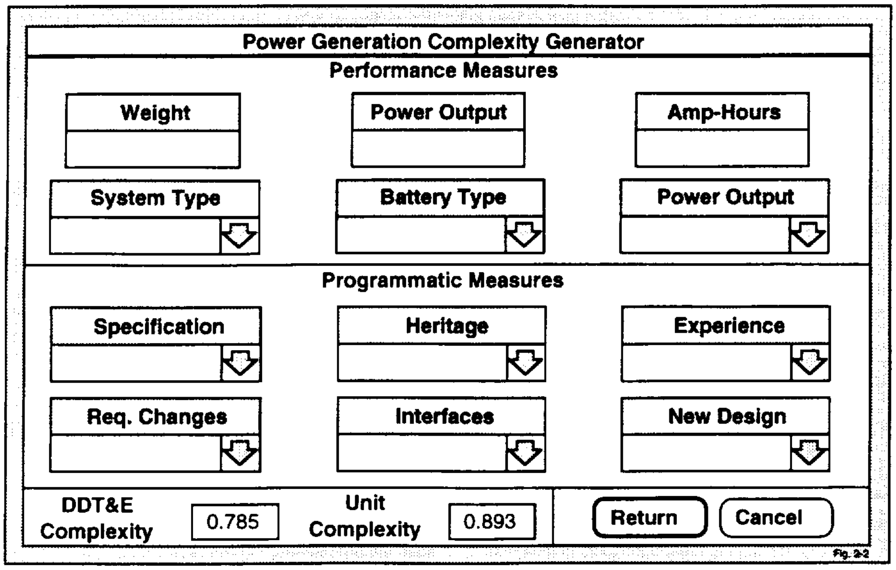


Figure 2-1 Complexity Generators Subsystem Example

When an analogous data point is chosen from the NASCOM-DB, the values shown in the performance and programmatic portions of the screen reflect the complexity of that data point (or the average of several data points if multiple data points are chosen). If none of the complexity variables are changed the complexity factors for D&D and flight unit will equal 1.0. This will give the same result as using the NASCOM-DB to calculate an assumed slope "a-value" and using a user defined complexity of 1.0. If one or more of the complexity variables are changed to more closely represent the complexity of the hardware to be estimated, the complexity factors will change accordingly.

The NASCOM Complexity Generators were based to a degree on a methodology developed for JPL called Cost Complexity Relationships (CCRs). The CCRs are more similar to the classical CER development approach where least squares regression methods are used to develop a cost estimating equation. They differ from normal CERs in that the complexity of each data point was normalized into several categories and removed from the cost. The remaining cost is said to be the "null complexity cost" and was used in a weight based regression. To estimate a new project, the weight based equation was used and the complexity of the new project was added back using the same factors used in the normalization. This approach will not work with the NASCOM Cost Model without some modification due to the "first pound" cost estimating methodology and the selection of most analogous data points. SAIC's five step process used to develop the existing Complexity Generators is described below.

STEP 1: Define Categories. The parameters that are appropriate for the Complexity Generators were identified. These parameters vary between subsystems. Most of the programmatic parameters were consistent between subsystem classes, but the technical parameters always vary.

The technical categories are parameters that can be measured or identified based on the design. Examples of technical parameters used in the NASCOM Complexity Generators include: weight, output power, solar array surface area, number of transmitters, bandwidth, level of redundancy, battery life, specification level, construction method, and storage capacity. The programmatic category includes parameters that are not as easily measured. Examples of the programmatic parameters include: inheritance, technology, new design, testing level, technology readiness level, design life, requirements changes, experience, schedule impacts, and interfaces.

STEP 2: Establish Category Relationships. This step in the Complexity Generator development process involved the application of regression analysis techniques to define the "curve" that best fits each of the complexity parameters used in a particular generator. Our experience developing the JPL CCRs proved invaluable in this process. The range of possible values for each of the complexity parameters was assigned a weighting factor based on its affect on the total cost of the element. Relationships were determined using regression methods, experience, and engineering judgment. The types of equations used include: linear functions, logarithmic functions, exponential functions, step functions, and combinations of functions. An example of the application of these multiple functions can be seen in **Figure 2-2.**

STEP 3: Determine "Null" Cost Equation. The determination of the "null" cost equation used the same approach developed for JPL. The complexity was normalized out of the data base using the category relationships established in STEP 2. This step often required specific data collection and analysis to determine why the normalization of select programs are not behaving as predicted. We found that "outliners" in this approach can be explained and corrected by additional data collection and analysis.

