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SYSTEMS FOR REMOTE-SENSING
INFORMATION AND DISTRIBUTION

8

*Useful
Applications of
Earth-Oriented
Satellites*

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL



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Applications of
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SYSTEMS FOR REMOTE-SENSING
INFORMATION AND DISTRIBUTION

Prepared by Panel 8 of the

SUMMER STUDY ON SPACE APPLICATIONS

Division of Engineering

National Research Council

for the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

In the fall of 1966, the National Aeronautics and Space Administration (NASA) asked the National Academy of Sciences to conduct a study on "the probable future usefulness of satellites in practical Earth-oriented applications." The study would obtain the recommendations of highly qualified scientists and engineers on the nature and scope of the research and development program needed to provide the technology required to exploit these applications. NASA subsequently asked that the study include a consideration of economic factors.

Designated the "Summer Study on Space Applications," work began in January 1967, guided by a Central Review Committee (CRC) appointed by the Academy. The Study's Chairman was Dr. W. Deming Lewis, President of Lehigh University.

Technical panels were convened to study practical space applications and worked intensively for periods of two to three weeks during the summers of 1967 and 1968 at Little Harbor Farm in Woods Hole, Massachusetts. The work of each panel was then reported to the Central Review Committee, which produced an overall report. Panels were convened in the following fields:

- | | | |
|-------|-----|---|
| Panel | 1: | Forestry-Agriculture-Geography |
| Panel | 2: | Geology |
| Panel | 3: | Hydrology |
| Panel | 4: | Meteorology |
| Panel | 5: | Oceanography |
| Panel | 6: | Sensors and Data Systems |
| Panel | 7: | Points-to-Point Communications |
| Panel | 8: | Systems for Remote-Sensing Information and Distribution |
| Panel | 9: | Point-to-Point Communications |
| Panel | 10: | Broadcasting |
| Panel | 11: | Navigation and Traffic Control |
| Panel | 12: | Economic Analysis |
| Panel | 13: | Geodesy and Cartography |

The Panel on Systems for Remote-Sensing Information and Distribution was organized in the early spring of 1968 and held several sessions before meeting for two weeks in Woods Hole during July 1968. This report was prepared at Woods Hole under the leadership of Dr. Arthur G. Anderson, the Panel Chairman.

The major part of the Study was accomplished by the panels; the function of CRC was to review their work, to evaluate their findings, and, in the context of the total national picture, to derive certain conclusions and recommendations. The Committee was impressed by the quality of the panels' work and has asked that the panel reports be made available to specialized audiences. While the Committee is in general accord with the final panel

reports, it does not necessarily endorse them in every detail. It chose to emphasize the major recommendations in its overall conclusions and recommendations, which have been presented in Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee.

In concluding this preface, it is emphasized that the conclusions and recommendations of this panel report should be considered within the context of the overall report of the Central Review Committee.

PANEL ON
SYSTEMS FOR REMOTE-SENSING
INFORMATION AND DISTRIBUTION

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1.0 SUMMARY

1.1 Field

This Panel was established to consider the problems and potential for the use of data gathered by remote-sensing or distributed collection devices with collection from satellite or aircraft. The considerations included the collection, processing, storage, and distribution of these data in both processed and raw form. In general, the problems considered focused primarily on those data-processing aspects of the total system that lie between the receiving ground station and the user. Inevitably, however, broader judgments were reached on overall systems aspects, partly because of the need for mission planning and control in the data-processing system, partly because of the inevitable need to designate operational priorities for the collection and dissemination of data.

1.2 Philosophy of Panel Operation

With the very large number of potential applications and agencies involved, this Panel had difficulty defining the magnitude of the user distribution net, its requirements, and the range of potential extension of the data-processing needs. We chose early to use detailed studies of illustrative current operations to size the likely requirements for various types of data handling; we then evolved methods for scaling the system requirements. Fortunately, substantial efforts in image handling, filing, and flexible space experimentation are in progress, and these programs provide readily available guides.

1.3 State of the Art

The handling of data from space to produce tables, tapes, lists, charts, and images has reached a high level of sophistication, as illustrated by the satellite programs of NASA and ESSA, and by the diverse scientific programs of NASA. Data can be relayed, recorded, and processed into image form with either analog or analog-digital processing; film can be obtained from either aircraft or satellite missions; images can be rectified, processed, and converted in a variety of sophisticated forms; and collection from distributed ground sensors can clearly be handled.* It is fair to say that the state of the art for the processing of such data is advanced, in the hardware and some of the software.

Less developed, but showing very rapid progress over the past decade, has been the sensor art. In this case, a wide variety of potentially useful

*See Bibliography - Appendix D.

sensing systems is available. In most cases the devices have neither been engineered for field operations nor proven in civilian applications.

The techniques for the use of the gathered data have developed variously. For distributed ground-sensor data, measuring variables which have been measured by man for years (e. g., river height), the processing of the data and their use appear to be clear. For data in conventional image format and color - and under the assumption that skilled interpreters already know how to interpret aircraft photography and will interpret these data - the preparation of the image data in image form appears readily feasible and can be done relatively quickly, either from video tape to hard copy or by reproduction of film photography. An extensive experience exists in this country for preparing these data in appropriate form for filing, retrieval, and reproduction. One would have to handle most of the image data in analog form, since the users are not prepared to handle it otherwise.

It is probable that additional training will be required if these new data are to be skillfully utilized. This will be particularly true as additional new techniques (pseudo-color and image enhancement, for example) are added. The need for additional training and the development of new interpretive skills could be a serious limitation to data use unless timely provision is made.

For the preparation of image data and its reduction in automatic form, however, the state of the art in technique and proven applications present serious barriers to progress. For example, to combine a study of signature characteristics with data-processing and sampling techniques, in a feasible and economical form, new application research technology is required, and the effort must be of significant size for timely use.

1.4 Environment

The electronic data-processing field operates within an environment of rapid technological progress, with rapid spread of the performance/cost benefits to the users. We expect hardware and software developments to continue in the next 10 years at a rate similar to that in past performance, with greatly improved storage densities, display capabilities, image-processing functions, and file-archive capabilities. Similarly, we expect a continued evolution of the technology for video-analog data processing, and continuation of past progress in film handling, reproduction, and measurement.

The sensor technologies are evolving at a rapid pace, although primarily for highly specific applications. Continued progress here is also anticipated.

We therefore conclude that the technological environment for the development of the data-collection and data-processing tools is one of rapid evolution, and that, except for money to buy the hardware, this is not the pacing element for application to new tasks. One should not infer from these comments that we are satisfied with the rate of progress above or could not envision ways to utilize greater progress. Rather, with limited funds, we believe that an earth resources program executed in proper priority, will not concentrate large development funding of these areas, which are substantially funded elsewhere. This does not exclude limited development efforts specific to earth resources.

If one reviews the applications, their technological status falls into two broad bands. In the first of these, the application of the data is a straightforward supplement to existing interpretive procedures, without changes in those procedures. This by no means implies that the importance of that supplement is insignificant; the studies performed indicate that it can, in fact, be very substantial. In the second case, the direct application of the data is primarily a matter of potential, with substantial effort required to prove it in, through combined field and laboratory work. This second area includes a very substantial potential for a revolutionary change in the way in which the data are processed, in the range of applications that can be handled, and in the introduction of new scientific and management methods for our natural resources. At the same time, although substantial enthusiasm and large potential benefits exist, no focused, critical-size activity is under way.

The consequence of this technological status and environment is that fairly straightforward operating applications could be effected rapidly. In this case, image data would be distributed by mail — as hard-copy imagery — for interpretation by skilled human interpreters. This bypasses serious near-term problems of information distribution and interpretation but would place a burden of expense on the agencies involved and would limit the timeliness of the data.

The realization of the full potential for remote sensing, including dramatic new methods and applications, will require a substantial, continued, and coordinated evolutionary applied research program.

1.5 Goals

The goals for consideration by this Panel were:

A near-term data-processing system to meet operational needs

A data-processing capability for support of new applications technology R&D

A logical path for development of the data-processing system to provide a continuing capability for operational and R&D needs

An identification of the problems (and potentials for their solution) that limit broad application of remotely sensed data

1.6 Illustrative System

Assuming no socioeconomic constraints, we envision a first-generation operational data-processing facility that would be in operation in 2 to 3 years and then evolve into a second-generation operational data-processing system operating in 10 years.

In parallel with this evolution of the data-processing system, we envision an applications research and development program of broad scope, dedicated to proving-in new techniques for subsequent use in operational earth-resource applications. The program would include heavy emphasis on what might be called earth-resources engineering — for example, signature-analysis studies combined with ground truth, and pilot programs to

demonstrate that certain species of resources can be consistently identified and measured by remote sensing in a timely and economical way. We envision that this R&D program would provide the required base for the evolution from the first-generation to the second-generation data-processing system.

1.7 Conclusions and Recommendations

1. We conclude that a relatively straightforward data-handling system can be put together on a time schedule that matches the first earth-resources-satellite needs. This system, which we envision as a central facility, would process satellite image data to provide output images for distribution to agencies and industrial users. It would require a relatively straightforward training program for interpretation by the users. It would also provide the functions of satellite mission planning and control, coordination of user requests, archiving of the data, and provision of data in appropriate form for experimentation by users. It would provide facilities for archives, and for distribution to major users of distributed sensor data collected by satellite. We recommend that this system be built to match the schedules for the earth-resources satellites (operating in 3 to 5 years).

2. We conclude that for full realization of the benefits of data-handling techniques, both in the rapid evolution beyond the first systems, and in the development of new applications, a significant, well-managed program of R&D organized to recognize priorities is required. We recommend its establishment.

3. We conclude that significant improvements will be possible in the data-handling capabilities and products. These will include extended capabilities for machine-assisted interpretation, some automatic interpretation, extended archival capabilities, and dramatically increased computational and display applications. We envision these improvements in a second data-handling system that would be in operation in 5 to 7 years after the start of the first system. We recommend that this second system be planned for — providing appropriate checkpoints for the feasibility of its constituent parts — and that subsequently it be built.

2.0 REQUIREMENTS FOR EARTH-RESOURCES DATA HANDLING

2.1 Data-Processing Bottleneck

This Panel was formed to consider issues raised during the first summer of the Space Applications Summer Study (1967), which indicated a need for consideration of the data-handling and distribution functions for data derived from remote-sensing platforms. Early estimates of data volume and of the potential data-processing requirements led to the conclusion that a very substantial roadblock to the use of the data could lie in the present capability for data processing. For example, imaging sensors operating at 5-MHz bandwidth can readily produce quantities of digital data of 10^{12} bits per day; if detailed digital processing of all these pieces of information is required, one can quickly run out of computer capacity, even with very large machines. In view of this, the Panel's earliest considerations probed the extent of need for detailed processing of the data.

2.2 General Assumptions for Earth-Resources Data

As a result of those studies — which included reviews with personnel from the Departments of Interior, Agriculture, and State, and visits to facilities at NASA, ESSA, and the Universities of Michigan and Purdue — we made the following assumptions for the earth-resources area:

1. The "user" will require data and can use it in raw and reduced form. The output to the user will consist of pictures, images, maps, tabulations, listings, and tapes of both digital and analog data.
2. The "users" include public agencies, scientists, private agencies, and individual entrepreneurs.
3. The user skill and capability will vary from that of "ESSA-type users," with substantial capability for processing and interpretation of data to produce output information, to "ultimate users," such as individual farmers, who seek only information for personal management decisions.
4. The sources of data that constitute user information, in the context of this report, include satellite photography and imagery, aircraft photography and imagery, both satellite and aircraft sensor data of other forms, ground sensor data (particularly as relay satellites provide the communication link), reduced data, and ground-truth data.

2.3 Detailed Assumptions for the First-Generation System

Within the above assumptions, the following further assumptions hold for the first-generation system:

1. A Data-Processing Center will exist to provide for receipt of the various forms of data, processing to form images, reproduction and

archiving of those images, searches in the files, generation of and distribution of data on satellite position and status, and command/control of satellites. It will possess analog/digital conversion facilities, digital and analog processing facilities for image processing, and a broad range of equipment for R&D by skilled personnel.

2. It is assumed that the major use of photographic and electronic image data will be in image form, and by a suitably skilled interpreter. The consequence of this assumption is to relegate automatic processing of image data, for interpretation, to an R&D role until the next-generation system. It will be important in that context, however.

3. a. It is assumed that such major archives as are maintained for (2) will be in analog form--with entry from the communication system also in analog form--either stored as photographs, on video tape, or both.

b. A capability must be provided to furnish digital tapes from video tapes for R&D experimentation.

4. a. The satellite image input to the system will originate from the satellites indicated in Figure 8.3.1. This, therefore, means a maximum of three satellites flying simultaneously--one for general use, possibly an additional one for hydrology and oceanography, and one for geology. Each satellite has three spectral channels. The data for geology may not be necessary beyond a three-pass output. This data source would probably be used by other earth-resource groups. As a consequence, we plan for a maximum of three-satellite output as the data source.

b. There is no attempt to provide for ESSA satellite requirements, which we assume are handled in their own unique systems. Copies of selected ESSA image data should be made available for R&D usage.

c. The image output from the satellites will be in analog form. A choice exists as to whether these data are relayed from the satellites by way of a relay satellite or by way of ground stations. We assume several ground stations. In costing-out the central system we assumed that communication facilities exist, and are not part of the new costs.

d. The output of the processing Center will consist mainly of images and analog tapes. In general, hard-copy images will form the primary output, with selected small volumes of video-tape output.

e. The customers for this output will be primarily government agencies or industry users, with smaller outputs on request by individuals (primarily scientists). The distribution to agency-type users, and the required frequency of coverage (see, for example, the report of Panel 1, Forestry-Agriculture-Geography) implies that no sophisticated new distribution system need be built as part of this system.

f. Processing at the Center will be to agency specifications. The minimum data added would be ground-registry data, sensor and filter characteristics, and satellite data.

g. If sufficiently inexpensive ground stations can be built, direct access to the satellite by local agencies would provide an opportunity for direct production of imagery--for both other national and international users. In this case the Center would provide the necessary ephemeris and other satellite data to these remote users.

h. Requirements for global coverage will be provided by means of an on-board tape recorder with ground stations in the United States.

5. a. The ground truth will be collected locally for operational use, and integrated locally with the imagery provided by the system.

b. In R&D cases, the ground truth may be brought to the Center for special treatment.

c. Regional studies and publications would be broadly distributed and perhaps also stored in the Center.

6. There will be an aircraft program for supplementary information and for R&D on sensors, application research, and data-processing techniques.

7. a. Satellite-relayed data from distributed ground sensors will also be used primarily by local agency users, although summary reports will be required centrally.

b. Where the economics show that local collection makes most sense, the data will be processed, stored, and summarized locally for distribution through channels that will not concern the Center.

c. Where the data are collected by satellite, they can be transmitted either to a center or to both a center and local agencies. For the purposes of this study the only difference between these two cases is the amount of distribution required, since we assume the data will be collected and archived at a center.

2.4 Consequences of the Assumptions

The consequence of these assumptions is that data will enter the first-generation data-handling function from aircraft and satellite data-gathering sources, the largest single source of data being the satellite imagery data. The processing of the latter data only in analog form produces an output product that lacks much of the value that one can anticipate for future systems that incorporate features of image enhancement and automatic analysis and measurement. Our judgment is that this early product would have significant utility, and not require large amounts of training for its early use. Beyond that, we are convinced that an aggressive R&D program could be mounted to upgrade the earliest standard-output products, and to develop advanced uses. This conviction, in part, forms the basis for our assumptions with respect to the experimental access to the first system.

3.0 SYSTEM CONFIGURATIONS FOR DATA ACQUISITION

3.1 Remote-Sensors Systems

A system employing remote sensors for obtaining earth-resources information may consist of many components such as:

1. Aircraft and spacecraft systems containing remote sensors and supporting equipments
2. Data-receiving centers
3. Data-processing and analysis centers
4. Distribution networks
5. Archives

These system components will be selected to support both operational or pilot operational activities (that will provide immediate or short-term benefits) and R&D activities (that will assure maximum long-term benefits). There are many options, both with respect to the characteristics of the individual components, and as to the manner of organizing and inter-connecting the individual components.

Let us consider a few of these options by discussing five possible sensing systems.

3.1.1 System I - High-Altitude Aircraft

A high-altitude aircraft equipped with high-resolution color and false-color-film cameras, side-looking radar, and a multiband visible and infrared (ir) scanner. All data obtained in flight would be stored on board (film or magnetic tape), and upon landing would be physically delivered to a regional center. Here the data would be logged in, developed, copied, and selectively distributed as follows:

1. Agricultural agency charged with the responsibility of estimating the total acreage of a certain crop
2. A large urban development and planning group
3. A signature-analysis research group
4. A national archives facility

Such an aircraft system will cover 1 to 10 million square miles per year, depending on the type of aircraft, altitude, and swath width. The smaller coverage assumes operation with a swath width of 10 miles, a 300-mile-per-hour aircraft, and operations several hours per day. The larger coverage assumes swath width of about 50 miles and five hours per day operation with a 600-miles-per-hour aircraft. In either event a number of aircraft would be required for single coverage--a substantial number (about

20) being required for single coverage of North and South America in one year.

3. 1. 2 System II - Satellite Film Return

A low-altitude (150 nautical miles) recoverable satellite equipped with film metric camera(s) capable of imaging the earth (perhaps stereoscopically) in color at a resolution of approximately 100 feet could be placed in sun-synchronous orbit for about two to three months. During this time it would be remote-controlled from earth to obtain complete and cloud-free (if possible) pictures of North and South America (about 15 million square miles). At the end of this period, the satellite reentry system would return the 2000 frames of exposed film to the earth's surface where it would be recovered and delivered to a central processing center. Here the film would be carefully developed, indexed, and copied (perhaps 50 times) for dissemination as follows:

1. U. S. Government cartography groups
2. Various government, industrial, and educational geological groups
3. Participating members of international organizations
4. National archives

(A somewhat similar system is discussed in Panel 2 Geology report. —Ed.)

