Reprinted from

Symposium on Machine Processing of Remotely Sensed Data

June 21 - 23, 1977

The Laboratory for Applications of
Remote Sensing

Purdue University
West Lafayette
Indiana

IEEE Catalog No.
77CH1218-7 MPRSD

PARAMETRIC DESIGN OF GROUND DATA PROCESSING/ SUPPORT SYSTEMS FOR ADVANCED SENSOR SYSTEMS

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I. INTRODUCTION

Ever-increasing data rates and data volumes associated with proposed large ground data processing/support systems for advanced sensor applications have made the costs of resultant data processing and analysis almost prohibitive. Though the prospective experimenter is most well-intentioned and well-motivated, he or she is immediately faced with a planner's dilemma: What is wanted, versus what budget and technology can provide. It has become obvious that the system user needs help early in project planning to meaningfully understand the impact of requirements on potential costs. With this helpful information available in a parametric form, the scientist-in-charge could make intelligent tradeoffs between scientific value and ultimate costs in the initial stages, thus assuring maximum return on dollar cost. Parametric analysis includes an initial scoping of the pertinent parameters to reduce the analysis to manageable proportions. An analysis of these crucial parameters leads to the choice of parameter sets which characterize the major system alternatives. These parameter sets are then used to define systems which cover the spectrum of expected values and which are representative of major classes of systems sharing common attributes. What is known and what must be assumed will be distinct for different situations by virtue of diverse development schedules, objectives, expected operational timeframes, historical precedents, etc.

This paper describes a parametric system design technique that has been successfully applied to ground data processing/support systems for advanced sensor applications. Parametric design is a highly effective tool in providing a reliable basis for budgetary cost estimates and system planning. Parametric design techniques should be applied when data processing requirements have not been stabilized or when final sensor system performance criteria is not well defined - conditions that normally exist during the initial stages of a new program. The parametric system design process establishes a direct relationship between system planners and budget analysts to perform realistic trades between requirements and implementation cost. These trades will eliminate surprises in advanced sensor ground processing costs and provide more effective budget utilization. This paper contains information of sufficient scope and detail to enable the reader to perform this parametric system design with a high degree of confidence.

Ideally, design requirements for a ground data processing/support for an advanced sensing system should be derived from a set of user requirements, a set of performance specifications, technical state-of-the-art constraints, and programmatic (e.g., budgetary) constraints. The process is iterative, as shown in figure 1.

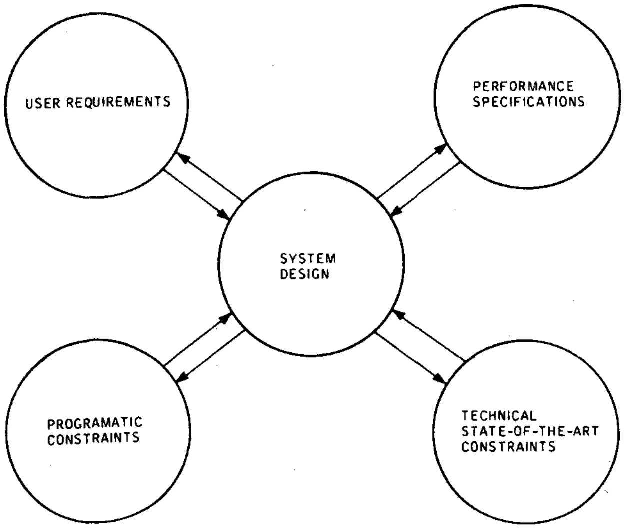

Figure 1 Major Input Elements Which Initiate System Design Iteration

The parametric design procedure differs from the preceding iterative procedure in several significant aspects, since specific users and hence specific user requirements and performance specifications are not identified at the initiation of the design. Instead of using a specific set of user requirements, sets of requirements are defined, with each set corresponding to a level of cost and complexity of the required ground data processing system. Thus, a shift from one set to another has the same effect as a modification of user requirements in the iterative design process. Each iteration in the design through the user requirements represents a possible data processing configuration satisfying a set of programmatic and technical constraints for the associated set of user requirements.

Thus, the design configurations represent "points" on a "graph" of costs against level of user requirements, so that, for planning purposes, the question "Given this set of user requirements, what is the cost of the required ground support data processing system?" can be answered for a wide variety of user requirements.

II. PARAMETRIC SYSTEM DESIGN TECHNIQUE

Parametric design of ground processing systems is a carefully defined and controlled analytical procedure. The procedure is divided into three major phases: 1) requirements definition; 2) system design; and 3) system costing. These phases are divided into subphases. The following paragraphs define those phases and subphases.