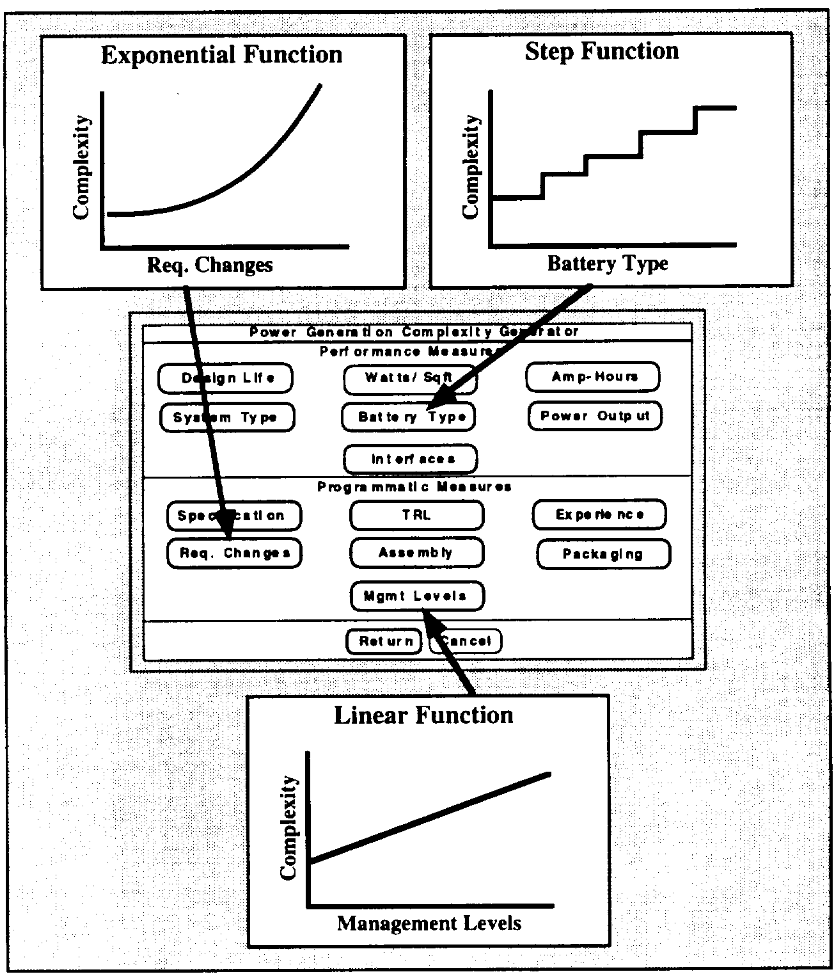


Figure 2-2 Complexity Element Relationship Example

STEP 4: Test, Validate, and Document. Before any of the cost complexity relationships were used in the NASCOM Cost Model, they were tested by SAIC using actual data not included in the development process. After thoroughly testing the generators the documentation was developed. The documentation include the data base used and the statistical validity of each of the complexity parameters and the "null" cost equation. It includes validity ranges of all parameters and recommendations of best results of all parameters and recommendations of best areas in which to use the generator.

STEP 5: Incorporation Into The NASCOM Model. The final step in the development of a NASCOM Complexity Generator was including it in the NASCOM Cost Model. This process involved adding the complexity equations to the NASCOM Cost Model and adding the normalization data for each data point into NASCOM-ADB. Both of these are required for the Complexity Generator process to work in the NASCOM Cost Model "first pound" cost environment.

2.2 Development of First Pound Cost CERs and Classical CERs

Very often homogenous cost data for similar NASA hardware does not exist because of varied cost reporting formats, differences in contract types, budget and scheduling constraints, redesigns or major engineering changes, and refocused mission requirements. The first pound cost estimating approach was developed to allow CER development with one or few data points due to this non-homogeneous data.