3. 1. 3 System III - Satellite Telemetry Systems

Three variations of possible long-life, unmanned, non-recoverable, readout, medium-altitude (400-500 nautical miles) satellite systems are presented here. All would operate in near-polar, sun-synchronous orbits, have a 2- to 4-year life, and have a three- or four-spectral-band imaging (television or scanning radiometer) system capable of 100-foot ground resolution. All of these systems would "see" the entire 200 million square miles of the earth every 17 days. Although all the systems would have a wide-band (5-MHz) radio-transmission capability for electronically delivering the imagery to the earth, they would utilize different communication links and routes.

It is advantageous to locate the first-generation data center at a receiving ground site, particularly if timeliness of data becomes an important system consideration. The alternative is to have rapid-scan capabilities at the ground station.

3. 1. 3. 1 System IIIA - Direct Regional Readout

This system would communicate its imagery data in real time directly to the ground. Ground stations with tracking antennas would receive data from the satellite when its orbit ground-track is within 500 miles of the station. Thus, the area coverage per ground station would be similar to the area coverage of System I--that is, one station for about 1 million square miles, four to six ground receiving stations for the United States and Alaska, 20 stations for North and South America, and 100-120 stations

for the world's landmasses and oceans. This system fits in well with regional (rather than central) processing and analysis centers, with the regional processing center placed at the same location as the receiving ground station. The satellite design is simple, with earth-position, attitude-control system, and transmitter sized for a 1000-mile distance between a 2- to 3-dB fixed spacecraft transmitting antenna and a 25- to 30-dB automatic-tracking receiving antenna. The satellite design is to a large degree independent of other systems (e. g., communication relay, satellite networks) and of operational use (e. g., number of ground receiving stations).

Should it be desired to have all or some of the processing functions performed at one central station, the four to six U. S. regional ground receiving stations could relay their information to the one central U. S. processing station via ground links or a geostationary communications relay satellite.

Participation of foreign countries could easily be accommodated by the implacement of combination ground receiving and processing stations within the participating countries. (The concept of a ship-borne or mobile station for temporary use in different ports of the world suggests itself.) (This is similar to a system, Configuration II, described in the Panel 7 report, Points-to-Point Communications. --Ed.)

3. 1. 3. 2 System IIIB - Relay via Geosynchronous Communication Satellite

In this option, the satellite transmits its imagery data in real time to the ground via one of a network of geostationary communication relay satellites. The relay satellite in turn would relay the information to one (or more if desired) central receiving ground stations. Thus, with the use of the geostationary relay satellite network, a single remote-sensing satellite can deliver global imagery in real time to a central ground station. The remote-sensing spacecraft must have sufficient transmitter power for a 25,000-mile range between the tracking transmitting antenna and the large fixed-area antenna on the communication relay satellite. (This is similar to a system, Configuration I, described in the Panel 7 report, Points-to-Point Communications. --Ed.)

Processing of all the global data could be accomplished at a single receiving and processing center. Dissemination of copies of the data to regional stations, user agencies, or foreign governments can be accomplished by either mail or radio frequency links if a real-time requirement exists.

Assuming the prior establishment of a Geostationary Communication Relay Satellite Network, System IIIB is the most economical and straightforward way of initiating a global monitoring capability.

3. 1. 3. 3 System IIIC - Direct-Delayed Readout

In this option, the ground receivers of IIIA and the direct readout from the satellite would be supplemented by satellite on-board magnetic-tape recorders for the taking of imagery at locations distant from established ground receivers. One assumes the existence of an additional recorder on board to provide a backup capability. The reliability of the recorders and

their operational life becomes a major consideration. Assuming that this can be adequately handled, the system would use two to three domestic receiving stations for repetitive U. S. coverage, and selected use of the recorders for coverage outside the United States. (This is similar to a system, Configuration IV, described in the Panel 7 report, Points-to-Point Communications. --Ed.)

This option appears to provide the cheapest entry to a quickly growing program and was assumed throughout our further discussions as the likely imagery option.

3.2 Distributed-Sensors Systems

The observation of the earth, its landmasses, oceans, and atmosphere, has and will continue to require direct or in situ measurements in addition to information obtained by remote sensing. There exists a complete spectrum of level of sophistication of direct-measuring systems, starting at one extreme with a pad and pencil for man to record his observations, to automated instrument platforms containing sets of instruments, telemetry and communications equipment. It is the latter class--automated instrument platforms--that will be considered in this discussion. Use of automated instrument platforms is normally restricted to instances in which:

1. Well-defined, repetitive measurements are required.
2. The site of the required measurements is remote from or not accessible to man.
3. Real (or near-real) time delivery of the data to the user or analyst is required.

Various global networks of such automated platforms, for observation of various terrestrial features, are indicated. The Points-to-Point Panel Report discusses in detail the manner in which a communication relay satellite can interrogate a global network of such distributed sensors and relay the measurement data to one or more receiving and processing stations.

3.2.1 Summary of Requirements

Discussions of the requirements for, and application of, automated instrument platforms appear in the other panel reports (Meteorology, Hydrology, Oceanography, Forestry-Agriculture-Geography, and Geology). A tabulation and analysis of the communication flow imposed by an entire network of distributed sensors is presented in the Points-to-Point Panel Report. The discussion that follows here attempts to establish the requirements on the Data-Processing Center of a global network of distributed sensors.

1. The network will contain land-based, ocean- and lake-based (buoys), and atmospheric (balloons) platforms.
2. The positions of most of the platforms will be fixed and known. Some platforms (balloons and drifting buoys) will have time-varying positions, however.

3. There will be a large variation in the number, type, and frequency of measurements taken on each platform. For example, many hydrologic stations will normally report a single parameter—river stage—on a once-per-day or once-per-week basis. However, in times of flooding, certain of these stations will be commanded to report hourly.

Another example is that of ocean buoys, which will act as platforms for a whole complex of oceanographic and meteorologic instruments that will require a rather long communication message four times per day. A third class is represented by the volcanic and seismic sensor that will normally be sampled periodically upon command, but will "sound" an alarm immediately upon sensing an earthquake or eruption.

4. Estimates of the size of the first-generation system are:
 - a. Number of Platforms ~ 20,000
 - b. Number of messages/day ~ 40,000
 - c. Number of bits/day ~ 10 million

3.2.2 System Function

The main elements of the Distributed Sensor System (see Figure 8.3.1) are:

1. The network of distributed sensors or automated instrument platforms
2. Communication relay satellite(s)
3. A group of governmental agencies with the responsibility, facilities, and organization for (a) monitoring and analyzing various data (such as remote sensing, manned observation stations, automated instrument stations); and (b) distributing basic data and analyses to various established users—other government groups, industrial, educational, and private groups, and foreign groups
4. A data-processing center(s) for (a) receiving observational data from space (remote-sensing spacecraft and distributed ground sensors); (b) organizing the data for dissemination to the various government agencies (e. g., ESSA, Dept. of Interior, Dept. of Agriculture) identified in (3) above, and for archiving; and (c) monitoring performance of and providing programming and scheduling control of the spacecraft data-collecting functions

With respect to the data from the distributed sensors, the processing center must:

1. Receive and decode the radio frequency signals relayed by the communication satellite.
2. Change the format of messages if necessary. For example, the single message from the ocean buoy may have to be re-formatted into two separate messages—one containing the meteorological information, the second containing the oceanographic information.
3. Sort and store the messages into piles, for dissemination to the various using groups.
4. Distribute some of the information—e. g., weather data—in near-real time (perhaps computer to computer) over hard wire links.

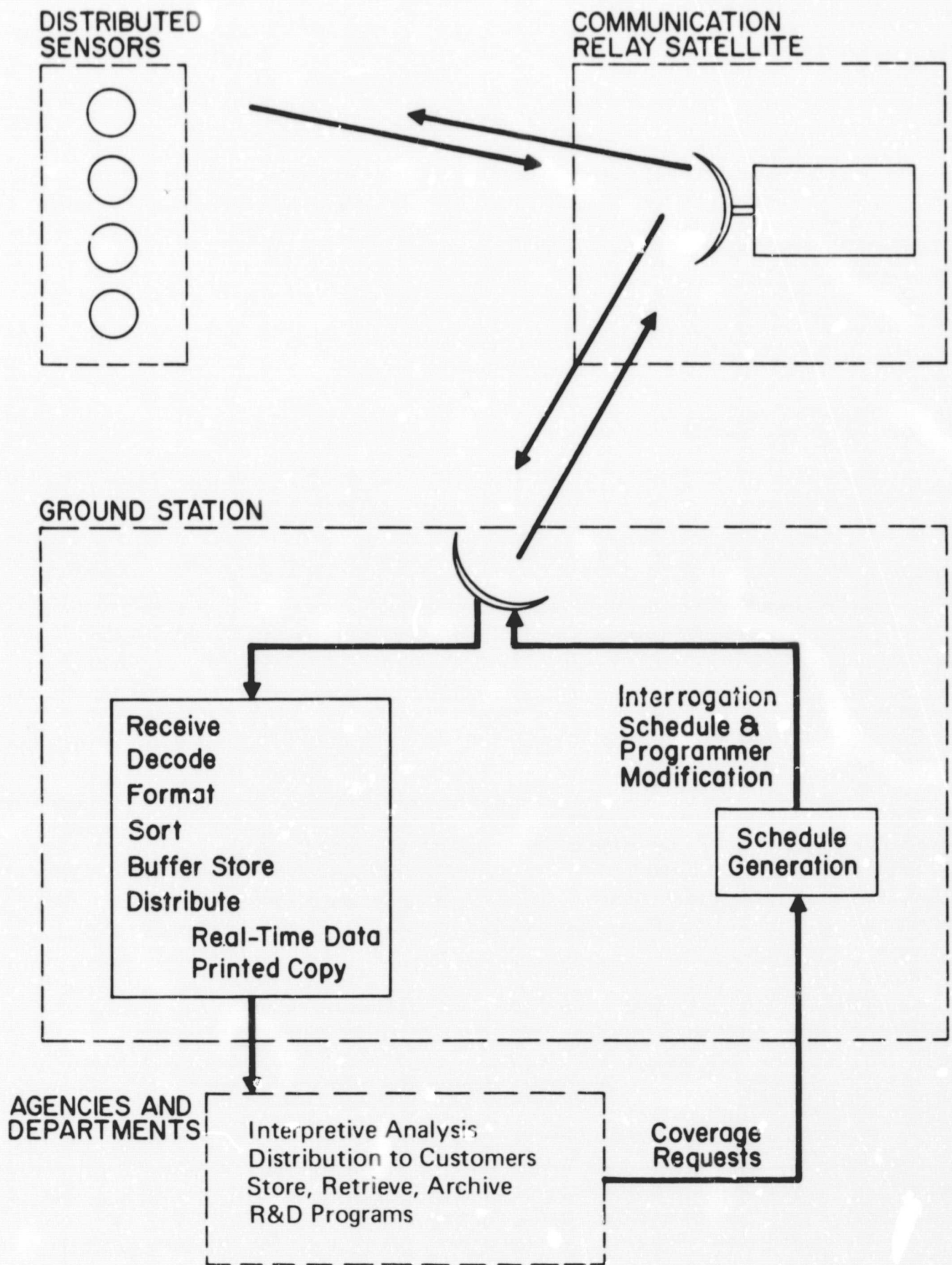


FIGURE 8. 3. 1 Functional system description - distributed sensors.

From a data-processing standpoint, the volume imposed by the single-center processing of global information is the most demanding, that is

1. The receipt, formatting, sorting, forwarding, and printing of about 40,000 messages per day (10 million bits); and
2. The generation of a comparable number of interrogation-command schedules

This volume, and the type of data manipulation required, are small and simple compared to the capacity and capability of modern high-speed computer and central-processing units. The spacecraft data-processing center will have at least one central processing unit; the load imposed by the distributed sensors would require only a small fraction of the time of such a unit.

4.0 DATA-HANDLING SYSTEMS

In considering the handling of the data from the satellite it is possible to draw numerous interfaces for describing the functions to be performed. The most useful breakdown for our considerations was to assume that the data-processing system would include command/control for the satellite data-gathering, and would also include an interface to the users.

4.1 Breakdown of Functions

With those interfaces, the following (non-unique) breakdown of data-handling functions was used:

- Mission Planning and Support
- Data Acquisition
- Pre-Processing
- Data Service Center
- Interpretation and Analysis
- Reproduction and Distribution

The interrelationships between these functions are shown in Figure 8.4.1.

4.1.1 Mission Planning and Support (MP&S)

This function provides the necessary planning, command, control, and verification to ensure that the mission is performed properly and that the data obtained satisfy user requests. Mission Planning and Support works with the users to establish an early plan for utilization of the satellites and for setting up priorities for the programming of the data-gathering resources. The users include operating users and experimental users; MP&S must have the capability to revise missions in response to user requests, to analyze the data (misfunction detection), and to do external analysis (for example, identification of clouds that make imagery useless).

This function provides predicted satellite data to ground receiving stations, in order to assist in the data-acquisition process, and also keeps a running record of satellite data such as timing, attitude, and sensor-house-keeping data, for later incorporation in the pre-processing phase of data handling. It provides (or designs) verification checks for incorporation in the data-acquisition and the pre-processing phases, to ensure that communications and sensor equipment is functioning properly.

4.1.2 Data Acquisition

Data acquisition provides an entry to the data-handling system from the ground-based receiving equipment. It provides for preparation of data

FUNCTIONAL BLOCK DIAGRAM

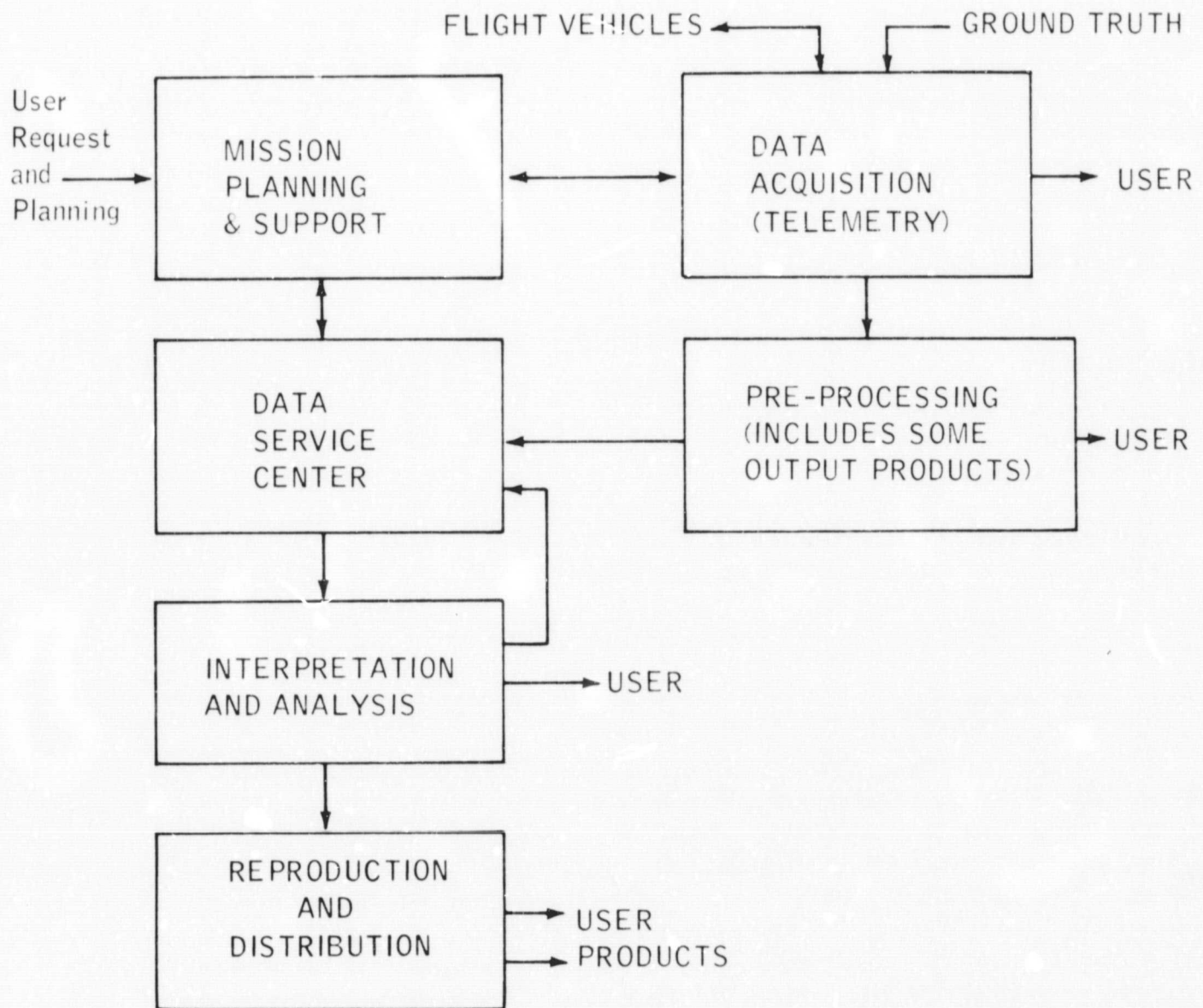


FIGURE 8.4.1 Block diagram of data-handling functions.

in a form suitable for entry and pre-processing, and also provides for both alarm and routine communications with Mission Planning and Support. The data-acquisition function provides for high-priority separation of time-perishable data, where required. Its most common output will be tapes for subsequent processing. Data acquisition must also provide a direct output to users who desire the raw data.