A. PHASE 1: REQUIREMENTS DEFINITION

The initial phase performed in a parametric system design is the generation of requirements. This phase comprises the following three critical subphases.

User Requirements Definition. This subphase provides generation of realistic user requirements that will bound the design effort and provide information necessary to develop the data processing requirements used in system design. The definition of user requirements requires the efforts of scientists/engineers who have an understanding of the user community and an ability to create. The assumptions and guidelines established in this subphase represent the most critical data developed in the parametric design process. A weakness in this data will greatly reduce the utility of a parametric design. The same applications that make a parametric system design useful will also expose a lack of definitive information for user requirements.

Data Processing Requirements Definition. The requirements that control the design of a data processing system are derived from user requirements. Therefore, user requirements must be developed in sufficient detail to provide the following information:

- Data throughput rate
- Data volume
- Data Processing Algorithm
- Data Products
- Operational Procedures.

An example illustrating the derivation of data processing system requirements from user requirements is shown in figure 2 (agricultural application).

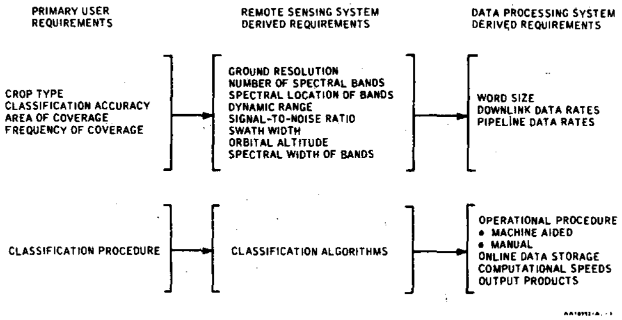

Figure 2 Example Illustrating Derivation of Data Processing System Cost Factors from User Requirements for Agricultural Crop Inventory Application

Key System Driver Definition. This subphase entails the selection and parameterization of "Key System Drivers", those requirements related parameters that drive ground processing system cost or technology.

To define the necessary key system drivers, the user must have a comprehensive understanding of the total data system, from sensor to product generation. Key system drivers must represent those parameters related to uncertainty of requirements and those significantly affecting ground processing system cost or technological feasibility. For, from these key system drivers, a series of "design points" is established. A "design point" is a set of key system driver values. Once these design points are established, the parametric design concept enters Phase 2, System Design.

While all phases of the system design effort are important, obviously these three critical subphases pace successful parametric design. However, the requirements phase cannot be terminated upon completion of the requirement generation task; it must overlap the design phase. Hardware and software designers must be supported by the same skilled scientists, having the same knowledge and understanding of user requirements, that supported requirements definition. In many cases initial requirements have proven unrealistic when related to design and must be modified.

B. PHASE 2: SYSTEM DESIGN

The system design process consists of three levels of design, tradeoff, and technology studies. The three levels of system design are: 1) Level I, functional design; 2) Level II, functional allocation; 3) Level III, detailed system design. These levels of design are performed for each design point selected. A complete new design is generally not required for all systems for each design point, many systems are unaffected by changes in "Key System Drivers". The multilevel design process requires the generation of detail sufficient to allow software and hardware costing. The examples cited within this paper were performed to levels allowing definition of the following:

- Off-the-shelf computer system sizing
- Special purpose hardware definition to number of racks/(rack complexity factor)
- Software sizing to (number of code lines)/(defined module)/(complexity factor)
- Technological development required (hardware/software).

Very often the initial user requirements drive the designer into processing capabilities beyond the current state-of-the-art. This situation requires the scientist and user to cooperate in a redefinition of requirements. The relationship between user requirements and system design must be maintained. A knowledge of this relationship will allow the user to perform an intelligent tradeoff between requirements and system cost.

C. PHASE 3: COSTING

Each system design is subjected to costing developed from analysis and experience with other similar systems. Costs are collected at both system and subsystem levels, providing cost information at the system and subsystem level for each design point. The series of design points selected thus yields rough-order-of-magnitude (ROM) costs and forms the basis of a system cost curve; the number of design points used is by necessity the number required to yield a continuous cost curve between the bounds established during Phase 1, Requirements Definition. As new requirements are levied, or existing requirements modified, additional key system drivers and thus design points are established and the cost curve varies with them, providing a basis of cost comparison at specific design points.