In the past three years SAIC has developed many CERs for NASA and improved and expanded the NASCOM-DB which is used to create CERs for NASA. We used the first pound cost methodology for the majority of the CERs produced for the Engineering Cost Office using the NASCOM-DB. We used classical CER approaches for many special analyses for MSFC. We also used classical regression methods for the development of the complexity functions in the Complexity Generators and for the development of all the CERs in the MECM model.

The development of a first pound costs CER required meticulous data analyses and normalization. These data were normalized to a set of ground rules consistent across the entire NASCOM-DB. Six major stratifications of the NASCOM-DB exist. They are: manned spacecraft, unmanned earth orbital spacecraft, unmanned planetary spacecraft, launch vehicle stages, liquid rocket engines, and scientific instruments. The economy of scale slope of b-value is selected from a table of values specific to subsystem type. This table was derived by SAIC after analyzing over 1,000 Classical CERs developed for all NASA centers over the past 15 years.

SAIC has structured NASCOM-DB first pound cost CERs such that they may be used in a variety of ways. Analog estimates may be created by using the weight of the hardware to be estimated and the most analogous NASCOM-DB data point a-value in the first pound cost equation (cost = a * ^ b). We also created tables of data points within each of the six NASCOM-DB data classes.

The first pound cost CER methodology is consistent with the SAIC-developed NASCOM Complexity Generator. The results of any NASCOM-DB first pound cost calculation, or least squares multiplicative, additive error, or "dummy variable" CER can be adjusted by any of the components of the Complexity Generator. An example is the Technology Readiness Level (TRL) curve recently developed for MSFC and shown in **Figure 2-3.** The trend shown in this curve allows adjustments for CER-estimated cost relative to the availability of the technology to be used in the hardware to be estimated.

In addition to the first pound costs estimating techniques, SAIC developed classical CERs in support of the NLS study, Access to Space, MECM cost model, Space Station Redesign, and rapid response items. PRC-Reg, GSFC-Reg, and Excel are some of the regression packages used by SAIC analysts. In fact we modified the program code for both PRC-Reg and GSFC-Reg to improve the output format and printing capabilities of these regression tools. In these and other related efforts, SAIC analysts employed standard methods to evaluate and verify all CER results such as the standard

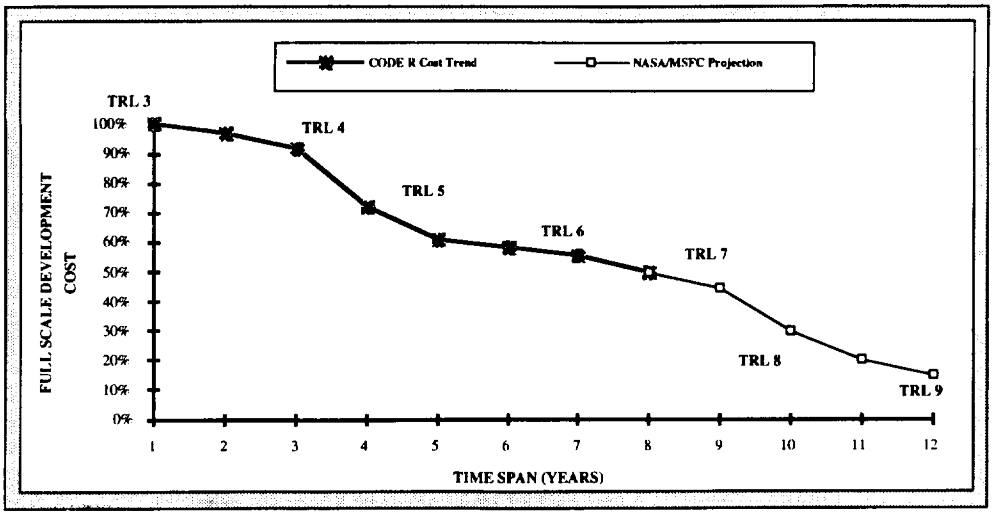


Figure 2-3 Technology Readiness Level (TRL) Example

error, the "t" statistic, the "F" test, correlation coefficient, etc.

The final steps in the SAIC approach to classical CER development was to determine results, draw conclusions and complete documentation. Contained in the documentation of CER development are the data points used, complete definitions of the cost content of the CER, the data analysis results, graphical display of the CERs with labeled data points and curve fit lines, and conclusions with CER recommendations and CER applicability ranges.