4. 1. 3 Pre-Processing

The pre-processing function provides standard processing of data for standard entry to the archives, and for delivery to the interpretation and analysis phase. As such, it includes input of analog and digital data and output of analog data in magnetic-tape, hard-copy-image, and graphic form, and output of digital data in tape, tabular, and graphic form. Pre-processing provides the functions of data conversion, editing, registry, and posting (for example, entry of data blocks on output image film). It provides a screening function for evaluation and verification of the converted data. Pre-processing also provides a direct output to users, or to the interpretation and analysis phase.

4. 1. 4 Data-Service Center

The Data-Service Center provides the archival function for the data-handling system. It provides files, indexes, and search techniques for the storage and retrieval of analog tapes, digital tapes, film, and other stored media. It provides output in the form of tape, film, index printouts, and catalogs of available data. The Data-Service Center is responsible for setting standards for the filing, gathering, and exchange of data--a key element in cross-disciplinary and broad user access to the data, and in the future utility and growth of the data-handling system. This function provides both standard output products, such as catalogs, and response to special search requests.

4. 1. 5 Interpretation and Analysis

The interpretation and analysis function converts data into useful user information. It will provide future-generation interpreter-assisted aids, and automatic interpretation techniques. In order to facilitate early experimentation with such techniques, the first-generation system provides advanced display capabilities and ready access to equipment.

4. 1. 6 Reproduction and Distribution

The reproduction and distribution function produces the multiple copies of data required and furnishes the distribution network for the dissemination of the user products.

4. 2 Existing Systems

Appendix B gives a summary of existing systems that have been sized in our review. These have included a review of ESSA, Weather Bureau and Satellite Center, Mapping, Charting, and Geodesy, and NASA Goddard Space Flight Center.

These reviews identified a number of the capabilities and problems that must be faced by the first- and second-generation data-handling systems, and furnished "existence proofs" in a substantial number of cases.

4.3 Centralization-Decentralization

This Panel spent substantial time and effort in attempting to determine the degree to which centralization is a necessary consequence of the data-handling functions. We concluded that, while a number of key functions must be central, or centrally directed, the number of choices for putting the system together is great. We further concluded that, with the rapid progress in data-communications and computer technologies, and with the necessary decentralization of some functions, complete centralization was quite unlikely.

The functions that require or benefit strongly from central location include mission planning and control, archives, a distribution interface for centrally located data, some common services, R&D planning and coordination, systems planning and standards. In the case of mission planning and control, it is fairly obvious that a unified, central control point must be in charge of the data-taking process on the satellites, and of the verification of that process. Archives should be centralized, in our judgment, to efficiently provide a single source for users from many disciplines and agencies. This does not preclude these users having localized files of their own. Where entry of data is to a single point, it is also obvious that a central distribution interface will exist. Where it is economical for major users to provide independent collection facilities, this interface could be bypassed, of course.

We envision the development of some common services to a multiplicity of users, where (1) the same data are to be processed in different forms for different users or (2) the same or different data are to be processed in the same manner for different users; or where (3) economies of scale will be provided by central location.

R&D planning and coordination and systems planning must necessarily be central, particularly where the R&D is closest to operational test, and as the system planning evolves to design phases.

Finally, the setting of both system and data standards is an essential element in the operation of a multi-user system. It must be centrally managed.

On the other hand, the elements that naturally promote decentralization include the need for diversified test sites, the availability of R&D talent, the needs for education of future talent, the availability of interpreters with specialized local knowledge, and the possibilities for close interaction with the users. Also, certain groups have officially assigned areas of responsibility that they would find difficult to centralize with others. Moreover, independent sources of funding may stipulate separate facilities. Each of these considerations provides a strong argument for noncentralization of the total data-handling function; collectively they provide an argument for regional centers of some sort. We have not tried to size those centers in this report.*

4.4 First-Generation System

This system should handle roughly EROS (see Panel Reports on Forestry-Agriculture-Geography, Geology, and others), GLU, and the

*Some discussion of this issue is contained in reference 43, Appendix D.

satellite in GEROS and other systems. It should satisfy the initial needs of Hydrology, Forestry-Agriculture-Geography, and Geology, and, together with suitable infrared sensors in the ESSA program (Nimbus and other satellites), should meet the needs of Oceanography. It is assumed that the existing and planned ESSA program will continue to meet the Meteorological needs. One of the satellites in the first-generation system could be placed to obtain low-sun-angle imagery, thus meeting this requirement of Geology. It should be realized that the discussion below is meant to be illustrative of the possibilities and time scales that are feasible, rather than outlining the only way to solve the identified problems.

4. 4. 1 Data-Handling System

We will define below the elements of a first-generation system for data handling. The assumption is that data may need to be handled in original film form, video, and as relayed data from ground-based sensors. The system functions for each of these forms of data will be discussed separately, although in operation all forms may be in the system simultaneously.

As was discussed earlier, we assume that there will be a central location in the first-generation system which is charged with certain necessarily centralized functions. Mission planning is clearly one of these functions, as are mission control, files and archives, production planning, standards and specifications, and overall R&D planning.

An essential element of the first-generation data-handling system is the provision for experimental use of significant data-handling facilities; although that capability, or parts of it, might also be provided outside the center, we feel that a critical-size capability is necessary in at least one location to promote experimental work to improve the system and develop new applications. We concluded that location of that capability at the archival and control center would provide significant advantages in economy and access to data.

For discussion purposes, the first-generation system is broken down as follows:

- I. Satellite Film
- II. Satellite Imagery
- III. Satellite Relay of Ground-Based Sensor Data
- IV. Aircraft Film
- V. Aircraft Imagery and Sensor Data
- VI. Ground-Truth Data
- VII. Research and Development (R&D)

For this first system I, II, and III are discussed below. We assume that IV is handled by regional organizations - possibly with an index to data maintained in the Center - and with the Center setting standards and specifications for its collection. V is assumed to be part of the R&D program, and VI is handled for pilot operations by agencies, as with IV, except for R&D ground-truth data. VII (R&D) is discussed for both first- and second-generation systems in Section 6. 0.

4. 4. 1. 1 Satellite Film, with Capsule Return

Roll Film Black & White Color Infrared Color	} <u>Input:</u> 10-20 thousand exposures
9" x 9" prints and transparencies Black & White Color False Color	} <u>Output:</u> Rectification (if needed) and reproduction of input
Mission Planning and Support:	{ Satellite ephemeris Satellite attitude Satellite housekeeping data Satellite timing Satellite command Mission plan from user requirements Mission control
Data Acquisition:	{ Capsule recovery Satellite data recording on tape
Pre-Processing:	{ Film processing Rectification, if needed Data block recording
Data Service Center:	{ Index film File film Provide search data Index and file satellite data, mission data
Interpretation and Analysis:	{ Agencies and other major user groups provide interpretation. Enhancement techniques
Reproduction and Distribution:	{ Film negatives provided to agencies and other major users; these users further reproduce for distribution in their organizations. Individual users have access by request.

4. 4. 1. 2 Satellite Imagery, with Relay to Ground Station

Input

{
Return Beam Vidicons--three wavelength bands,
Analog Data Rates--5 megahertz
Two ground stations, minimum
Satellite includes two tape recorders with 200-300 hr life.
Entry to data system is analog tape.
Potential volume equivalent to 100,000-200,000 images/yr.

<u>Output</u>	{ Pilot operational: <ul style="list-style-type: none"> { Hard-copy images in black and white or color { Volume: 50-100 thousand B & W/yr { 15-30 thousand color/yr
	{ R&D and special products <ul style="list-style-type: none"> { Analog tapes { Digital tapes { Film { It is expected that these users will require a small volume of data.
Mission Planning and Support:	{ Satellite ephemeris { Satellite attitude { Satellite housekeeping data { Satellite timing { Satellite command { Mission plan from user requirements { Mission control and schedule { Special data request entry
Data Acquisition:	{ Ground stations prepare* analog tapes for video and digital tapes for satellite data. Ship to center
Pre-Processing:	{ Analog tape to film conversion { Analog tape to digital tape (small volume) { Data-block generation { Film-processing functions including overlap, rectification as needed { Screen film for quality, coverage--and record
Data-Service Center:	{ File and index analog tapes { File and index film { File and index digital tapes { Process search requests { Provide index catalog { Provide output from file for operational use and R&D
Interpretation and Analysis:	{ Pilot Operational: existing agencies and major users { R&D: capability and advanced display
Reproduction and Distribution:	{ Distribution: existing agencies { Reproduction: volume assumed is of order of 10 copies per original

*Exceptional cases, where it was desired to view imagery immediately, would be handled by having a video-film recorder and a skilled interpreter at the ground station and, possibly, special display equipment. Location of the Center at the ground station, of course, makes this unnecessary.

4. 4. 1. 3 Satellite Relay of Ground-Based Sensor Data

Input	{ Either ground station or direct satellite to center Digital recording on tape Volume ~ 40,000 messages per day
Output	{ Pull off high-priority data Tape output otherwise Searches, tabulations
Mission Planning and Support:	{ Satellite data Satellite comman. /control Mission plan from user requirements Mission control and assurance
Data Acquisition:	{ Ground stations Data relay Tape generation
Pre-Processing:	{ Edit tapes Prepare operating tapes Prepare tables
Data-Service Center:	{ Index and store tapes Index and store maps Provide searches Provide index tables
Interpretation and Analysis:	{ Operational: Agencies get tapes R&D: Primarily sensor-oriented
Reproduction and Distribution:	{ Tapes to agencies Data relay

4. 4. 2 Sizing of Data-Service Center

In considering input data in the form of I-film, II-imagery, and III-relay of ground-based sensor data, we concluded that the systems might obtain data of Form I, would obtain data of Form II, and probably would obtain data of Form III. We consequently were led to a complex of equipment large enough to handle II, after which the requirements for handling I and III were relatively simple.

Again, there are a number of choices for handling this data processing. On an interim basis one could utilize the separate facilities of a number of different organizations and make do for the early stages of the system. This is not a good solution once the satellites are flying and producing data on a regular basis; nor does it remove the requirement, at that time, of a heavy load of dedicated system time. A dedicated Center was consequently assumed for this job.

DATA SERVICE CENTER HARDWARE AND SOFTWARE

<u>Hardware*</u>	<u>Software</u>
Receiving equipment**	Indexing
Analog video recorders (8)	Tracking
Tape recorders (8)	
Video-film recorders (3)	Distribution
Analog/digital; digital/analog conversion	Mission planning; required for R&D and special products
Computer complex (full complement of equipment)	Mission validation
Archives: films; tape	File handling; search
Film processors	Data-block generation
Film reproducers	Film handling
Display (highlighted because of its likely expense)	Table generation
Voice grade links (to ground stations for control and low-data-rate purposes)	
Facilities	

*We estimate hardware costs of the order of \$1.5 million to \$2.0 million per year. This does not include people, consumables, or software costs. The estimates are, of course, only rough general estimates and do not contain the detail required for substantive budget planning.

**We have not included receiving equipment as part of the Center, but have included the recording and distribution equipment. One of the possible choices is to locate the Center at a receiving-station site. We assumed this to be the case for the satellite-relayed distributed sensor data. The choice is not necessary on economic grounds, for the image data, until timeliness of the data required wide-band facilities.

4.4.3 Standards

Early in the first-generation system it will be important to begin to define the standards to be used in the collection, storage, retrieval, and processing of the data. Much experience exists throughout government agencies in the standards for data in image and electronic form. Early decisions should not preclude evolutionary adoption of increasing standardization in order to maximize cross-referenced use of data, nor should those early decisions needlessly hamstring early experimentation.

4. 4. 4 Displays and R&D Equipment

It is assumed by the Panel that extensive equipment and support facilities for R&D experimentation will be made available in the first-generation system. As a consequence, expenditures for advanced display capabilities will be required in order that R&D experimenters can rapidly view the output, in various forms, of their experimental machine programs and so that the experimenter can, with the computing equipment, begin to learn methods for automatic and semiautomatic interpretation of the image data. No less important is the need for a powerful and flexible facility for computation, analog-to-digital conversion for digital signal-processing, flexible film-processing and enhancement capabilities, and programming support.

4. 4. 5 Archives

The first-generation system is the start of what can become a most important center of information generation and exchange; it is, therefore, necessary to begin the preparation of archives plus provision for ready access to data and information. As a consequence, at the beginning of operations, we envisioned all the original data being archived with, or as part of, such a center. This archival storage should, so far as possible, include tape, film, and other records for future research. We do not recommend that all earth-resources data be considered for storage in such a center. In fact, we believe it can be shown that this is impractical and inefficient. However, the system should be designed in such a way that indexes to the other earth-resources data—which might provide benefits in the interpretation of remote-sensed earth-resources data—could be subsequently incorporated into the archives.

4. 4. 6 Digital versus Analog Data

We have assumed that most of the distributed data would be in film-analog form. However, the experience obtained in the ATS and other ESSA-NASA programs shows that significant advantages can be gained from the digitizing of the analog data obtained from vidicons and mechanical scanners. Such form of the data allows one to correct and transform them in numerous ways. Our judgment, consequently, is that analog-digital conversion must be provided for R&D and special users. The special users would include those for whom conventional film-processing could not provide the degree of image correction or enhancement required.

In the early stages of the first-generation system we do not envision that more than a small fraction of the imagery will require such conversion. Because of processing costs, the conversion of data to digital form, and subsequent automatic interpretation or correction, will require attention to special equipment and special techniques, if it is subsequently to be done as a regular, comprehensive service. It is not clear that such treatment of all the data would ever be needed.

4.5 Second-Generation System

4.5.1 General

There is no doubt that significant further reductions in digital-computer computation cost/operation, very significant increases in digital-tape storage capacity/unit area, and a vastly enlarged display and display-interaction capability will occur over the next 10 years. These increases in data and image-handling capability will make it possible to do extremely useful image-processing jobs in digital form and at useful rates of production, if thoughtful use is made of the capabilities available.

As we see the potential future for image-data handling, it will consist of an evolution from the first-generation data system, which utilizes analog image-processing and hard-copy imagery for most interpretive operations, to a second-generation system with continued use of hard-copy imagery for interpretive scanning and with digital-processing operations for classification, sampling in detail, and for man-machine examination of particular detailed situations.

4.5.2 Pacing Elements

We do not view the development of new computer, display, or hard-copy hardware as the pacing element in this evolution (although it is certainly tempting to invent new devices that would appear to provide useful solutions to selected problems). In these areas it is more likely the availability of money to buy state-of-the-(then) art - supplemented by a few special devices - that will determine their availability to the program. To avoid misunderstanding, we point out that the equipment will not be cheap, and the facilities, collectively, would be the leading civilian image-processing center in the world, with one of the major computer complexes. We do, however, conclude that other elements of the program are pacing elements:

1. The present research and development program to provide timely development of techniques based upon sound application-research programs is inadequate in both magnitude and coordination. It consists far too heavily of scattered and poorly planned "shots" at opportune objectives. The thoughtful programs are inadequately funded, equipped, and staffed.
2. An auxiliary part of this R&D program is the development of special equipment, such as reliable, reproducible standard sensor packages, and the provision of supporting data and image-processing equipment and staff. But this equipment is just that - supporting- while the main objective must be a broad R&D program that provides, as its planned output, working, proven, and practical techniques for classification, enhancement, and measurement of natural-resource parameters of importance.
3. An additional element of the R&D program is ground truth. This data input, one of the most neglected aspects of the program to date, is an essential ingredient of a scientifically sound program. These data are expensive, and the costs will be a significant element of the program.

We conclude that a significant, coordinated, R&D program organized according to priorities is the pacing element to the realization of the potential of earth-resources remote sensing. Without such a program and the will to realize its benefits, remote-sensing outputs will remain just another supplementary aid to the classical interpreter. As such, they may pay their way, but they are not likely to provide profound changes in the understanding or management of resources.

4.5.3 A Possible Second-Generation System Configuration

Imaging

Mission Planning and Support	As before*, but with a far greater role in planning and coordination
Data Acquisition	As before*, with greater bandwidth
Pre-Processing	Analog tapes Selected digital tapes Imagery Some automatic screening
Data-Service Center	Vastly expanded in the range of indexes to storage--includes ground truth, other interpretive and predictive data (e. g. , weather forecast)
Interpretation and Analysis	Greatly changed through addition of on-line display and interpretive aids, automatic interpretive techniques for measurement of signature areas and changes over time sequence - a flexible, operational facility for new natural-resources interpreter and scientist.
Reproduction and Distribution	Still a high volume of imagery to agencies Visual aids generated Summary data Provision for analog and digital tapes Some operational agency work performed in the Center or one of its satellites
Remote Use of the Center	The interpretation, analysis, and distribution problems can be greatly affected by the existence of time-shared terminals to the Data-Service Center from remote users. Data, including video data, can be made available to analysts at their home locations.

*First-generation system

4.5.4 Predictions and Assumptions

1. Satellite Data from Ground-Based Sensors

We expect a significant increase in the number of sensors and in the worldwide use of such data.

2. Entry Points

We assume that the second-generation data system will have data entering the system from satellite imaging, ground-based sensors, and ground-truth sites. We assume no film input from either aircraft or satellites will be required, although handling such data would not be a heavy burden.

3. Data-Service Center Hardware: Costs and R&D Facilities

Estimated costs, not including R&D -- \$20 million/yr. for equipment, manpower, and supplies. We have estimated that the Center should be in operation at this level within 10 years.

4.5.5 Design Considerations

The evolutionary development we are proposing should give adequate time for the second-generation system to be designed with care. The following considerations are important for development of the design.