Hardware function costs are based upon 1) availability of off-the-shelf items, or 2) necessity for a new design. This decision is made by analyzing the function to be performed at the unit level. Off-the-shelf systems are selected wherever possible because of reduced costs and technical risk. The off-the-shelf cost is determined from several vendors whose equipment specifications met the functional requirements. A mean cost is used. If suitable off-the-shelf equipment cannot be found, a new design is selected. The costing of new designs is based on engineering experience and includes engineering design, drafting, manufacturing, documentation, equipment checkout, and parts.

The software to be costed is of two basic types: 1) software systems procured from hardware vendors; and 2) special build systems and application software. In all cases off-the-shelf software is used where available. The software costing algorithms used for pricing special-build software are based on number of lines of new code and the associated complexity factor. The estimated size (number of lines of code) of each software module is based on the following information:

- Engineering estimate based on line counts from similar software
- Software code models generated by programming small segments of the required software.

Three examples of actual parametric systems design exercises are presented in this paper. Example 1 describes the successful parametric design of a ground data handling system for the Earth Observatory Satellite (EOS). Example 2 presents a study currently being performed for the United States Department of Agriculture (USDA) utilizing the parametric results of Example 1. This example illustrates multiple application of a single parametric system design. Example 3 illustrates the difficulty in identifying and parameterizing "Key System Drivers".

III. EXAMPLE 1: A STUDY OF GROUND DATA HANDLING SYSTEMS FOR EARTH RESOURCES SATELLITES

This study was sponsored by the Lyndon B. Johnson Space Center to define the probable costs, technical risks, and performance tradeoffs for a ground data processing system to support an earth viewing remote sensing system using multispectral scanners (Earth Observatory Satellite). Although actual user requirements were not defined to a level to permit detailed, optimum design, the study results nevertheless were to enable Government program managers at planning levels to estimate budgets, schedules and procurement cycles.

In accomplishing these ends, a parametric approach to the definition of a data processing system was established: costs, technical risks and performance were presented as functions of principal design cost drivers determined by user requirements *assumed* after a logical, detailed analysis of similar projects and probable needs. The study established *classes* of user requirements, each class consisting of a range of values for pipeline data volume rates, resolution, survey area, survey repetition rate, number of data channels, word size, etc.

The study thus answered the question, "Given a class of user requirements, what will be the costs of the supporting ground data system?" for a wide range of user requirements.

The following provides a summary of user requirements and the principal results of the study. A functional diagram of the ground processing systems designed to support the Earth Observatory Satellite is presented in figure 3. The associated cost and implementation timelines are also shown in table 1 and figure 4. Summary cost is presented for each design point and the timeline is shown for only one system (10 meter IFOV 1/12 year).