2.3 Training of NASA Personnel

The complex nature of the cost estimating models and techniques developed under this contract call for comprehensive documentation and training. The importance of the results derived from these models make it essential that users are knowledgeable of the model capabilities, limitations, and assumptions made during development.

SAIC has provided this type of documentation on numerous occasions in the performance of this contract. Documentation examples are listed in **Table 2-2.**

- Updated NASCOM-DB documentation
- User's Guide for NASCOM-ADB
- User's Guide and a two volume set of model documentation for MECM
- User's Guide and documentation for GOCM
- User's Guide for the STEM

Table 2-2 SAIC Developed Documentation

Having a well written, complete set of documentation for a cost model is often not adequate information to get a fast start in using the tool. For this reason we prepared and presented training material for several of the models developed under the CSATD contract. **Table 2-3** lists some examples of NASA training performed by SAIC.

The SAIC provided training included hands-on computer use, training presentations, example problems illustrating cost and schedule estimating techniques, and handout material with quiz problems.

- Two day training session on the NASCOM-DB and NASCOM-ADB
- Two classes of one half day training in the use of the MECM cost model
- Training session on the development approach and uses of the NASCOM-Lite model
- NASA Headquarters training on the NASCOM-DB, NASCOM-ADB, and NASCOM-Lite

Table 2-3 SAIC NASA Training

3.0 Task 3: Development of Schedules, Plans and Requirements

SAIC greatly expanded the Schedules, Plans, and Requirements task under the CSATD contract. We placed greater emphasis on the schedule analysis by initiating an aggressive program resulting in the accumulation of almost 1,300 documents containing historical aerospace schedules, establishment of a major Schedule Collection in REDSTAR, creation of a Schedule Notebook, and development of automated schedule models.

SAIC also has expanded the program planning support role. Work included the development of implementation and project plans, Guidelines development, and WBS and logic network preparation. We provided independent reviews and assessments of NASA program planning, procurement and technical management documents.

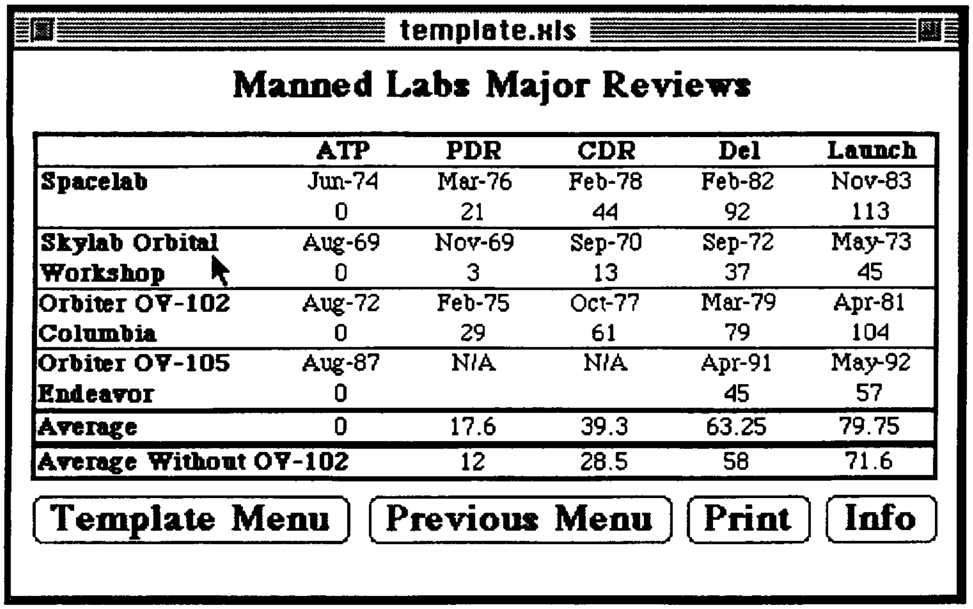
3.1 Schedule Development

Our scheduling skills were demonstrated in the CSATD contract by the development of schedules for the Space Station Hab Module, SEI, Spartan Missile, Nuclear Propulsion Testing and four different schedules for the Access to Space Study. Further, we analyzed the NASA Strategic Plan and pointed out schedule inconsistencies as well as developed a NASA "new start" schedule and a long range launch schedule for the plan. SAIC also developed a presentation on schedule slip factors for PP02 and prepared numerous letters which were sent by MSFC to project offices and major aerospace contractors requesting historical schedule data.