The major underlying philosophy for the second-generation system should be a concern for the development of high-quality service. The quality of the overall service should not be degraded by limiting the data-acquisition system to current practices in measurement techniques, network design, and data-handling procedures. The main emphasis in design should be placed on the potential for changing these practices to achieve higher-quality support.

A high degree of automation for the 1978 implementation is a proposed goal. It is desirable and feasible, both technically and economically. The principal requirements for attaining automation are:

1. Resolution of any conflicts between sensor design, parameter definition, and standard practice
2. Refinement of the definition of requirements for the various regional programs
3. Development of initial designs for all interfacing subsystems

The development of the design of the second-generation system can be based on the following three major elements:

1. Scientific element - includes identification of the scientific objectives of the system in the broadest sense. It also includes the selection of times (discrete or otherwise) and of sampling points that will satisfy the objectives to an acceptable degree.

2. Technical element - consists of the observing or sensing techniques to be used in providing the anticipated measurements.

3. Service element - may be called the procedural, data-handling, or operational element. It involves all the activity between the sensor and the interface with the users, including data processing, display, quality control, and organization.

Based on these design elements, tradeoff analysis should eventually be undertaken. The general order for tradeoff analysis can be to:

1. Develop a reasonable set of scientific objectives for the deliverable products, including a set of parameter-sensing points, and frequency of delivery.

2. Specify the techniques and classes of equipment to be used for deriving the parameter set.

3. Specify the service concepts of the design that will deliver the product effectively and efficiently.

The general methods and many of the data-flow alternatives are shown in Figures 8.4.2, 8.4.3, and 8.4.4. The purpose of the procedures outlined in Figure 8.4.2 is to enable management to make decisions concerning the implementation phase of the study and the future of the data-acquisition program. They help define more clearly the costs and benefits of likely alternatives in making decisions. A primary concern is to identify major data-acquisition problems, provide alternative solutions, evaluate costs and benefits related to each alternative, and determine which configurations are most appropriate to potential goals of the decision-maker.

Several key decision steps are necessary to arrive at a detailed description of all network locations to be incorporated in the evolving data system. Each succeeding decision level depends upon preceding decisions, and unless some simplifying assumptions are made, the number of potential configurations becomes astronomical.

The first step in accomplishing this objective is to determine user requirements. But in a very real sense, defining user requirements implicitly fixes the station density, the types of parameters to be measured, and the frequency of measurement. Determining requirements must be considered an iterative process. One approach to the design could be by identifying parameters that can be measured. Included in this step should be an estimate of parameter density/accuracy and frequency of observation.

The next step, primarily a definition of the first-generation system, would be to identify a baseline of activity against which to measure proposed new systems. Parallel to this step, an effort can be made to decide which observational techniques should be used to provide a given set of data. Also, alternative configurations of each of the networks within the subsystem can be postulated.

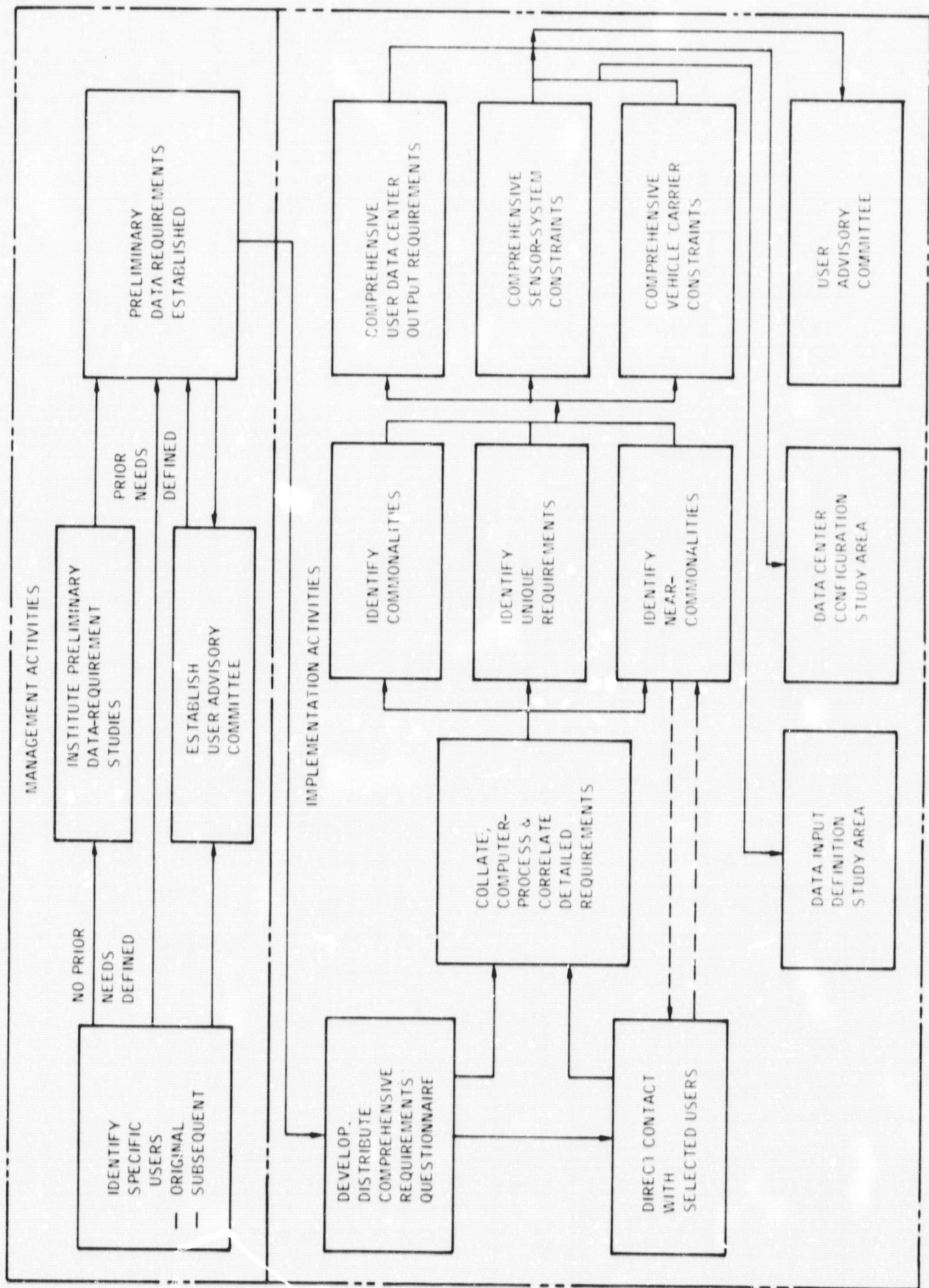


FIGURE 8.4.2 Suggested procedure for determining user requirements.

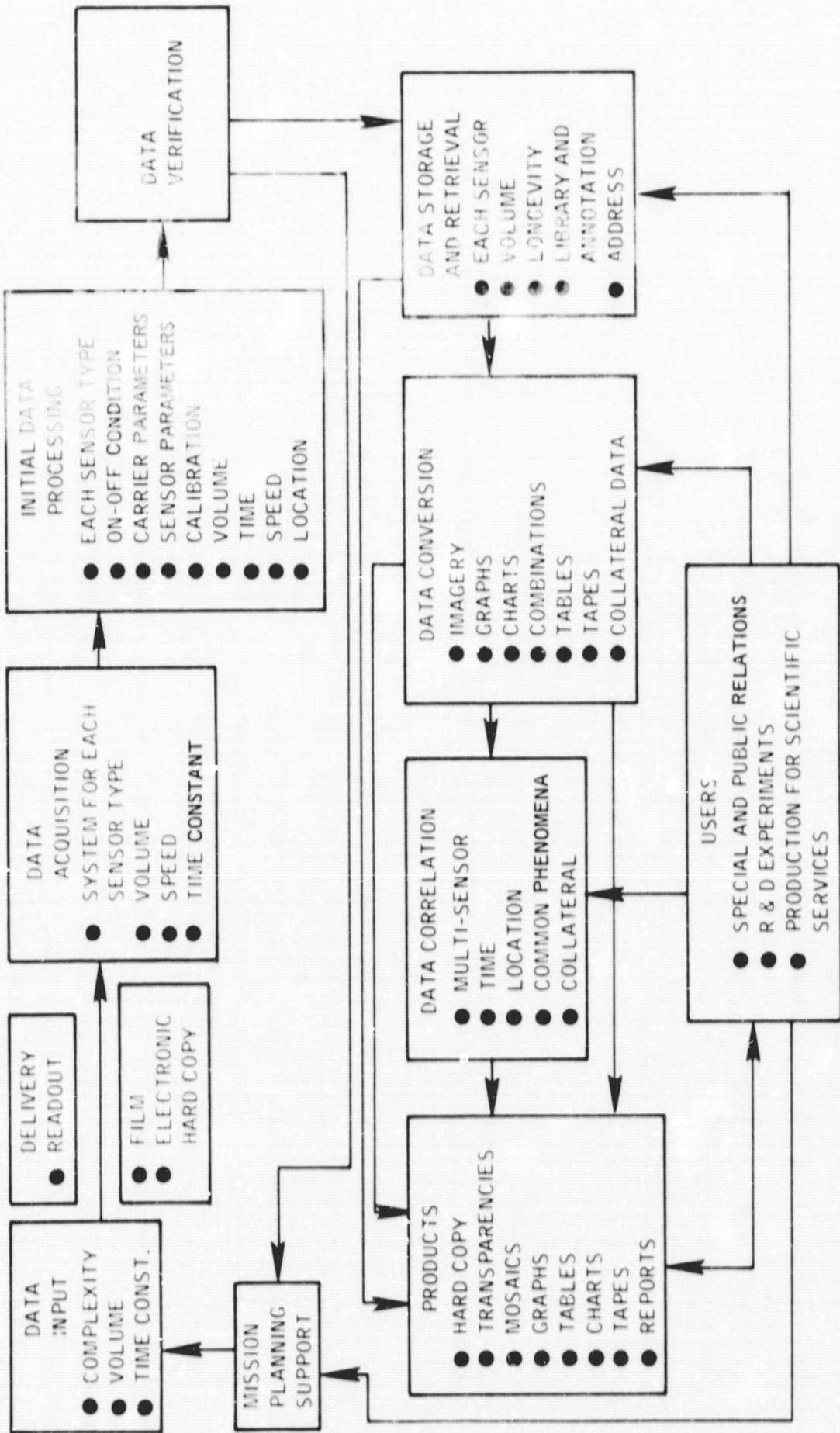


FIGURE 8.4.3 "Road-map" for the complete systems design of second-generation system.

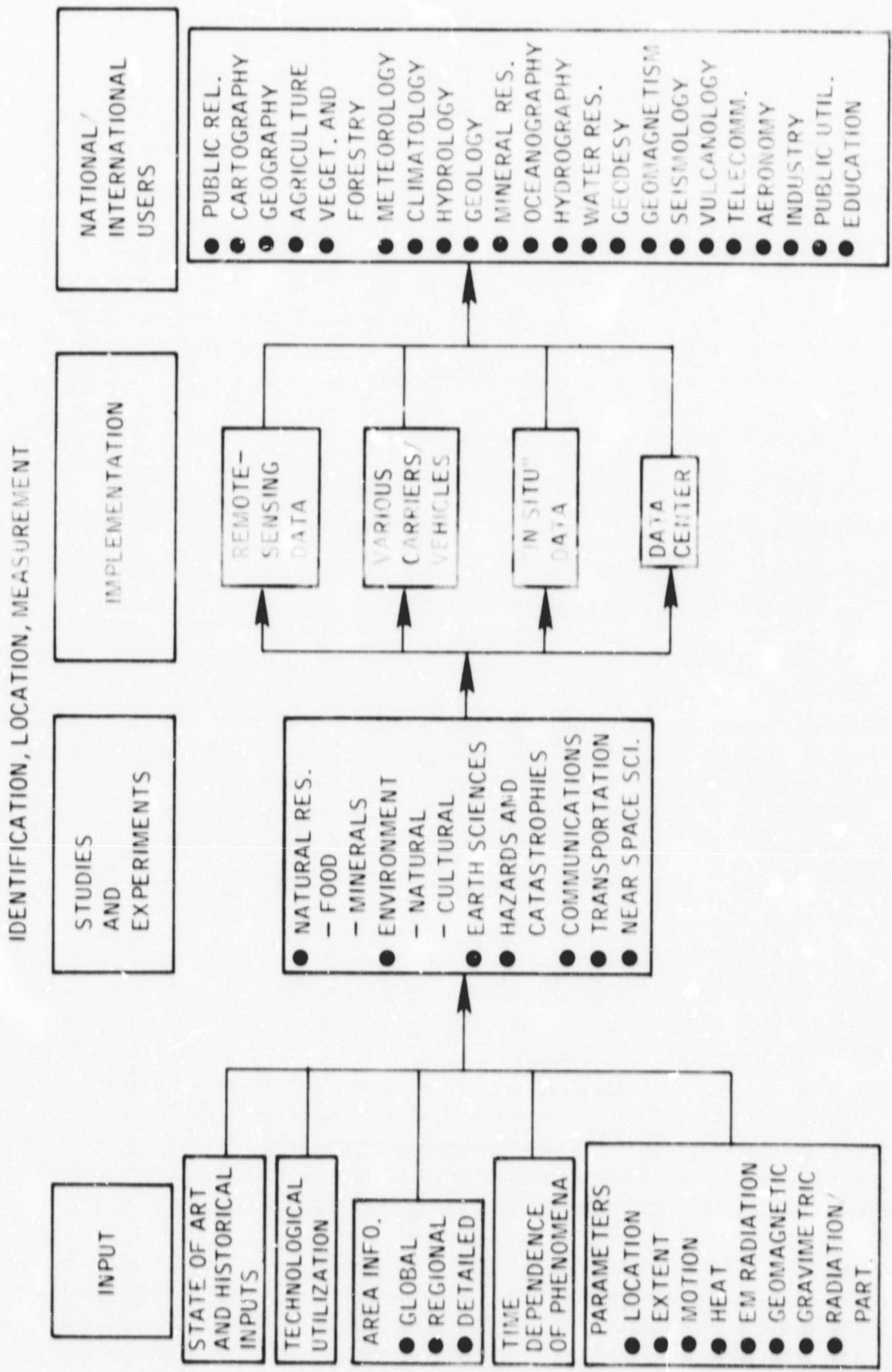


FIGURE 8.4.4 An example of the development of data flow from input to users.

The remaining steps are primarily analytical in nature, and include analysis of alternatives, analysis of tradeoffs, and conclusions and recommendations.

4.5.6 Evaluation of Alternative Plans

Subjective factors for evaluating a system can be discussed from a number of viewpoints, such as performance or effectiveness and benefits. To be useful, however, they must be eventually related to the function of the systems being evaluated. In this case, the system will be serving many user groups. It is thus important that the subjective criteria be related to the user. This suggests using "user satisfaction" as a vector, with components from a portion or all of the other subjective criteria.

For any type of information provided by the major input networks, a subjective measurement for alternative network designs can be defined by addressing the following basic questions.

1. Who wants the information?
2. How will they use the information?
3. How and where must the information be provided?
4. What consequences result if the information is not received in the prescribed manner?

Because of the varied demands of a large and complex set of user groups, a dilemma arises in attempting to derive singular answers for each of the questions. A simple method of resolving the dilemma is by compromise; however, to compromise by designing a network to meet the requirements of all users equally increases the cost to impractical limits. Another method of achieving a solution is to assign priorities to the different user groups. A potential pitfall in this approach is that it causes fixed objectives for the overall system, while only a portion of one subsystem is being studied.

Since the system will be concerned with a number of basic types of observations, one solution might be to have each type of observation network oriented toward the degree of emphasis placed on it by the requirements of a particular user group. From this viewpoint, there is a set of goal-oriented alternatives for each type of network. A combination of networks that includes the specific objective from each type of network forms the basis for an integrated network, which can be goal-oriented by management emphasis of a particular component network. Figure 8.4.5 shows an example of data flow in which the perishability of the data is the criterion.

The capacity of any system design to meet ever-changing inputs, procedures, technological developments, and output characteristics is perhaps the most important of the subjective criteria. A well-conceived design should not be outdated before it can be implemented. Unfortunately there are many more questions than answers in this area.