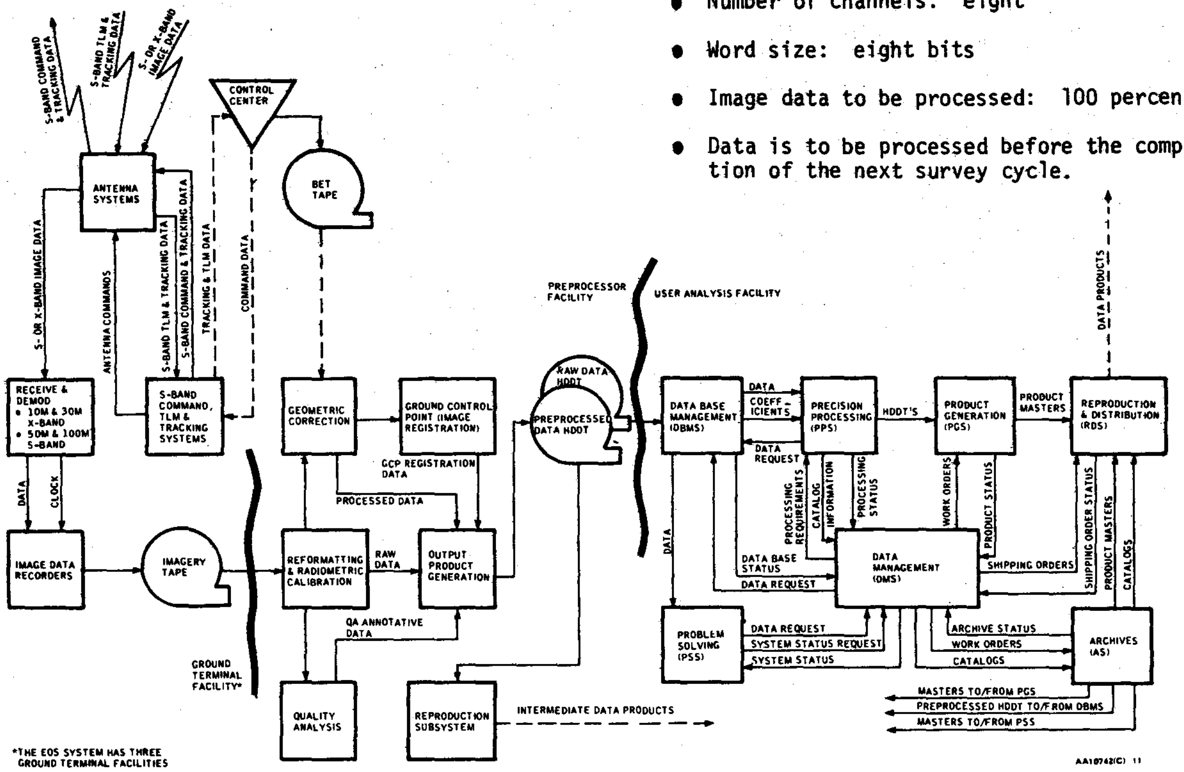

Figure 3 EOS System Functional Diagram

FACILITY	CONFIGURATION (COSTS IN MILLIONS)				
	10 METER 1/12 YEAR	10 METER 1/4 YEAR	30 METER 1/12 YEAR	50 METER 1/4 YEAR	100 METER 1/4 YEAR
GROUND TERMINAL FACILITY	6.823	6.823	4.617	1.611	0.923
PREPROCESSOR FACILITY	34.926	33.851	10.496	7.896	7.877
USER ANALYSIS FACILITY	65.555	48.151	55.670	27.786	27.554
TOTAL	107.304	88.825	70.783	37.293	35.354

*COSTS ARE ESTIMATED TO THE NEAREST THOUSAND DOLLARS.

Table 1

Ground Data System Cost Summary*

A. USER REQUIREMENTS

A summary of the user requirement generated for this parametric design follows.

- Resolution: 10 meters to 100 meters
- Area to be surveyed: 4,000,000 square nautical miles (nmi) (Continental United States)
- Survey Frequency: 1/24 year to 1 year
- Maximum amount of data to be retained in rapid access memory: four survey cycles
- Swath width: 100 nautical miles
- Number of channels: eight
- Word size: eight bits
- Image data to be processed: 100 percent
- Data is to be processed before the completion of the next survey cycle.

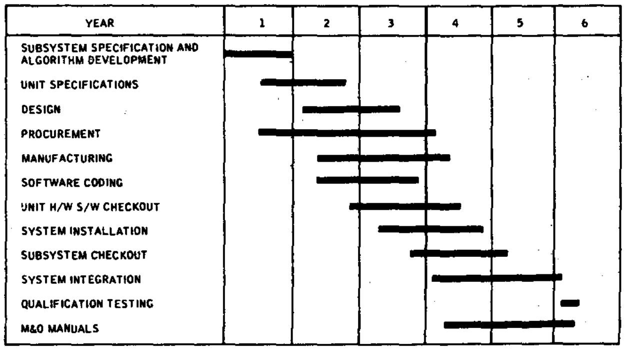

Figure 4 Implementation Timeline for 10 Meter IFOV 1/12 Year

B. PRINCIPAL RESULTS AND CONCLUSIONS

Application of the parametric approach just described to the definition of an EOS ground data processing system results in the following primary conclusions.

- The ground data processing system costs are related to *classes* of user requirements
- Ground data processing system costs vary exponentially with pipeline data volume rates required
- Pipeline data volume rates themselves vary 1) as the inverse square of the resolution; 2) directly with the survey area; 3) directly with the survey repetition rate; 4) directly with the number of channels; and 5) directly with word size
- For high resolutions (10 meters, eight bands) and frequent coverage (less than 18 days) of the Continental United States, the current state-of-the-art is such that the ground data processing system cannot be built to process 100 percent of the data
- Ground data processing systems were configured and costed for resolutions of 100, 50, 30 and 10 meters for coverage of the Continental United States at intervals from once per quarter to once per month. The costs varied from $36 million to $107 million
- Implementation schedules for a ground data processing system vary from 4-1/2 to 5-1/2 years.