New documents containing historical schedule data were obtained from NASA individual contacts, other government agencies, and hardware development contractors. The new schedules, along with existing ones, were made into separate Schedule Collection section of REDSTAR. Additionally, an extensive Schedule Notebook of over 1,000 schedules on 77 aerospace programs was developed that contained all the basic schedules collected. The schedules were categorized according to twelve classifications (unmanned vehicle systems, solid motors, etc.) provided by PP02. Using this data base SAIC developed historical schedule templates for project categories that indicate typical or average schedule duration between milestones.

Under the contract, SAIC also developed charts on changes in NASA processes and their impact on NWODB. These types of data were researched by SAIC for their impact on NASA program planning. We also reviewed the literature to identify projects where major successes have been obtained in the development of reduced schedule development time.

SAIC developed the Schedule Template Evaluation Model (STEM) which is a dynamic model that was based on historical schedule data. It is operational and two versions of a User's Guide have been published by SAIC. STEM allows the creation of new project generic schedules using the historical data base inherent in the model, or it allows the user to manipulate milestones to develop his/her own schedules. An example template screen from STEM is shown in **Figure 3-1.**



	ATP	PDR	CDR	Del	Launch
Spacelab	Jun-74	Mar-76	Feb-78	Feb-82	Nov-83
	0	21	44	92	113
Skylab Orbital	Aug-69	Nov-69	Sep-70	Sep-72	May-73
Workshop	0	3	13	37	45
Orbiter OV-102	Aug-72	Feb-75	Oct-77	Mar-79	Apr-81
Columbia	0	29	61	79	104
Orbiter OV-105	Aug-87	N/A	N/A	Apr-91	May-92
Endeavor	0			45	57
Average	0	17.6	39.3	63.25	79.75
Average Without OV-102		12	28.5	58	71.6

Figure 3-1 STEM Provides Schedule Templates for a Variety of Space Missions

Aerospace program costs and schedules are tightly coupled to each other, and both are strongly dependent on technical requirements. However, the parametric linking of cost and schedules has always been a rather difficult task. This is due in part to the fact that cost data tends to break down into various levels of hardware end items and system type functions, while schedules are subdivided into program milestones and other calendar related events. These two different breakouts are not easily crosswalked to allow cost to be shown on schedules, or vice versa, with any high fidelity of detail.

SAIC made much progress in this difficult linking area in the currently operational, automated MECM model. Costs werre time-phased based on actual microgravity historical schedule milestone data which we collected, normalized, and developed into individual TERs for microgravity programs of varying complexity. While the average development and unit production schedules are known, judgment must be applied as to the distribution of cost within the given time period. This was typically done at the subsystem level using beta spreading functions.

Non-optimized schedules definitely impose cost penalties that should also be assessed. SAIC accounted for this phenomena in MECM through establishment of a curve relating cost savings and penalties to schedule duration in terms of percent from an established CER-output cost. This curve was based on relationships from commercially available parametric models. We found that microgravity cost CER outputs were tied to a schedule which normally exceeded the optimum schedule by 20 percent.

Cost and schedule relationships have also been included in the automated NASCOM-Lite Cost Model which was developed under this contract. In that model, the STEM templates are called up on the screen and the appropriate one selected for the type of program. Time-phasing is then based on that template using user-determined beta distributions at the subsystem level. This model does not have the schedule-driven cost penalty feature of MECM.

In the last months of the CSATD contract, an additional automated cost-optimizing schedule tool was programmed called SACOM (Schedule And Cost Optimization Model). This model uses, as input, the costs developed in NASCOM-Lite (or NASCOM Cost Model when operational at contract end). It allows the individual major program elements, with their associated costs, to be moved about on the overall schedule until a program funding profile is obtained which best matches the expected program budget and minimizes cost and manpower peaks and valleys. Limited program logic was built in to ensure the integrity of the program is maintained while these schedules are moved. For example, the software will not allow system tests to occur before the system test hardware is built, or schedule compression beyond reasonable expectations. This model operates at the subsystem level and provides graphic display of funding, overlaid on the schedule, as well as, numerical output. Preliminary cost penalties associated with non-optimum schedules were incorporated in the SACOM model.