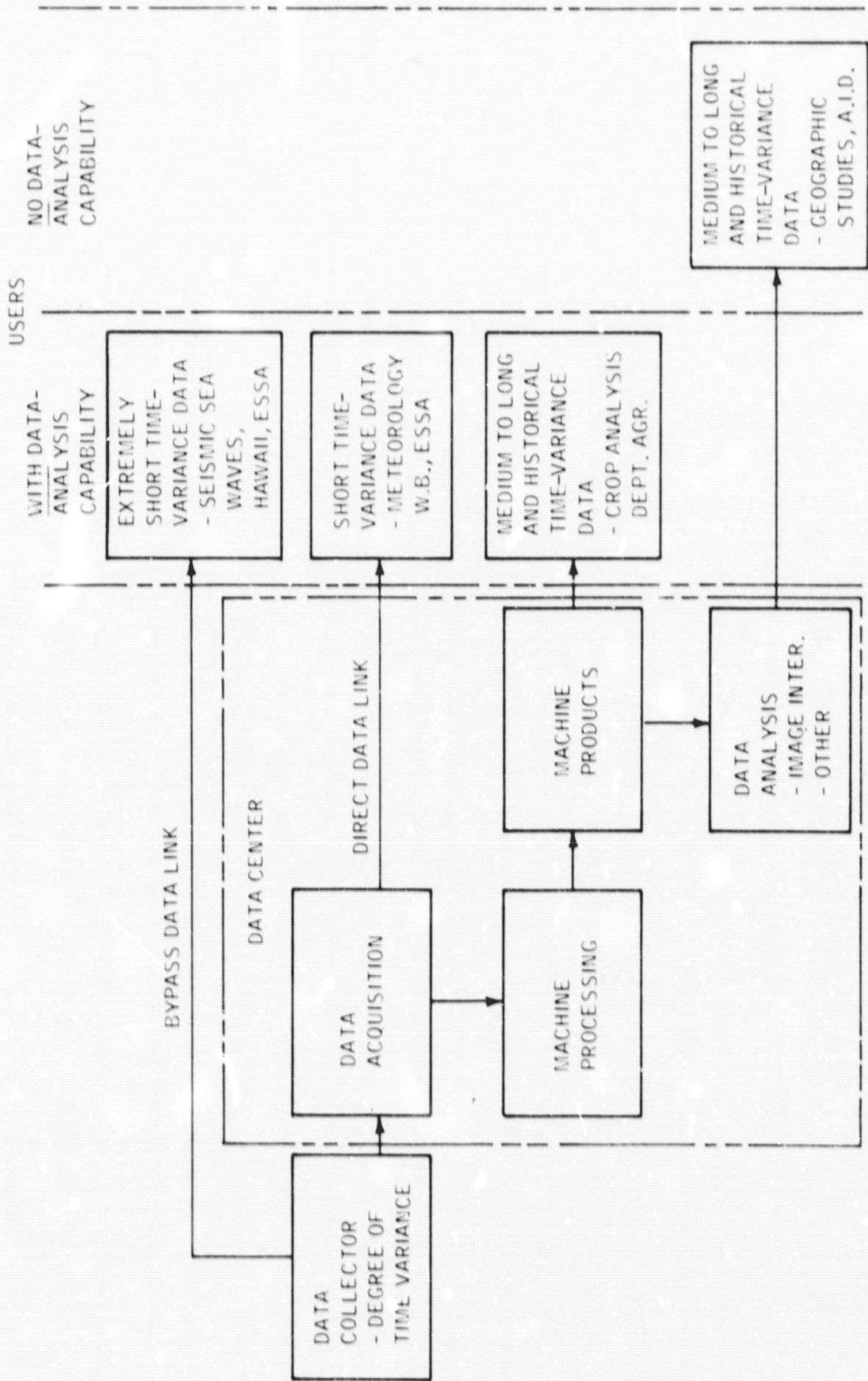


FIGURE 8.4.5 An example of data flow through the Data Center, with emphasis on the perishability of the data.

5.0 TRENDS IN DATA-PROCESSING EQUIPMENT

One of the main factors favoring an evolutionary approach comes from the continual development of new equipment. This is equally true in data processing and the development of new sensors and spacecraft.

A curve representing the speeds of large computers relative to the years in which they became available shows an exponential growth in speed from the UNIVAC I in 1951 until the 360 Mod 91 in 1967. The trend has called for a factor of 10 in raw computing speed every 5 or 6 years. A new computer on this trend-line has appeared every 3 or 4 years. During the same period the cost of large computer systems has gone up continuously, but at a much lower rate than that of raw performance. The net result has been a considerably improved performance-to-cost ratio.

One can make similar analyses of computer characteristics, such as reliability, and physical parameters such as physical size, and storage size. They all show the steady improvement of a new, growing field. A leveling-off has been predicted almost every year, but there is no real evidence that the rates of improvement will change much for the next 8 to 10 years. These comments apply best to the larger, general-purpose processors. Different rules may apply to smaller, special-purpose computers, which are built under greater constraints.

In addition to raw computing speed, the most significant trends in data processing are probably (1) the continuing improvement in storage devices, and (2) the development of communications-based, multi-access systems. All these trends can be very important to the evolution of data-handling systems.

The use of communications-based data processing can make much of the Data Centers' computing power available at remote locations. Similarly, it can make data stored at remote locations available at the central facility, upon request. This concept of time-shared terminals (including video) alone could easily dominate the future evolution of the data-handling system.

The following table gives some estimated figures concerning computer speeds and storage, both at the present time and at the time of the second-generation data system. These industry trends are illustrated in the following table and figures.*

*Figures 8.5.2 and 8.5.4 are reprinted with permission from DATAMATION, January (February), published and copyrighted 1968 by F.D. Thompson Publications, Inc., 35 Mason St., Greenwich, Conn. 06830.

Figure 8.5.3 is reprinted with permission from INTERNATIONAL SCIENCE & TECHNOLOGY, January, published and copyrighted 1965 by Conover-Mast Publications, Inc., 205 East 42nd Street, New York, N.Y. 10017.

TABLE 8.5.1

COMPUTER SIZE AND SPEED CHARACTERISTICS:
PRESENT VALUES AND ESTIMATED VALUES AT THE
TIME OF THE SECOND-GENERATION SYSTEM

Device	1968 Value		Estimated 1978 Value	
	Speed	Capacity	Speed	Capacity
Large Computer	8 million instructions per second	2 million 8-bit bytes internal core	700 million instructions per second	128 million 8-bit bytes
External Storage Devices				
Tape (standard 1/2")	32K bytes/sec	4M bytes	512K bytes/sec	64M bytes
Drum (1 head/track)	1.2M bytes/sec	4M to 12M bytes		32M bytes
Disk Pack	156K bytes/sec	100M bytes	> 4M bytes/sec	3×10^{12} bytes
Bulk Core	512K bytes/sec	4M bytes	>2M bytes/sec (effective)	>8M bytes
Archive Storage Devices				
Flexible Media Video Technology*	6M bits/sec	3×10^{12} bits	} >20M bits/sec	} > 10×10^{12} bits
Data Cell (Magnetic)	56K bytes/sec	800M bytes		
Data Store (photo digital)	500K bytes/sec	2.38×10^{12} bytes		
Laser Recording**	500K bytes/sec	245M bytes		

M = Million
K = Thousand

* Experimental - see Damron S. et al., AFIPS - 1968 Fall Joint Computer Conference, Vol. 33, part 2, p. 1381

** Experimental - see McFarland K. and M. Hashiguch, ibid, p. 1369

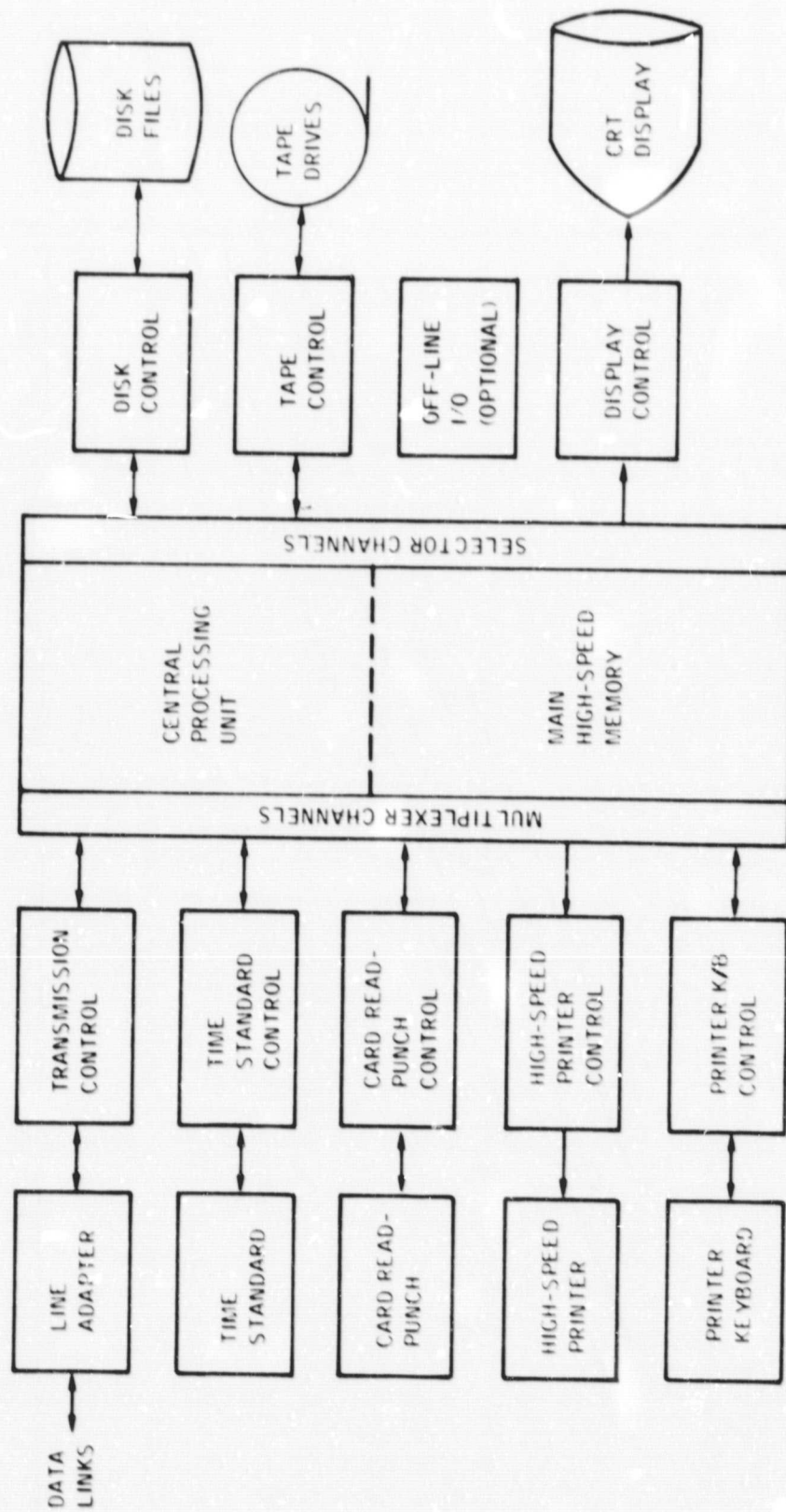


FIGURE 8.5.1 Diagram of a general-purpose computer.

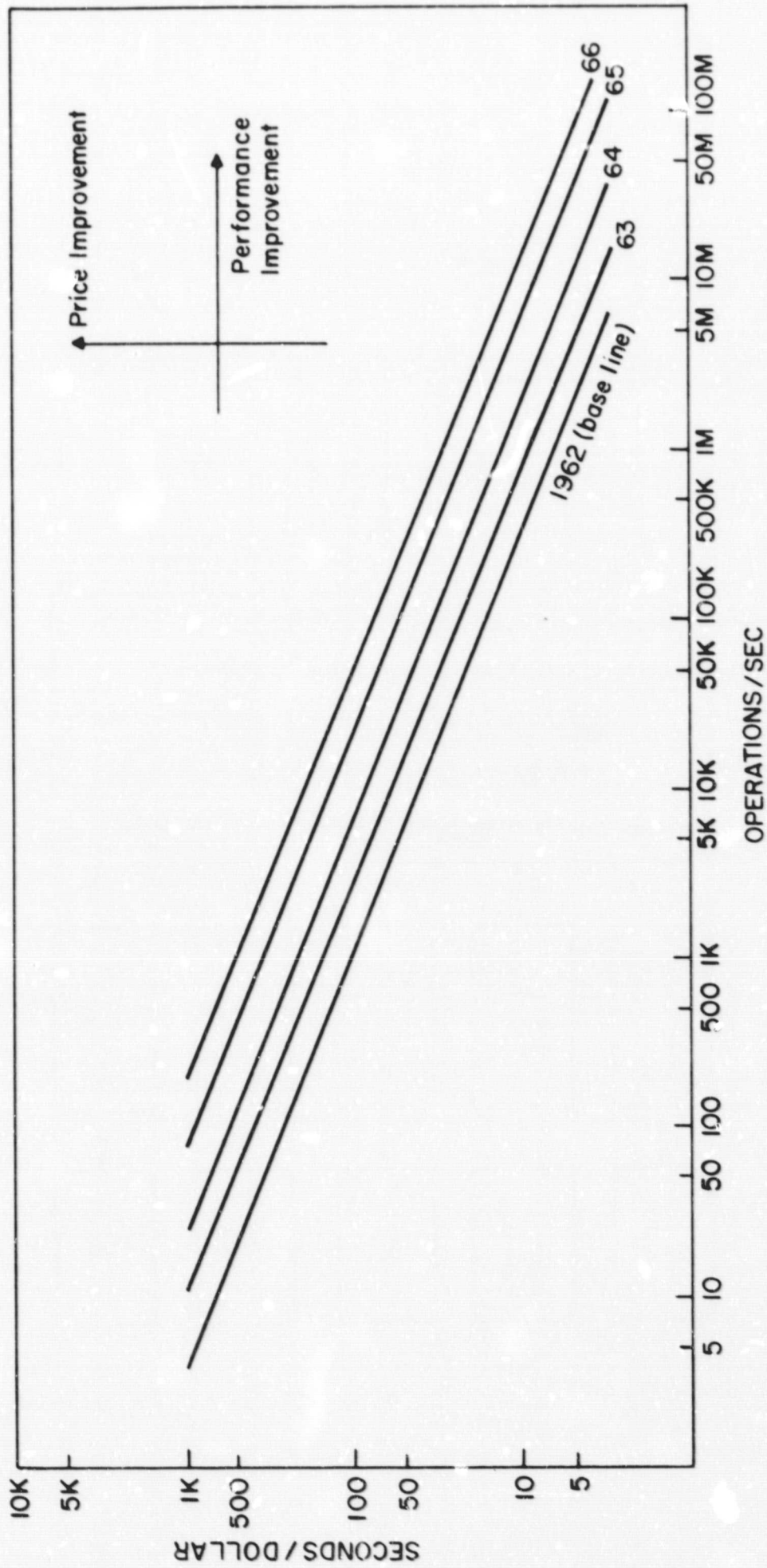


FIGURE 8.5.2 Observed cost-performance relationships of the entire scientific computer market as a function of time, showing the steady improvement in performance and reduction in price per operation.

Ref: Datamation, January 1968, K. E. Knight (reprinted by permission)

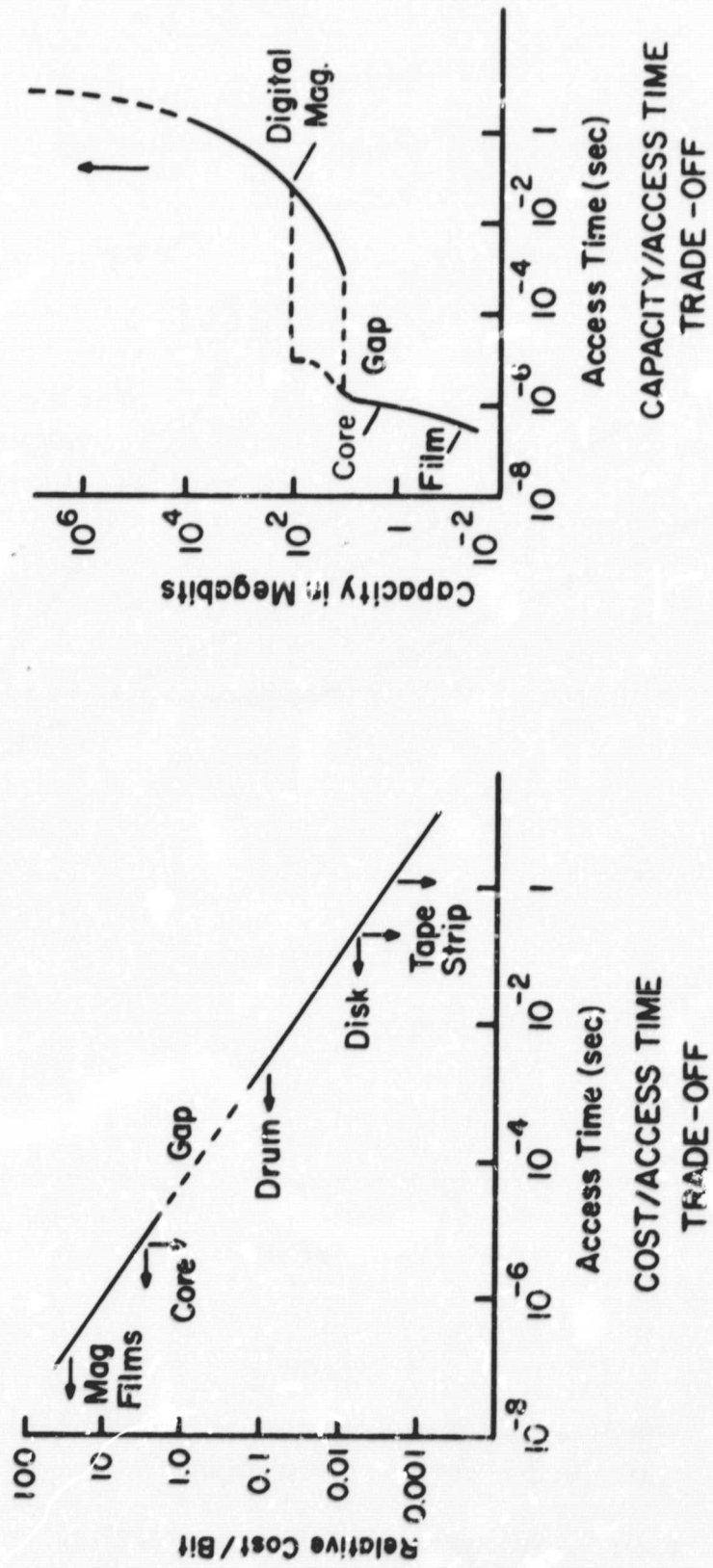


FIGURE 8.5.3 Characteristics of computer storages. Cost versus access time and capacity versus access time. (Arrows indicate trends.)