IV. EXAMPLE 2: LEVEL A REQUIREMENTS FOR A GROUND DATA MASS STORAGE AND PROCESSING SYSTEM FOR AGRICULTURAL REMOTE-SENSING APPLICATIONS

This study was performed for the United States Department of Agriculture as a part of the activity entitled USDA-RSURTF Synthesis and Comparison of Alternative Subsystems Spacecraft. The study addressed a central mass storage and processing system to be used by the USDA to receive, store, process, and distribute data from Landsat C and the thematic mapper (Landsat follow-on). The conceptual design was derived from guidelines provided by USDA personnel during August 1976. Costs were based on design, acquisition, installation, test, and delivery of a central mass storage system accessible by specified organizational elements throughout the USDA. The costs are for the delivery of central mass storage and processing subsystems only. The conceptual design is a tape-oriented, serial-communications processing system, which uses minicomputer technology.

A. USER REQUIREMENTS

The data volume and rate established for this study were as follows:

Landsat C system (five channels, 80-meter resolution) acquires 4×10^8 bits (400 megabits) per 100- by 100-nautical-mile scene, including oversampling and housekeeping overhead. Daily acquisition rates of 30 scenes/day leads to an acquisition of 12×10^9 bits (12 billion bits). Online storage of 600 scenes requires the storage of 0.24×10^{12} bits (one-quarter trillion bits).

Thematic mapper (six channels, 30-meter resolution) with overscanning housekeeping data acquires 4×10^9 bits (4 billion bits) per scene. Daily acquisition rates of 30 scenes/day require daily storage of 1.2×10^{11} bits (one-eighth trillion bits). Online storage of 600/scenes/day implies the storage of 2.4×10^{12} bits (2.4 trillion bits).

The acquisition of Landsat C data over the Continental U.S. in a 4-hour block via Domsat implies an incoming rate of 0.8×10^6 bits/sec (0.8 megabits/sec). Acquisition of similar thematic mapper data in a 4-hour block via Domsat implies an incoming data of 8×10^6 bits/sec (8 megabits/sec).

The step from Landsat C to the thematic mapper involves a factor of 10 change-in-acquisition data volumes and rates. Furthermore, the final system design must accommodate online storage of multiples of trillions of bits and data rates of 10 or more megabits/sec, because data acquired and stored must also be distributed from storage.

The following requirements for the mass storage facility (MSF) were obtained from the data volume and rate requirements.

Capacity. Capable of expansion to 5.0 trillion bits of online user data.

Error Rate. Not to exceed one unrecoverable error in 10^{11} bits.

Transfer Rate. Capable of a sustained data rate of approximately 10 megabit/sec for a single host with an expanded MSF system.

Media. Recording medium reusable, available off-the-shelf.

Persistence. Recording medium capable of storing data at least as long as a CCT without significant compromise.

Technology. Off-the-shelf and field proven.

Transferability. Storage modules written at one read/write station shall be readable at other stations.

Availability. Fully expanded, 24-hour/day host service.

B. SYSTEM CONFIGURATION, ROUGH-ORDER-OF-MAGNITUDE COST AND PHASED DEVELOPMENT

The system configuration and rough-order-of-magnitude (ROM) cost analysis addresses each facility independently in terms of functional design and level A functional requirements. The host computer facility, and the unique applications processors for Large Area Crop Inventory Experiment (LACIE), Forest Service (FS), Statistical Reporting Service (SRS), and Soil Conservation Service (SCS) are not addressed.

The following is a summary of the final system configurations.

Mass Storage Facility (MSF). Conceptual configuration design is that of an online, high-density, magnetic-tape, data-storage system implemented in a multiprocessor environment.

Data Acquisition Facility (DAF). Incoming Landsat raw data is blocked, indexed, and transmitted to the central MSF by the DAF.

Processors. The following processing facilities are serviced by the MSF.

- Host computer facility - An existing USDA facility that acts as a terminal access interface (for approximately 3000 terminals) and as a report summary manager
- Preprocessor - Performs quality-analysis processing, geometric correction, ground control, point registration, and mosaicking of "raw" data
- Analysis processor - Performs classification and change-detection processing
- Output product facility - Produces images and thematic map overlays
- Unique application processors - The LACIE, FS, SCS, and SRS may develop, maintain, and operate processors that access the MSF.

The development of the final system configuration was accomplished in four steps, as follows:

Phase 1. In this configuration the data is received by USDA in the form of images and CCT from GSFC 5 days after downlink from Landsat. Only 10 percent of the data (600 scenes/yr) acquired over the continental U.S. is received.