SAIC developed time-phased generic logic networks utilizing several different techniques. We used the powerful PC-based ARTEMIS 7000 software and hardware including a 36 inch roll-fed 8 pen plotter to support PP02 requirements under the contract. We have also used "Finest Hour" in the preparation and development of generic logic networks for the generic unmanned launch vehicles and the Laser Beamed Power Study during the contract. We also developed a logic network for the "NASA Approval Budget and Procurement Cycles". In addition, we developed schedule logic that tied the NASA project planning activities with OMB circular A-109 and the budget cycle. Microsoft Project has been used to develop logic networks for other MSFC projects as has Open Plan. Each of the software systems has its own set of advantages and disadvantages. SAIC has developed "work arounds" for many of these including color coding and hand manipulation of the network to avoid over laid lines or lines underrunning unrelated activity boxes. Time-phasing of major logic networks was accomplished by indicating time durations on the activity boxes.

3.2 Program Planning

SAIC prepared program planning documentation and reports relating to project management functions, management topics, and other program planning related subjects as requested by PP02. For example, SAIC prepared draft implementation plans for the LUTE Project. This plan was then used by the LUTE Project team to finalize their planned approach that was submitted to NASA Headquarters for approval. Other examples of program planning documentation developed during the contract include several seminars (currently called guidelines) prepared for use by PP02. Some topics that we were researched, developed, and presented are Project Plans, WBS, Management Directives, Project Planning, and NASA Agreements.

Another important program planning task that was accomplished during the contract was the development of Phase A and B data requirements packages. SAIC developed packages for both in-house and contracted Phase A and Phase B studies. The packages were developed to be consistent with Phase C/D requirements which were the responsibility of MSFC's Science and Engineering Directorate.

SAIC has a great deal of overall experience and involvement in the program management functions. Our unique NASA experience covers the total gamut from early NASA programs of the 1960s to the latest NASA programs and projects. We understand which functions and topics are important. We have prepared many handbooks, guidelines, and presentations in the past and will continue to do so. We know the basic NASA Directives System and how changes are made to it. We also understand what is needed and how to get prior practices and other documentation that we will use to prepare new guidelines and presentations. Our personnel have established working relationships with many of the current and former NASA program and project managers, and are experienced in interviewing and obtaining information from them. We also have technical writing skills, graphic capabilities, and presentation talents that will be brought to bear in the development of presentations.

III. ADDITIONAL TASKING

In addition to the mainline tasks accomplished for the Program Development directorate of MSFC, three in-scope tasks were performed under the contract for other NASA elements. These were the development of the Microgravity Experiments Cost Model for the MSFC Microgravity Projects Office; the development of the Ground Operations Cost Model for the Kennedy Space Center (KSC); and the calibration of the PRICE Systems Cost Model for NASA users, directed by the NASA Headquarters Comptroller Office. Some of the synergistic elements of these activities have already been mentioned in the discussion of contract accomplishments for MSFC, but specific work performed is described in the following paragraphs.

1.0 Ground Operations Cost Model (GOCM)

SAIC completely reworked the old GOCM that had been developed for KSC by another contractor. The original model would only estimate Shuttle ground operations and lacked documentation, flexibility, operating speed, simplicity, and overall credibility. The model was reprogrammed by SAIC as a menu-driven spreadsheet model that estimates facilities, schedules, manpower and costs at many levels and provides reporting, charting, supporting data bases, and documentation. It will estimate up to two different type vehicles in flow at KSC, which is another major enhancement. The model will estimate ground operations cost of over 80 different combinations of current and future launch vehicle elements including expendable, partially reusable, and reusable concepts.

SAIC totally rebuilt the data base using newer Shuttle actuals than were in the old model. A more uniform and inclusive WBS was also established. From those actuals was extrapolated an extensive “knowledge base” for a wide range of vehicle stages and elements which were scaled from the Shuttle baseline. This knowledge base was developed utilizing engineering judgment and knowledge of the various new vehicle configurations and requirements. When two different type vehicles are in flow simultaneously, synergism of vehicle elements or stages is accounted for and common use of facilities, if appropriate, is likewise considered in the resulting cost and schedule estimates.