Ref: International Science & Technology, January 1965,
 A. S. Hoagland (reprinted by permission)

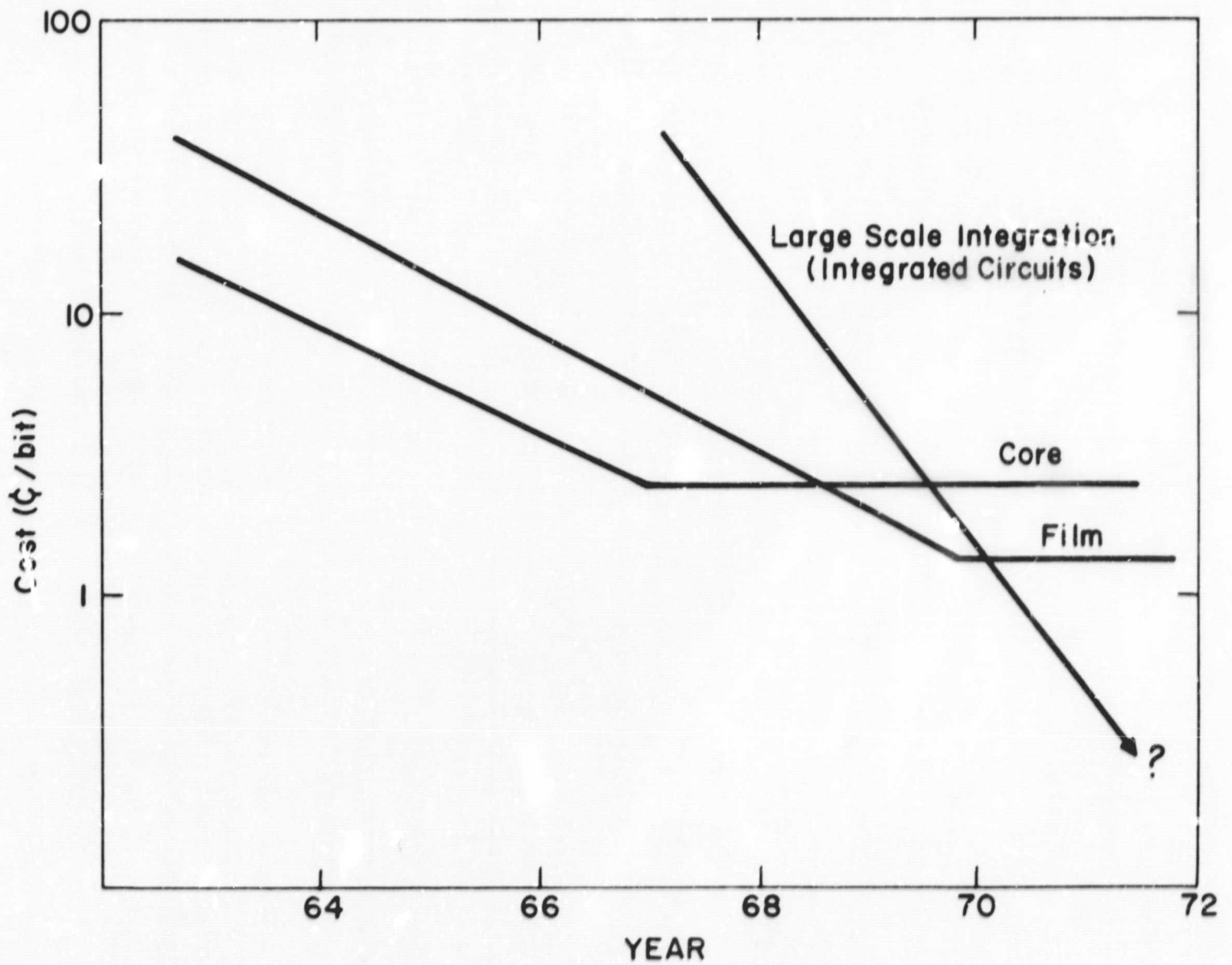


FIGURE 8.5.4 Projected comparison of costs per bit for various computer storage technologies versus time.

Ref: Datamation, February 1968, David Mayne
(reprinted by permission)

6.0 RESEARCH AND DEVELOPMENT PROGRAM

6.1 Application

The program of research and development discussed here includes the work which develops applicable techniques and new products for incorporation into the first- and second-generation data systems. As such, much of it is discussed in the Forestry-Agriculture-Geography Panel Report (Panel 1) and in other earth-resources panel reports. However, we will highlight here the elements of the total program that we feel to be the most significant.

6.1.1 Overall Coordination

The R&D program will include elements directed to development of sensors, platforms, and data-processing hardware. Those hardware developments must be guided by (and not become the reason for) the user needs and the evolving user-oriented R&D techniques and new-product program. We envision the R&D program as being under a management heavily oriented to extending R&D programs through to pilot-operational phases. This requires an integration of hardware, science, ground observations, and a test program under a management dedicated to demonstrating feasibility of new user techniques and products.

In addition to the stress we place on the centrally directed and more engineering-oriented program ("engineering" in the sense of carrying programs to pilot-operational phases, although the individuals involved in the program may be engineers and scientists of physical and biological science backgrounds), we anticipate a fairly broad-ranging exploratory scientific element in the R&D program. This part of the program provides opportunity for developing dramatic new understanding, highlighting potential new applications, and involving and training people in the university community.

6.1.2 Sensor Development

A strong need exists for standard, calibrated, dependable sensor tools for both flight and field tests. We have not concerned ourselves with the magnitude of this job, but restate its importance and the need for the development of these tools under the guidance of the scientific users.

6.1.3 Data Handling

Once again, and even more strongly than in the case of sensors, we believe that the prime requirement is not radically new tools, but rather a

fitting of the available and developing tools to the needs of the scientific user. We can see the need for special display equipment, high-speed analog-to-digital conversion, and possibly special processing capabilities (both analog and digital). The special equipments should not be an R&D end in themselves, but rather a service provided to the user. At the risk of saying it too often -- the hardware-oriented development work should be viewed as an underpinning to the main program of user-oriented R&D, not as the program.

6.1.4 Facilities

As we have discussed elsewhere, we assume at least one location where extensive experimental facilities for data handling (including access to ground truth) are available to the experimental R&D community. Both first- and second-generation data systems should have some portion of their personnel working on data-service improvements and the incorporation and development of new services. Examples include better methods for presenting data, data-reduction services, display programs, new exception reports, and so forth. The improvement of this service requires an understanding of user needs, and an interaction with the main R&D program.

6.1.5 The Main Program

As we see the R&D program, the heart of it involves the development of new user-oriented science and products. This is where the extensive ground-truth programs reside, where the work on sensor-signature research occurs, and where the test operational flights and data analysis provide a service. It will be necessary in this program to be sensitive to a balance between user products that can be developed quickly and those of a longer-range nature, particularly for the wise investment of manpower. Programs where the uncertainty in the development of useful new products is least - for example, where detection of snow or water provides the basis for measurement - should receive first attention of the development groups. High-risk areas, where scientific knowledge or empirical discrimination is least, should be tackled by small, exploratory efforts. These comments may appear obvious, but they need to be emphasized. Within those reservations, the time schedules and test programs noted in the Forestry-Agriculture-Geography Panel Report are quite reasonable.

6.1.6 Costs

Although somewhat outside the scope of this Panel, we judge that the "main program" would run about \$30-40 million per year, with a time scale for build-up to this level of about 5 years. Funds at this level would allow groups of about 50 professionals to focus on each of perhaps 10 major application areas, and to receive a significant amount of support from hardware and flight-test groups.

6.1.7 Educational Needs

The need to consider educational requirements is apparent throughout the Panel study. These requirements are listed on the following page.

1. Training of the presently available interpreters in agencies, such as Agriculture, in the use of imagery obtained from satellites in the first-generation system (This is probably the most urgent need, calling for strenuous and immediate efforts by agencies and universities.)

2. Training of the same community in the skills needed for interpretation of data obtained from unconventional sensors in aircraft, balloons, and other carriers (sensors other than conventional cameras with black and white or normal color film)

3. Exposure of members of the user communities, and in particular decision-makers, to the nature and value of remotely sensed data from space and aerial platforms

4. Education and training to partially meet the manpower needs by reeducation and evolutionary training of interpreters to prepare them for work with future generations of systems that will use more sophisticated sensors and data-processing techniques

5. Formal education programs within the academic community to produce, on longer time scales but with greater depth and strength in fundamentals, the skilled interpreters, scientists, managers, planners, and decision-makers needed for effective programs

Our conclusion is that this training must necessarily be a key part of the overall plan for development within the earth-resources remote-sensing program. Large parts, if not all, of this training and education program should be under the guidance or supervision of the organization responsible for the R&D program.

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7.0 INTERNATIONAL CONSIDERATIONS

The Panel spent appreciable time studying international considerations in order to determine their possible effects on alternative systems. They reviewed past history, considered the lessons to be learned, considered the effect international considerations would have on various systems, costs, and benefits to the United States. The World Weather Watch was reviewed. This effort is summarized in Appendix A.

8.0 PROBLEMS

8.1 Standards

We have assumed throughout that a data-processing system would provide output for a number of users, including users from diverse disciplines, users involved in various applications, and users requiring R&D access or special products. The utility of the system will be limited by the extent to which records can be kept, and can later be used, converted, summarized, and otherwise manipulated by this broad range of users. This requires that standards be established and maintained for the ways in which the data are obtained, processed, and placed in archives. Such standards must be established with respect to sensor instrumentation, to ensure the ability to repeat and extrapolate data obtained by different users. Standards in the archival handling of data will provide means for common search and classification. Finally, standards in the evaluation procedures - for example, the evaluation of classification techniques - will greatly aid development of improved procedures.

The manner in which these standards are established can have a great effect upon the system performance. Fortunately much experience already exists for the indexing and archive-management standards for the structuring of photographic-image files. Without doubt, however, one of the aims in the evolution of a useful data system is early attention to the development of useful standards.

8.2 Control

In a multidiscipline, multiapplication data system such as this, priority, scheduling, and verification of the mission is a key element. It requires establishing thoughtful allocation of the resources among users and designing for optimum utilization of those resources. The user, in turn, requires a method for determining what data are available in the system, so that he can react on the system to improve the utility of the data to his needs. The user-control-archive interface is a complex one, and will require thoughtful efforts, as noted in our previous discussion of the second-generation data system.

The R&D program presents a somewhat different problem of control. As we noted previously, this program is a key element in the evolution from first-generation to second-generation systems. Thus it must be planned as part of this evolution. This planning requires a setting of priorities among the various application areas. The incorporation of the output of R&D into the second-generation system requires that the development part of R&D be carried to a pilot-operational phase when it is clear that the solution really works in a

working environment. Such setting of priorities and pilot-operational extension of the R&D program will require central planning and management, in our judgment, if timely and effective programs are to be developed.

8.3 Education and Upgrading

Throughout the organizations utilizing the data - and particularly as new sensors and new forms of processing are introduced - there will be a need for education and upgrading. As discussed previously, these needs extend all the way from training the new Ph. D. to the matter of enhancing interpreter skills. This promotion of education and upgrading must be part of the R&D and data-center plans.

8.4 Who's in Charge?

This is a big question, for which there is no obvious answer. The Panel recommends that NASA be given this responsibility, since it is obvious that some organization must be in overall charge of data gathering and verification. The R&D and planning require overall direction. The options for assigning this responsibility are numerous. Our judgment, however, does not lead us to be sympathetic to a "committee approach." Rather we believe that clear authority should be established and responsibility fixed for the various elements of the program, at least those that clearly require central direction or collection of data.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

We are convinced that satellites with imaging sensors can be flown and can provide useful output data in the near future. We are further convinced that such early satellite systems can evolve to significantly more broadly useful systems through the incorporation of subsequent programs in sensors and data-handling technology.

We envision a program for earth resources that proceeds from relatively straightforward data-gathering and -processing functions, to a substantially improved system, over a period of 10 years. The first system would handle data in forms that major users are already prepared to interpret, while the second system would include provision of new products, some automatic interpretation, and completely new services based on new, not yet formalized working knowledge. The essential and pacing element in the transition from the first to the second system is an aggressive, well-managed R&D program.

The characteristics of that R&D program must include (a) a selection of the most important problems and priorities, (b) a dedicated effort to prove the feasibility of their solutions by the combined talents of scientists and engineers who carry the solution to a test-operational phase, and (c) the organization of these efforts around data-processing, ground-truth, and test-platform facilities. The R&D program must be evaluated in terms of its demonstrated and proven implementable programs. These programs will require a marriage of skills in earth-resources sciences for signature analysis (including temporal, spatial, and spectral signatures), data-analysis and -sensor skills, and experiment design.

9.2 Recommendations

1. We recommend that a satellite program to provide pictorial information be initiated immediately. This early implementation will provide a means to solve many of the future operational problems, and also provide much of the understanding required for future, more sophisticated systems.

2. We recommend that planning, with appropriate checkpoints, be initiated for the evolution of that early system to a substantially broader system, using more sophisticated sensors, over a period of the next 10 to 12 years. Responsibility for the planning and coordination is a critical consideration in this program; the responsibility should be assigned early and should be clearly defined. We envision that NASA will carry this responsibility.

3. We recommend that the R&D program for this evolutionary approach include substantial, focused efforts directed at carrying applications through

to the test-operational phase. These efforts are required to prove in new applications and techniques in a timely manner for incorporation into the evolving system. It is essential that these efforts be given priorities and be closely coordinated with the planning of that system.

4. The broad field of earth resources provides a rich potential for new understanding through, and uses for, the application of remote-sensing and data-handling techniques. Research in these areas is essential to the necessary education and training, and to very broad aspects of future systems. We recommend continuation and expansion of the present broad-scope research program.

APPENDIX A

INTERNATIONAL IMPLICATIONS

A. 1 The Promise

Just as, in the United States, the opportunities for remotely "seeing" the earth and for collecting data from it provide us with an opportunity better to understand our environment and use our resources, so also for countries outside the United States the vehicles we fly and the sensors that can be developed will provide broadly useful tools in the service of man. The ability to view large areas in substantial detail and to do this often and cheaply could provide the developing countries with the opportunity to utilize their limited resources better.

It would not be correct, however, to assume that these will be free benefits that come to all without effort, because of investment by the United States. The need for local ground truth that underlies the use of the data, and the accompanying need for skilled interpreters to relate ground truth to the data, of themselves rule out the sort of program in which a benefactor hands a country the solution of its problems. The remote-sensed data must be regarded as a tool that can be used in the skilled management of resources --both in this country and abroad. Even with free data, the investment in skilled resources is still required; and many of the applications remain to be developed and/or adapted to local environments.

The opportunity to view the earth in some detail also poses problems of the possible proprietary nature of the data collected. Every country may not necessarily agree to being observed--particularly if there is any implication whatever that the results of the observation may be prejudicial to national or personal interests. The gathering of data must be carefully handled, with the interests of all affected in mind, and with proper involvement and safeguards, if the gathering of data is to be acceptable.

Despite such problems and costs, however, the use of remote-sensed data clearly appears to usher in the start of a better way to do (parts of) the job of observation, planning, and management of natural resources. The potential applications in agriculture, forestry, geography, geology, hydrology, oceanography, meteorology, metropolitan and regional planning, and education promise benefits to all countries. Our problem then is to understand the opportunities and alternatives for international participation.

A. 2 Past History--Lessons to Be Learned

It is obvious, in assessing the potential for fruitful working relations between countries, that one ought to ask what has been successful in similar

situations in the past. We have long histories of international societies, worldwide scientific studies, bilateral scientific and technical programs, and joint development efforts, to mention just a few relevant experiences. Here we will address ourselves to an examination of just two programs, and the useful conclusions to which they lead one considering cooperative studies. Those programs are the Automatic Picture Transmission (APT) program of ESSA and the proposed U. S. bilateral programs for remote sensing of earth resources, between the United States and Brazil and the United States and Mexico.

A. 2. 1 The Automatic Picture Transmission Program (APT)

The Automatic Picture Transmission satellite program is described in greater detail elsewhere. Let us, however, note briefly that it transmits image data to earth continuously at a relatively low data rate. As a consequence, it is possible for cheap ground stations to be constructed, with standard costs running from \$5,000 to \$30,000, and with homemade devices substantially cheaper. These stations can put out images that show local cloud environments on a regular basis and are also rapidly provided with the minimum location information needed to identify image coordinates. The images are not as good as those that ESSA can provide and they are neither corrected nor provided with grid information. But they are produced locally and quickly for whatever use local users wish to make of them. The reception accorded the APT program has been so good (over 400 stations) that one now must be concerned with the problems of upgrading the system, since so many users and so much equipment are involved, representing a significant investment.

A. 2. 2 The Bilateral United States-Brazil-Mexico Programs

In brief summary, these are bilateral programs between Brazil and the United States and Mexico and the United States. In the program the United States is providing training in remote-sensing technique and the interim use of aircraft, while Mexico and Brazil are providing their own scientists; each country has access to the data and the ground truth. This allows the U. S. scientists to gain broader understanding of the application requirements and the utility and favorability of ground truth, while it gives Mexico and Brazil access to new techniques and experience in their use. The expectation is that ultimately both Mexico and Brazil will have their own aircraft in a continuing program. On the U. S. side, NASA and the Departments of Agriculture and Interior, have been involved in the proposed projects.

A. 2. 3 Lessons

These programs illustrate, each in its own way, a number of lessons that have been learned and applied in getting shared remote-sensed data projects going. It is our judgment that many of these lessons warrant consideration in each and every future attempt to set up such exchanges.

1. Entry costs. The APT program shows that, where a large number of interpreters are already in operation, a low-entry-cost device designed

to assist timely interpretation can be most successful. A dedicated effort to develop ways to bring useful results cheaply to local interpreters should always be considered. Beyond that, a continuous effort to provide additional information through essentially the same equipment also should be made (for example, relay of ATS images through the APT satellite). It is not obvious that a cheap-ground-station solution will always be the best. But technical ways to provide the easiest entry of skilled interpreters, agencies, and countries--in order to provide the broadest access and use--should always be considered.