Phase 2. In this configuration data is received by the USDA in the form of HDT directly from GSFC within 48 hours after downlink from Landsat. Data is radiometrically corrected with geometric correction coefficients supplied. All data (6000 scenes/yr) is received but only 600 uncorrected scenes are to be maintained online at any time.

Phase 3. This configuration differs from phase 2 in that a Domsat receiver is used to receive data from GSFC. Data is received within 24 hours after downlink.

Phase 4. This configuration is augmented to accept thematic mapper acquired data. This will require replacement of the Domsat receiver complex and augmentation of all systems to accommodate the order-of-magnitude change in data rates. In addition, a laser beam recorder and mapmaking facilities are added.

C. SUMMARY COSTS AND IMPLEMENTATION SCHEDULE

The summary costs are shown in table 2 and the implementation schedule for the final system is shown in figure 5. Experience has shown that in the development, installation, and delivery of major computing systems such as the one described herein, the minimum time frame for cost-effective procurement is in excess of 4 to 5 years, depending on the number of independent subsystems. The system proposed herein was a highly integrated set of subsystems, with associated technological questions of acquisition, communications, storage, accessing, and processing. Because the impact of a change varies as the square of a number of module interfaces, and the number of interfaces is relatively large, the opportunity for design

Facility	Phase 1	Phase 2	Phase 3	Phase 4
Mass storage facility	$3420	$ 2 630	$ 920	$ 3 470
Data acquisition	-	1 775	2160	5 010
Preprocessor facility	-	8 830	-	3 335
Analysis processor facility	5400	6 120	-	2,700
Image generation facility	-	5 990	-	18 530
Total	$8820	$25 345	$3080	$33 045
Annual operating cost	$1300	$ 3 800	$ 460	$ 5 000
Level B design	$ 250	-	-	-

[Cost in $1000]

Table 2

Summary Costs

"goofs," schedule slips, and cost overruns is considered to be relatively great. Thus, a reasonable implementation time is believed to be 6 or 7 years minimum.

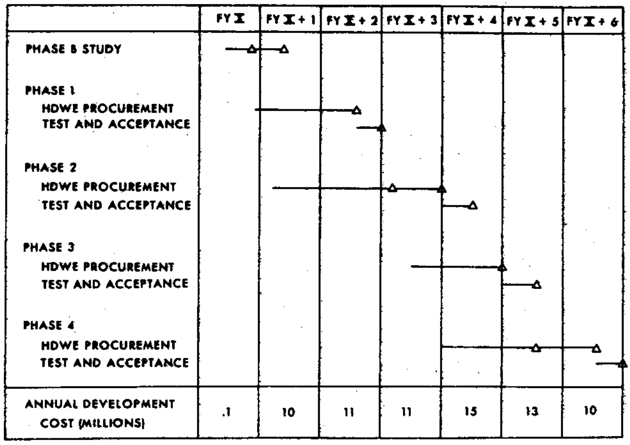

Figure 5 Implementation Schedule

D. CONCLUSION

The costing of this system is believed to be conservative because the system requires at least as many basic hardware units as a data-bus-oriented system in which minicomputers act as traffic controllers rather than as serial throughput devices. A subsequent, more detailed design level may indicate the technical, operational and/or cost superiority of a data-bus-oriented conceptual design. However, this possibility does not in any way invalidate the cost and schedule estimates given here. The cost differences between the two concepts are negligible at the requirements level of detail (level A) available at the time of this study.

V. EXAMPLE 3: A PARAMETRIC ANALYSIS OF SHUTTLE ERA DATA PROCESSING SUPPORT REQUIRED FOR THE DISCIPLINE OF ATMOSPHERIC AND SPACE PHYSICS

This study was sponsored by the Lyndon B. Johnson Space Center. It provided parametric costing for Shuttle ground data processing support equipment to enable reasonable estimates of costs attached to NASA's estimated maximum and minimum requirements. The study addressed a systems functional overview, system cost estimates, and implementation timeline.

The Interferometer Spectrometer was chosen as the representative Shuttle instrument for the Atmospheric and Space Physics Discipline. Four cases were based on four spectral resolutions of the instrument, as follows:

- Case I - Spectral resolution 0.01 cm^{-1}
- Case II - Spectral resolution 0.05 cm^{-1}
- Case III - Spectral resolution 0.1 cm^{-1}
- Case IV - Spectral resolution 0.5 cm^{-1}.

A. REQUIREMENTS AND ASSUMPTIONS

The following were the general assumptions upon which the system concept of the ground data processing equipment was based.