This model and Users Guide have been delivered to KSC as of the contract end and the GOCM has been in actual use at KSC for some several months. The model has been beta tested at KSC and the results have been excellent.

2.0 PRICE Calibration for NASA Users

SAIC was requested to support efforts of the NASA Headquarters Comptroller Office and PRICE Systems in calibrating the commercially available PRICE Cost Model for NASA users. This effort had been underway with PRICE Systems prior to our involvement but little headway was being made. SAIC’s efforts were primarily to collect, normalize, and provide historic cost and technical data on NASA projects to PRICE; to interview PRICE users at all NASA centers and determine their needs and concerns relative to using PRICE as a cost estimating tool; and to write briefs and reports to be distributed to all NASA PRICE users on topics relative to calibration procedures.

SAIC developed a survey form, interfaced with NASA centers by visit, telecon, or through the survey form and determined who the PRICE users were at each NASA installation, what their unique needs were, how calibration was currently being accomplished, and what they considered to be problems or shortcomings with the PRICE model. This effort resulted in two report deliverables which were distributed NASA-wide: "GE-PRICE Enhancements—Survey Results" and "GE-PRICE Enhancements—Selected Support Tools and Methodologies".

SAIC researched, wrote, and published NASA-wide two Technical Briefs: "The Data Collection Process" and "PRICE Schedule Adjustments to Reflect a NASA Environment". These briefs provide NASA PRICE users information and guidance as to ways to best utilize the PRICE model. In addition, SAIC collected, normalized, documented, and provided PRICE Systems with subsystem level technical descriptions on AMPTE-CCE, CRRES, COBE, HEAO-1, HST-SSM, Landsat-1, GRO, External Tank, ERBS, Galelileo Orbiter & Probe, Magellan, and UARS. These data were to allow PRICE Systems to attempt to calibrate their data base to reflect NASA projects and tie costs to these technical parameters. SAIC also proposed a simplified, subsystem level approach using NASCOM data for calibrating NASA projects. Data and methodology to exercise this approach is planned to be developed in a follow-on SAIC effort for NASA.

3.0 Microgravity Experiments Cost Model (MECM)

SAIC developed and delivered an entirely new cost model for the Microgravity Projects Office. This was a two year effort which ended June 30, 1994 and included cost, schedule and technical data collection, analysis and normalization; WBS development; data stratification, regression and CER development; computer model structuring and development; model analysis and beta testing; model and data base documentation and Users Guide preparation; and actual microgravity project cost estimating.

The initial data collection efforts centered on MSFC microgravity projects, but was expanded to include JPL and LeRC microgravity projects as well. Data at varying levels of detail on a total of 52 microgravity experiments was collected. Because of the need for low level data, an additional 75 spacecraft data points were added to the data base. After normalization, the data was matrixed against 74 different technical, schedule or cost parameters. A standardized WBS consisting of seven subsystems and 21 components was also established and all data was displayed against this WBS. Statistical regressions were run and CERs were established for DDT&E and flight unit costs utilizing various technical parameters including weight, volume, power, temperature range, etc. The total applicable data base was used to establish each CER slope, but two curves, spacecraft and microgravity, were developed so that microgravity's lower costs could be accounted for.

The automated cost model was developed in a user-friendly manner with Help buttons, warning messages, a straight forward estimating approach, and excellent documentation. Both IBM and Macintosh versions of the model were developed.

A schedule estimating feature was added to the model which would accept user schedule inputs or generate its own schedule based on microgravity historical data. In addition, a cost penalty/benefit for schedule adjustments calculation was programmed into the model so that overly optimistic or pessimistic schedules impact the resulting cost estimate.

Finally, a cost risk feature was developed which provides risk profiles and contingency allocation for all appropriate cost elements in an estimate. The analysis considers the risk associated with the CERs themselves and the risk associated with the technical inputs to the CERs.

The automated model, documented data base, and users manual have all been delivered to MSFC and the model has been in use for several months. Training classes on the use of the model were also conducted by SAIC for a number of MSFC microgravity project managers and business management personnel at the time of model delivery to MSFC.

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