One must also exercise caution. When considering the technical alternatives for entry, one should bear in mind the technical capability for upgrading as the technology progresses. A low entry-cost for satellite A is fine, but not if it means that very expensive equipment must be purchased to utilize similar output data from an upgraded satellite B.

2. Evolution. Both programs show a strong sense of the need to build on established human skills and organizations and to expand those skills through the entry of new data.

The lesson is clear: Insofar as possible, look to existing organizations which provide scientists, interpreters, and distribution nets, and provide those organizations with easy access to data and training.

3. Development of skills. The bilateral remote-sensing programs illustrate a major point. It is absolutely necessary not to oversell by creating the impression, for example, that data from satellites will "solve all problems." On the other hand, it is absolutely necessary to develop skills in ground-truth and application research with remote-sensed data if the satellite (or aircraft) data are to be useful. Every program that envisions the use of such data should be carefully laid out not to assume too much, but to provide for the training and the development of skills required to interpret the data. In many cases this training and application research will be the most expensive component of programs for developing nations. These costs should consequently be assessed very carefully, and efforts should be made to develop ways of minimizing them.

4. Mutual involvement-mutual benefit. The advantages of arrangements in which both parties participate on equal footing, no exchange of money is involved, and scientists and governments on both sides believe the arrangements to be of benefit to them, are obvious. These advantages can come from exchange of data, or other means of sharing.

5. Realism and getting going. The bilateral programs with Mexico and Brazil are fine illustrations of what is required. It is clear that aircraft provide quick and easy entry into experimental work with remote sensing, and that use of aircraft--at least for ground-truth and high-resolution application--will continue for a long time. Their use, in short, provides a method for getting started with the training and research that will be required in any event. Understanding of what can be done in the near future, plus the

experience gained in programs such as these, will be most useful in future efforts to broaden participation. It is essential to get started--but realistically.

6. Pragmatism. As one reviews the various techniques and organizations that have been utilized in international cooperation, it becomes clear that no universal solution emerges. In some cases an international organization exists, thus providing the obvious base for establishing international programs. In other cases, it is easier and better to establish bilateral efforts and to learn by doing quickly. Situations will vary with objectives, the parties involved, and time. Our only conclusion here is to anticipate that it would be most worthwhile to make an early review of potential types of exchanges and participations. This should include a judgment of possible alternative ways in which cooperation might be established, followed by establishment of procedures to clear regional hurdles well ahead of time in high-priority cases in which benefit appears to be most obvious or research most necessary.

7. Voluntary nature of the program. It is essential that countries that participate do so on a voluntary basis, with a strong sense of the benefits that thus can come to them. To the maximum possible extent, programs should provide for contingencies should a country cease to participate, or should the program over a participating country be terminated, so that these eventualities can be dealt with without extensive or system-influencing effects on total programs.

A. 3 The Data and the User

We address ourselves primarily to earth resources data. These data will consist of photography, imagery, and other forms of sensed data from satellite and aircraft, and relayed data from ground-based sensors. The user can be provided these data in either raw or reduced form, and can get the data in the form of pictures, maps, tables, tapes, or reports.

We make the following judgments which may provide a guide to action:

A. 3.1 Satellite Imagery

1. The easiest way for image-oriented data to be put to operational use broadly throughout the world will be as presentations that look like pictures. This is so because of the present level of skills in the world, because of the facility of pictures for presenting a lot of data for interpretation, and because of the status and cost of automatic image interpretation. The "pictures" may contain some image processing, such as feature enhancement, as our techniques develop; but it is our judgment that for a substantial period, final interpretation will be largely done with photograph-like presentations and skilled interpreters.

2. Where immediate access to these images is not required, the images can be provided cheaply. The major cost to the user will not be that involved in obtaining the image (this assumes that the images would be

provided at cost, not including the cost of the satellite and ground equipment--that is, the cost would be the incremental cost to produce the additional desired images) but rather the costs of ground truth and skilled interpreters.

3. Where immediate access to image data is required, the costs can be substantial, if wide bandwidth and high-quality images are required. Alternative means of relaying information, studies of low-cost recording and receiving equipment, and remote stationing of skilled interpreters bear consideration here.

4. A substantial program of R&D in the techniques for image-data processing makes good sense for the United States. In countries able to afford a substantial program in earth resources, similar programs may be set up. In less-affluent countries there will nevertheless be a requirement to anticipate the use of such techniques, and to gain experience in their application. For those cases, a consideration of alternatives, such as touring education programs, periods in the United States for work in a major image-processing center, and joint study programs would be worthwhile. Tapes (analog or digital) should, of course, be provided for scientists and countries in a position to process such data.

5. The volume of images from early satellites to countries interested only in their own country's imagery on an operational basis is not large. For example, the imagery for the United States from EROS would be of the order of tens of thousands of images per year. A given country might, of course, choose to produce and disseminate a large number of copies.

A. 3. 2 Satellite Photography with Film Recovery

Copies of this photography can be distributed cheaply, will represent a low volume of photographs, not counting subsequent reproductions. (We assume something like one copy per country.) They will require skilled interpreters, and will cost the receiving country little compared with ground-truth and interpreter costs.

A. 3. 3 Aircraft Photography and Aircraft Imagery

1. The interpreters will still use the data in image form, except for R&D programs. The aircraft regimen will be heavily oriented toward ground truth, training and R&D, and high resolution.

2. Cost of aircraft and associated sensors and equipment can be high. This illustrates once again the high cost of ground truth and other local data-gathering systems. Sharing of planes and processing facilities may reduce this cost. Some ground truth may always be required. It is not obvious, but some aircraft use may always be required also.

A. 3. 4 Ground-Based Sensor Data Collected by Satellite

1. The data rates here are generally low. Where urgency of reporting is not required, the data can be provided cheaply by providing copies on tape or printed copy, or by low-bandwidth lines.

2. Where the data are required quickly, satellite broadcast appears to offer cheap receiving stations for the data rates involved.

3. Once the data have been collected at a central place (we assume this will be done in the United States for U. S. satellites) it is not an expensive matter to provide files of the data, and of summaries, reports, and tabulations. The United States might wish to provide this service at a reasonable cost for countries desiring such a service. Similar services could be provided to districts, regions, and agencies in the United States if such processing is required.

A. 3.5 Costs

Implicit in most of the above discussion is the assumption of a fairly simple first-generation system based on use of images and skilled interpreters and on feeding low-data-rate ground-sensor data into existing agencies, with a buildup of capability through training and experience that allows evolution to a more extensive second-generation system. The incremental (to extra participating countries) costs of obtaining the image data and of processing the ground-sensor data do not appear to be large, compared to ground-truth and interpretation costs, if image data are not needed immediately. This assumes further that heavy filing and processing costs will not be incurred. This could be wrong if heavy volumes of aircraft photography are kept and indexed in detail, if electronic processing of aircraft imagery has to be provided by the host country, or if extensive files and indexes of ground truth and imagery should develop. Over the ten-year or so period between the first- and second-generation systems, countries that really gain benefits from remote sensing on a broad scale are likely to evolve to a position of wanting some, at least, of those capabilities.

1. Option No. 1 - Satellite photography

It appears that the only realistic procedure would be to provide duplicates of the original photography to any user desiring them. Copy costs are cheap; and interpretation by humans, the feasible method, would comprise the major cost anyway. Simultaneous disclosure to all participants is probably required.

2. Option No. 2a - Satellite imagery

Provide requesting countries with imagery. This provides a low-cost entry for those countries.

Option No. 2b - as above

Provide also an opportunity for scientists from user countries to spend time in "the center," so that they can study ways of enhancing the value of the imagery and have an opportunity to prescribe the form in which operational imagery is provided to them.

Option No. 2c - as above

Provide copies of analog tapes to the user country to allow scientists to experiment with analog signal-processing for image enhancement.

or

Provide digital tapes for experimentation.

3. Option No. 3 - Satellite imagery

Provide wide-band broadcast of the image data to the country. The country has then the choices implied in 2.

4. Option No. 4a - Satellite collection of ground-sensor data

Collection at a central location; transmission of high-priority data to participating countries; distribution of tapes or reports by mail.

Option 4b

As above, but add broadcast of information for collection by any country desiring local information directly. Relatively low cost.

5. Option 5a - Aircraft imagery and data

The country has its own aircraft and sensors.

Option 5b

The country shares aircraft and sensor packages with other participating countries.

What is necessary?

Depending on the application, desires, and funding, the minimum alternative requirements range from the low cost of Option 1 or 2a to the high costs of an alternative which includes all of Options 3, 4b, and 5a.

A. 3. 6 Benefits to the United States

The benefits of broad participation, to the United States, can be summarized as follows:

1. Prestige and leadership in foreign policy
2. Possibly increased effectiveness of foreign aid, due to availability of better information
3. Potential benefits from the national scientist-foreign scientist relationships that would develop
4. Full participation by foreign scientists in R&D, any of their discoveries or developments in the area of correlating remote-sensing imagery with ground data helping the United States
5. Global earth-resources data are desired by the United States.

A. 4 World Weather Watch

A. 4. 1 History

For the past 10 years the United States has played a leading role in urging that the World Meteorological Organization preside over the development of a new world weather system utilizing observation satellites, communications satellites, and computers, for what has been called the "World Weather Watch." The World Weather Watch concept was originally developed by the late Dr. Harry Wexler of the U. S. Weather Bureau, Professor Jule Charney, National Academy of Sciences, and others.

The World Meteorological Organization (WMO) meets as a congress in Geneva every four years. It devoted much of its 1967 meeting to preparing plans for the World Weather Watch. These plans will have such an impact on the future of environmental science that it seems imperative to devote a section of this report to them.

The purpose of the World Weather Watch, as given in the 1968-71 plan of the WMO Congress, is to "enable the unprecedented opportunities which now present themselves for progress in the atmospheric sciences to be seized, and to enable all members to derive the full benefits from the improved meteorological services which such progress will make possible. Such improvements will have a profound impact on the agriculture, commerce and industry of all nations and will permit more accurate and timely warnings of severe storms and other weather hazards for the protection of life and property. It will further the safety and efficiency of international air and sea transportation and provide essential support to nations in the management of water resources and food production."

The primary purpose of the World Weather Watch is to ensure that all members obtain the meteorological information they require for both operational work and research. It is conceived as a worldwide system composed of the national facilities and services provided by individual members, coordinated and in some cases supported by WMO and other international organizations. It is stipulated that the World Weather Watch shall be used only for peaceful purposes, due account being taken of the national sovereignty and security of states, in accordance with the provisions of the Charter of the United Nations and the spirit and traditions of the World Meteorological Organization.

A very important purpose of the World Weather Watch is to stimulate and facilitate the research work that is necessary to improve the accuracy and extend the useful range of weather forecasts, and to enable the possibilities of weather and climate modification to be assessed. The successful implementation and operation of the World Weather Watch depends on an adequate program of education and training.

The information required includes both meteorological observations and processed data. For operational work, the information must be received in a timely and coordinated fashion, while for research purposes the information must be readily accessible in convenient forms.

The essential elements of the World Weather Watch as planned are:

1. The observational networks and other observational facilities, called the Global Observing System
2. The meteorological centers and the arrangements for the processing of the observation data and for the storage and retrieval of data, called the Global Data Processing System
3. The telecommunication facilities and arrangements necessary for the rapid exchange of the observations themselves and of the processed data, called the Global Telecommunication System
4. The research program
5. The program in education and training

In the overall development of the World Weather Watch plan, the intent is to make maximum use of existing facilities and arrangements in all the different fields of activity involved.

A. 4. 2 The First- and Second-Generation World Weather Watch Programs

The World Weather Watch is intended to be a dynamic system, flexible enough to be adapted to changing conditions. New techniques of observation, telecommunication and data processing should be introduced as soon as they have been proven to be sufficiently reliable and economical. The program will consist of two broad, continuous, and parallel "streams of action." The first stream will involve the introduction of proven technology into the existing international meteorological system. The second stream will involve the development of new technology in order to achieve the ultimate goals of the World Weather Watch at a reasonable cost.

In broad terms, the initial phase of the first stream will seek to achieve by 1971:

1. A substantial improvement in the Global Observing System to provide better and more complete data for meteorological analysis and forecasting
2. Implementation of the Global Data Processing System
3. Improvement of the Global Telecommunication System

During the period 1968-71, efforts will also be made to effect a significant acceleration of the program of education and training of meteorologists, both at the national level and under international auspices, as well as planning the Global Atmospheric Research Program (GARP).

It is hoped to bring the new technology to operational status in the early 1970's, so that it can be incorporated into the first stream. It involves the development of physical models of the atmosphere, for operational use by meteorological services in weather prediction (using high-speed electronic computers) and of such devices as meteorological satellites, horizontal

sounding balloons, and automatic meteorological ocean buoys. The second stream also involves the use of further developments in such areas as communication satellites and electronic computers.

The Global Data Processing System will consist of three different classes of meteorological centers:

1. World Meteorological Centers (WMC's), which are located at Melbourne, Moscow, and Washington. They are regarded as service centers for analyses and prognoses of the large-scale atmospheric processes, for use by all members as aids to forecasting and to assist in other long-range planning.

2. Regional Meteorological Centers (RMC's) which will be established in 1968-1971 where the need exists.

3. National Meteorological Centers (NMC's). In some countries national needs will require advanced centers equipped with computers and other modern devices; in others, where the needs and the resources of the country are less, more modest facilities will suffice.

The Global Telecommunication System is to be organized on a three-level basis:

1. The main trunk circuit
2. Regional telecommunications networks
3. National telecommunications networks

APPENDIX B

METEOROLOGY EXPERIENCE AS A GUIDE

A. ESSA Weather Bureau

INTRODUCTION

During the first year of the Summer Study, each of the panels independently discovered that data processing would become a key problem in any proposed future operational system in its particular discipline. Currently, probably \$100 is spent on gathering data for every \$1 spent on processing data. It was also recognized that many of the disciplines wanted similar or identical data. A common system for the storage, indexing, and distribution of all earth-resources data seemed very desirable, even if the actual processing of the data varied greatly from one field to another.

After examining the requirements of a number of users in more detail, we find that some of the commonality begins to evaporate. Although all disciplines will be plagued by large volumes of data and the difficulties in retrieving relevant information from files, there is a wide divergence in the type of data wanted (e. g., hard film, processed spectral signatures, rectified maps, tables of numbers), the resolution wanted, the amount of processing required, and the frequency of coverage needed.

There has been a wide divergence of opinion on the need for centralized processing versus decentralized processing. Part of this difficulty stems from the fact that many of the disciplines are in purely research phases now. Trying to see past the problems of the moment, through their likely paths of research and development, and onward to one or more operational systems, is a difficult assignment for a researcher. The future users may be quite different people, with different motivations, when compared with those who presently lead their respective fields. Estimates by present users tend to be either (1) too conservative because they ask only for results well within the state of the data-processing art; or (2) too optimistic because of extrapolations made by projecting research frontiers into full operation.

Fortunately, in estimating the future course, we do not have to estimate in the dark. Several large data-processing systems are presently in existence, in the environmental sciences. These have proved very helpful in sizing the problems, and in obtaining actual data-flow, cost, manpower, and time figures. The following sections describe the operation of the ESSA meteorological services in some detail. Both the traditional meteorological network and the satellite picture-processing system are described, since both have direct implications.

Meteorology has for several reasons traditionally led the environmental sciences in data processing: (1) The economic value of timely, accurate weather forecasts has been apparent over the years, so that funding has been made available. (2) The governing physical laws of motion, and the numerical methods are much better understood in meteorology than they are in most other environmental sciences. (3) The early products from satellites—cloud photographs of a coarse-scale resolution—were of immediate use in meteorology, where large-scale phenomena are of prime importance. The other environmental sciences generally require much finer resolution of phenomena of prime usefulness to them.

On the negative side of this selection, meteorology has a greater need for central processing of data than most of the other applications. Any conclusions drawn from the weather networks must be carefully evaluated in those terms so as not to prejudice the case for decentralized processing.

Almost all existing large data-processing systems have developed in an evolutionary way. As a general rule, those that have evolved naturally seem to end up better suited to their tasks than those which are designed all at once.

The ESSA systems described below are the result of long evolutions of 30 years or more. The equipment (including the computers) has been successively replaced and upgraded over the years. The main trends have been toward: (1) higher-speed equipment in all parts of the system; (2) more reliable equipment and better quality control on measurements and procedures; (3) all digital-processing whenever possible; analog devices have been declining in importance; (4) system components of greater generality and flexibility tend to replace older specifically designed components; and (5) addition of new tasks and products to the existing load of the system (very few products are ever dropped once they have been found useful).

THE EXISTING METEOROLOGICAL DATA-PROCESSING SYSTEMS

Probably the best example of a large operational (non-classified) data-collection, processing, and distribution network in the environmental sciences is the ESSA Weather Bureau. In fact, four agencies represent the major meteorological operations in the United States: the Weather Bureau, the Air Force, the Navy, and the Federal Aviation Agency. In addition, NASA is substantially funded for its part in the weather-satellite program.

The satellite data system and the traditional meteorological data system of the Weather Bureau are still largely separate in their data-collection and processing phases. However, the distribution of processed data to users takes place over common communication networks. Because both the traditional meteorological network and the satellite system have direct bearing on our considerations for SERI, they will both be described here in detail.