- One atmospheric and space physics mission per year; mission duration of 7 days; data acquisition of 11.25 hours
- Downlinked interferometer-spectrometer data to be subjected to polycoding, modulation and clocking
- Data received by preprocessor system to consist only of interferometer-spectrometer experiment data and experiment related housekeeping data.

The data rate (bps) for the interferometer spectrometer was calculated using the following equation:

$$\text{Data Rate} = 12.64\times10^{4}\left(\frac{V}{K}\right) \quad \text{(8-bit words)}$$

where V is the mirror velocity and K is the sampling coefficient. The volume of data collected was calculated by using the total data acquisition time for the mission.

The data acquisition parameters for each of the four cases are shown in table 3. Note that samples per mission (total experiment data volume) are the same for all cases.

CASE	SPECTRAL RESOLUTION cm^{-1}	S (SAMPLES PER VECTOR)	T (TIME TO COMPLETE 1 VECTOR)	GROUND DISTANCE BETWEEN VECTOR ACQUISITIONS
I	0.01	1×10^6	5 SEC	40 n.m.
II	0.05	2×10^5	1 SEC	8 n.m.
III	0.1	1×10^5	0.5 SEC	4 n.m.
IV	0.5	2×10^4	0.1 SEC	0.8 n.m.

CASE	VECTORS ACQUIRED PER MINUTE	VECTORS ACQUIRED PER PASS	VECTORS PER MISSION	SAMPLES PER MISSION
I	6	135	4,050	4.05×10^9
II	30	675	20,250	4.05×10^9
III	60	1350	40,500	4.05×10^9
IV	300	6750	202,500	4.05×10^9

Table 3

Data Acquisition Parameters

B. SYSTEM CONFIGURATIONS

The preprocessor system was divided into the following basic functions:

Input Preparation. To be designed utilizing high-speed logic; to accept 3.52 Mb/s serial input interferogram data, perform pulse code modulation (PCM) demodulation, frame synchronization, message identification (ID), polycode checks and limit checks; to store the checked raw data on high density digital tape (HDDT's); error conditions to be tabulated and stored.

Quick-Look Analysis. To be performed during the 3.75 day data acquisition period; near-real-time samples of checked interferogram data to be picked off input data stream, and to be Fast Fourier Transform (FFT) converted to spectrogram data; Interferogram and spectrogram samples to be plotted and stored; associated housekeeping parameters and off-limit conditions to be tabulated and stored.

Data Correction. To be performed within a following 10.25 day period; input data stored on HDDT to be radiometrically and geometrically corrected, reformatted, and stored on CCT for use by the analysis processor system.

Test and Reproduction. To consist of test tape generation, test control, tape reproduction, and hardcopy of any prior tabulated or plotted data.

Data Management. Typical interactive functions (e.g., control, analysis, and coordination).

Figure 6 is a functional flow diagram of the system.

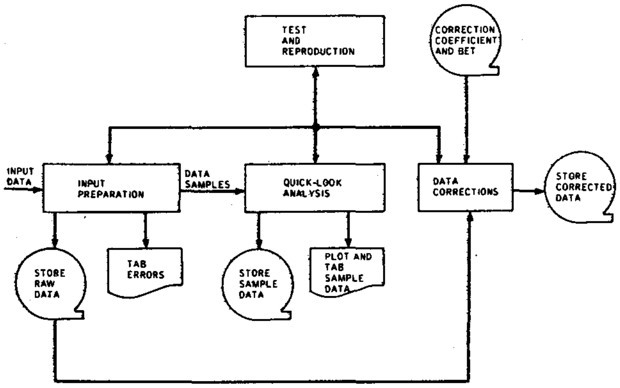

Figure 6 Preprocessor System Functional Flow Diagram

The Analysis Processor System will consist of the following subsystems:

FFT Processor Subsystem. To accept preprocessed interferometer data and perform interpolation, apodization, and FFT; output spectrogram data recorded on CCT's.

Product Generator Subsystem. To use spectrogram CCT's to perform automatic line detection and contour mapping.

Reproduction and Distribution Subsystem. Copies the products of the generator subsystem.

Archival Subsystem. For storage of master copies of original products.

Data Management and Development Processor Subsystem. To have overall control of the analysis processor system, functioning to monitor overall system health, monitor operational status and provide subsystem control, monitor and control products generated and distributed, keep index records of products in archival, and receive special requests from the users and monitor the generation of the products requested.

Figure 7 is a functional flow diagram of the Analysis Processor System.

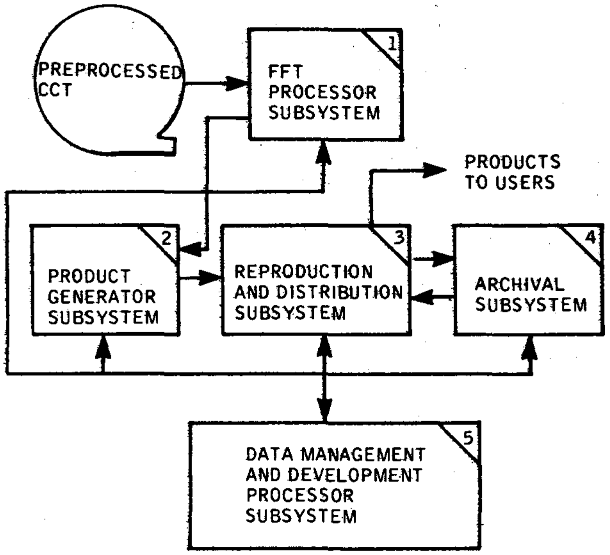

Figure 7 Analysis Processor System

C. COST SUMMARY

Table 4 contains the total ROM cost for the preprocessor system and analysis processor system. Cost includes basic ROM cost, installation, checkout, and integration (35 percent of the basic ROM cost), and maintenance and operations manuals (15 percent of basic ROM cost).

SYSTEM	(COST IN THOUSANDS OF DOLLARS)			
	CASE I	CASE II	CASE III	CASE IV
PREPROCESSOR SYSTEM	1814.0	1814.0	1814.0	1814.0
ANALYSIS PROCESSOR SYSTEM	5041.3	5477.7	5580.4	6292.8
TOTAL ROM COST	6855.3	7291.7	7394.4	8106.8

Table 4

Shuttle Ground Data Processing Equipment Total ROM Costs

D. CONCLUSION

In this study, the cost of ground data processing did not vary as expected. Further analysis of the chosen parameters showed that the turnaround time for complete data processing and the interferometer-spectrometer scan mirror velocity should have been parameterized. By varying these two parameters, an ROM cost spread would have been realized.

VI. SUMMARY

The preceding discussions and examples of parametric systems design should provide sufficient information to enhance the reader's capability to perform similar studies. The importance of the requirement phase cannot be overstated, and the difficulty in development of user requirements has caused many systems design efforts to fail. The selection and parameterization of "Key System Drivers" will determine the effectiveness of the results in bounding the cost and technological feasibility of a proposed ground processing/support systems for an advanced sensor system.

Two additional conclusions should be summarized: 1) design detail; and 2) personnel requirements.

A. DESIGN DETAIL

The level of design detail required to assess system cost and technological feasibility should be performed to the software module and hardware unit level (i.e., decom, array processor, etc.). One can make many high level assumptions at the system level that prove very costly during implementation. Gross estimates of software cost can be in error by factors of from 2 to 10. This paragraph is intended to point out that while assumptions must be made in the areas of user requirements, once requirements are fixed, the design must proceed in an orderly manner.

B. PERSONNEL REQUIREMENTS

The engineers and scientists performing parametric system design must be highly skilled. Those engineers used in the requirements definition phase must be competent in spacecraft systems, sensor systems, communications, recording, data processing, and user disciplines. The design engineer must be qualified in the design area of the systems (i.e., digital processor, real-time operating systems, etc.).

In conclusion, it is suggested that there are two types of planning and budgeting systems design: *useful, and useless*. To be useful the system design must positively relate to the cost and technological feasibility of the proposed ground processing/support systems.

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Currently responsible for management of problem analysis for space applications using the National Space Shuttle. Associated with mission planning since joining JSC (then the Manned Spacecraft Center) in 1963. Previously served as a senior analyst with RCA and as an assistant professor in the Rich Computer Center, Georgia Institute of Technology. Joined the NACA at Langley Research Division in 1948. Publications address Wind Tunnel Instrumentation, Data Processing, and Orbital Mechanics.

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Currently a member of the Earth Resources Program Office, responsible for analysis of Shuttle payload data processing requirements for the Payload Operations Center (POC). Previously acted as principal investigator for the NASA Earth Observation Aircraft Program Project 045, verifying an atmospheric computer model using experimental data. Acted as project scientist for Skylab Earth Resources Experiments multispectral camera facility data recovery project. Recipient of the Sigma Xi research fellow award for outstanding research, University of Houston, 1970.