THE WEATHER BUREAU DATA-COLLECTION NETWORK

Traditional synoptic weather measurements are made at predetermined times and locations all over the world. Most measurements are made every 6 hours (0000, 0600, 1200, 1800 Z), although many are made hourly and some every 12 hours. Weather observations are of four types: (1) surface measurements; (2) upper-air measurements (made via balloons, rockets, or aircraft); (3) radar measurements; and (4) satellite measurements.

Worldwide there are approximately 7000 surface weather stations that record pressure, temperature, dewpoint, wind velocity, clouds, pressure tendency, snow cover, precipitation accumulation, visibility, and sea-surface temperature (when applicable). Of these, approximately 3800 are in the proposed World Meteorological Organization regional basic networks, and report on a regular daily basis.

Surface stations are of the following types: (1) full-time (24 hours per day) stations; (2) part-time stations, which perform the same functions as full-time stations but are not open all night; (3) second-order (fee basis) stations. Usually a local part-time observer is appointed and paid a fee for each observation. The observations usually are telephoned to a nearby Weather Bureau office; (4) automatic meteorological observing stations, usually located at remote strategic locations; and (5) reports from ocean shipping.

Upper-air measurements by balloons are of two kinds: (1) visual tracking of free rising pilot balloons (called PIBALS), and (2) electronic tracking of balloon-borne instruments by means of radio direction-finding equipment (called rawins if wind only is measured and rawinsondes if pressure, temperature, and water vapor are also measured). Upper-air stations are classified in a manner similar to surface stations. There are, however, no automatic upper-air stations. Globally, there are approximately 3500 pibals, 2200 rawins, and 1600 rawinsondes per day.

Rocket sondes and aircraft measurements of upper air are much less frequent, although important for special applications.

Radar equipment especially designed for weather work has become very useful for obtaining certain information, such as storm location, severity and movement, heavy precipitation. Radar is particularly valuable in detecting severe storms that spawn tornadoes, in tracking hurricanes, in detecting hazardous flying conditions, and in locating heavy precipitation areas that may lead to flash-flooding.

DATA ANALYSIS AND WEATHER FORECASTING

The analysis of the meteorological variables, and the preparation of forecasts is normally carried out in three stages: (1) analysis of the weather data on a hemispheric scale and preparation of prognostic charts. This work is done at primary centers by the Weather Bureau's National Meteorological Center for general use in the United States, and by the Air Force and Navy

weather centers, for additional military needs, particularly overseas; (2) at twelve guidance centers. Forecasts are made on a more limited area using the hemispheric-scale material along with local data; and (3) area centers, to arrive at a local forecast, then make modifications to the above forecasts to take into account local terrain and special conditions. There are 13 area centers in the United States. The 12 guidance centers also serve as area centers to their localities.

The National Meteorological Center (NMC) at Suitland, Maryland, is the largest primary center. It is divided into four divisions: (1) the Analysis and Forecast Division, which analyzes the current state of the atmospheres and produces short-range predictions (less than 72 hours) by manual charting and analysis; (2) the Extended Forecast Division, which prepares advance forecasts and outlooks ranging from three days to a month; (3) the Development Division, which conducts studies aimed at devising and testing new methods of numerical weather prediction; and (4) the Data Automation Division, which utilizes electronic data-processing techniques to produce daily automated analyses and forecasts.

Figures 8. B. 1, 8. B. 2, and 8. B. 3 describe the flow of data within the Data Automation Division. Figure 8. B. 1 shows the high-speed data links from U. S. and overseas stations into the computers. Figure 8. B. 2 shows the data flow within the acquisition and storage devices. The two IBM 360 Mod 30's (2030) are used to control the data flow. Figure 8. B. 3 shows the data flow from computer to computer for its twice-daily cycle. Approximately one million words of raw data (not including satellite data) enter the system twice per day. Approximately 430 FAX charts per day are prepared. Teletype groups in the amount of 550,000 per day are transmitted, giving NMC's forecasts and analyses. In addition, approximately 200,000 automatic-relay groups are also sent.

DISTRIBUTION OF WEATHER BUREAU PRODUCTS

All the effort spent in preparing the above products is matched in cost and complexity by the data-distribution networks. Most of the collection and distribution system is made up of leased facilities. The Federal Aviation Agency provides a very significant level of support.

The following is a list of the major non-military weather communications systems utilized to distribute the NMC products:

Service A (60 circuits)	International (8 circuits)
Service C (6 circuits)	National Facsimile (1 circuit)
Service O (23 circuits)	Hi Altitude Facsimile (1 circuit)
RAWARC (4 circuits)	Forecast Center Facsimile (3 circuits)
Ag-Met (10 circuits)	Intra-Alaska Facsimile (1 circuit)
Local Service (90 circuits)	Misc Others (13 circuits)

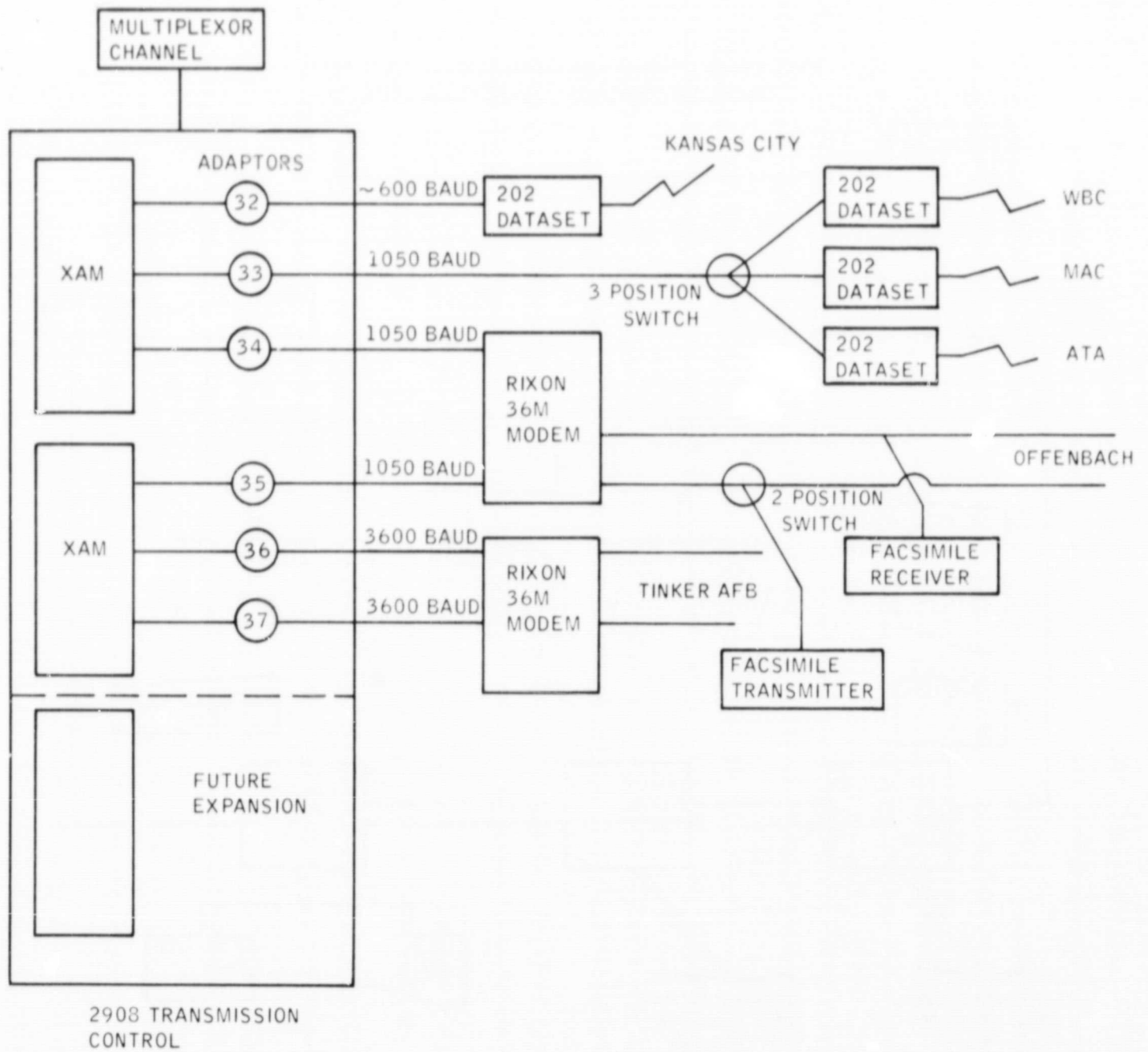


FIGURE 8. B. 1 Entry of high-speed data lines into the National Meteorological Center computer system.

DATA ACQUISITION AND MANAGEMENT SYSTEM
NATIONAL METEOROLOGICAL CENTER

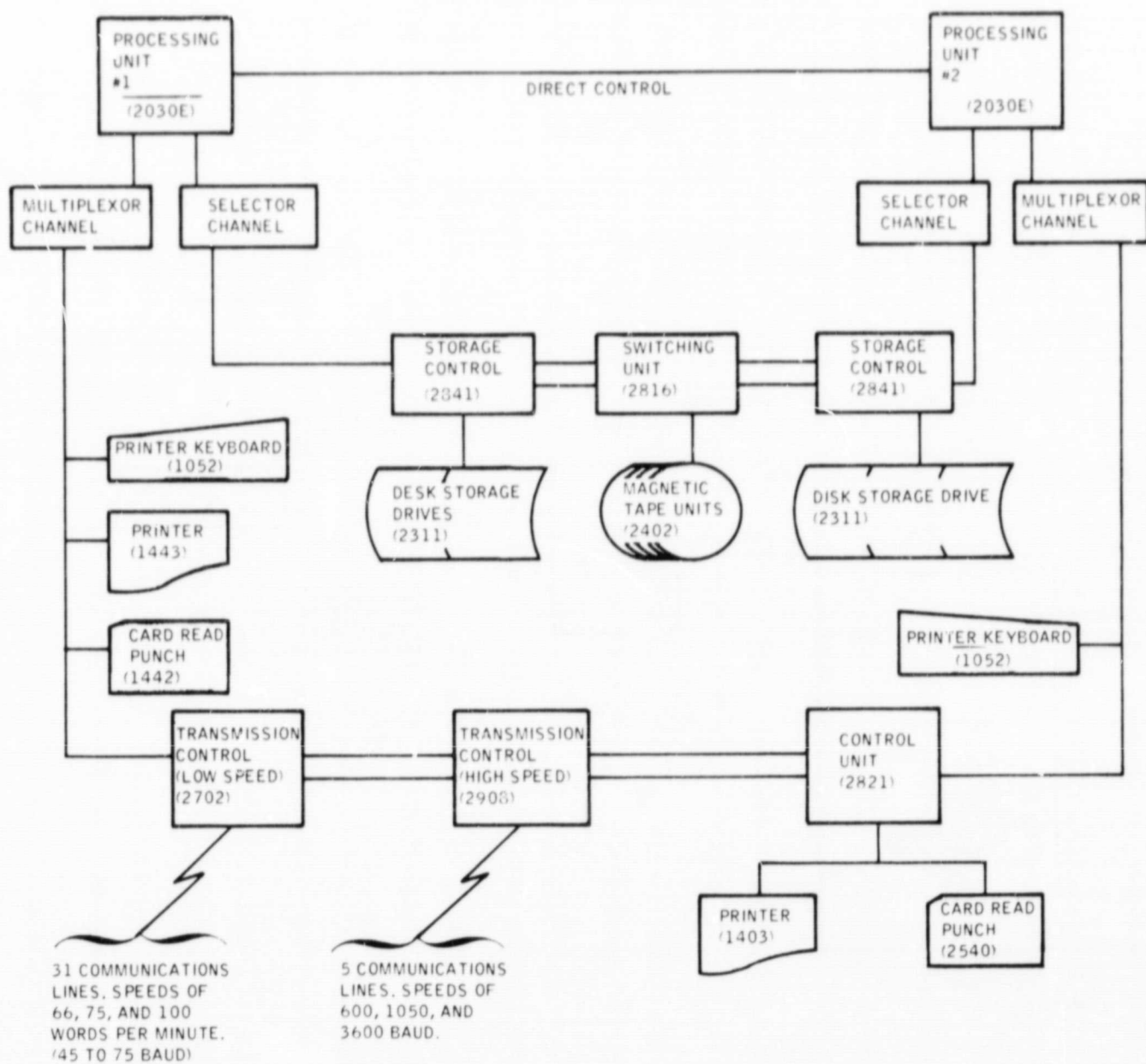


FIGURE 8. B. 2 Data acquisition and management system, National Meteorological Center.

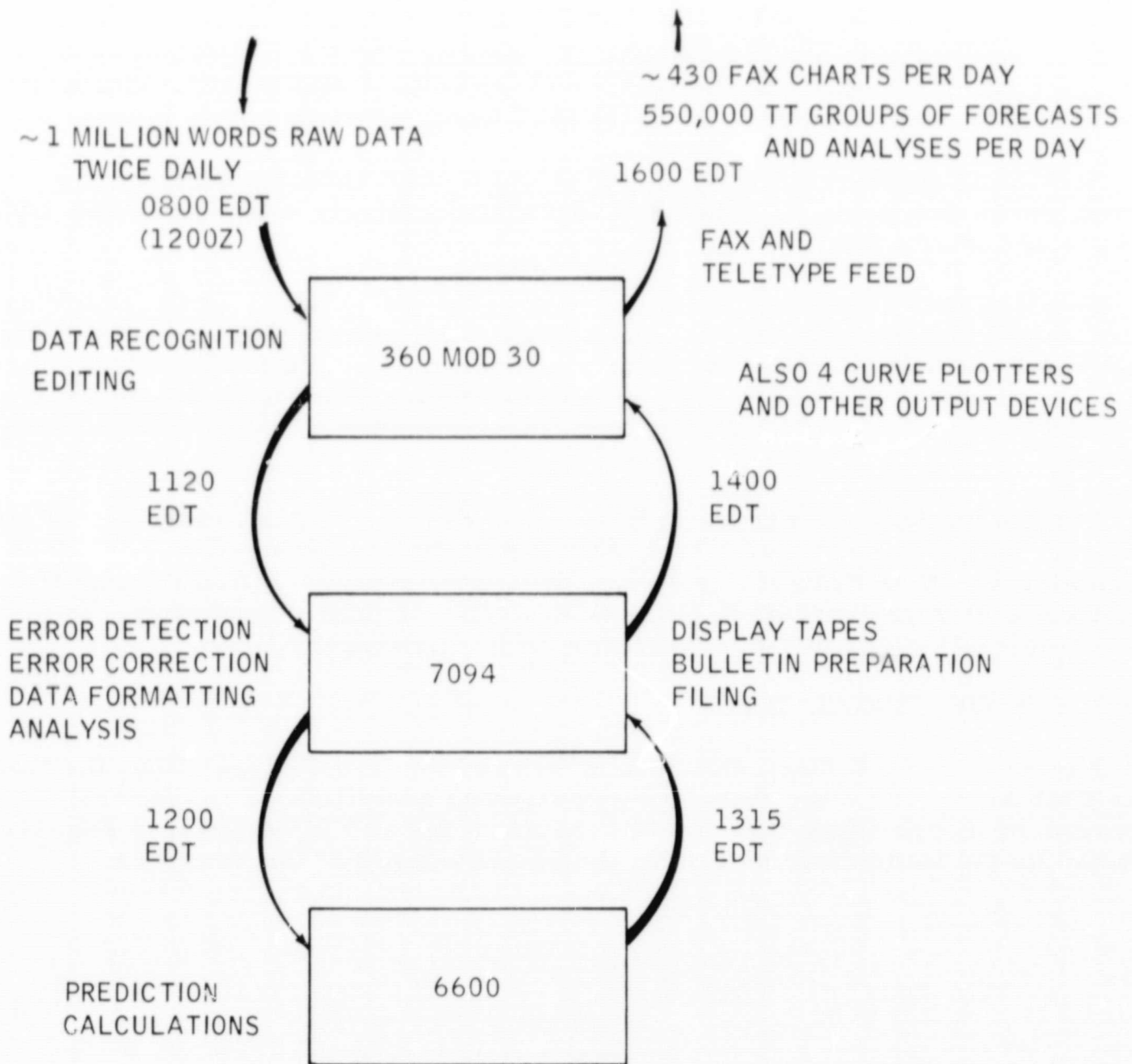


FIGURE 8. B. 3 Data flow between the computers at the National Meteorological Center, and nominal times for processing.

A typical Weather Bureau office will have a drop on Service A, Service C, the National Facsimile Network, and probably the RAWARC system.

Service C is a long-line teletypewriter system (100 words per min). It is operated by the FAA. It is often called "the meteorological network" as it carries most of the U. S. surface synoptic and upper-air data and basic public forecasts.

Service A is also a teletype network operated by FAA. Its objective is to collect and distribute hourly surface observations and aviation weather. It uses higher speed-express circuits (857 wpm) between major points.

Service O combines teletype, cable, and radio circuits between the United States and foreign countries. RAWARC collects and distributes radar reports and storm warnings.

The National Facsimile Network is used to distribute a comprehensive set of charts depicting analyses, prognoses, and selected observational data. It serves approximately 250 Weather Bureau offices, 320 military and other government units, and about 200 extension-service (non-government) users -- over 750 drops in all. The charts are also relayed to Alaska over military channels.

For completeness, Figure 8. B. 4 shows the Air Force Automated Weather Network, which has extensive high-speed data links overseas. The Automated Weather Network is a fully duplexed communication system that operates at high transmission rates with error-checking capability. It is also completely computer-to-computer on its high-speed links.

SUMMARY OF FISCAL DATA

Tables 8. B. 1, 8. B. 2, and 8. B. 3, taken from the Federal Plan for fiscal year 1968 summarize the fiscal information on activities of the federal government in providing meteorological services and in conducting research that has as its immediate objective the improvement of the services.

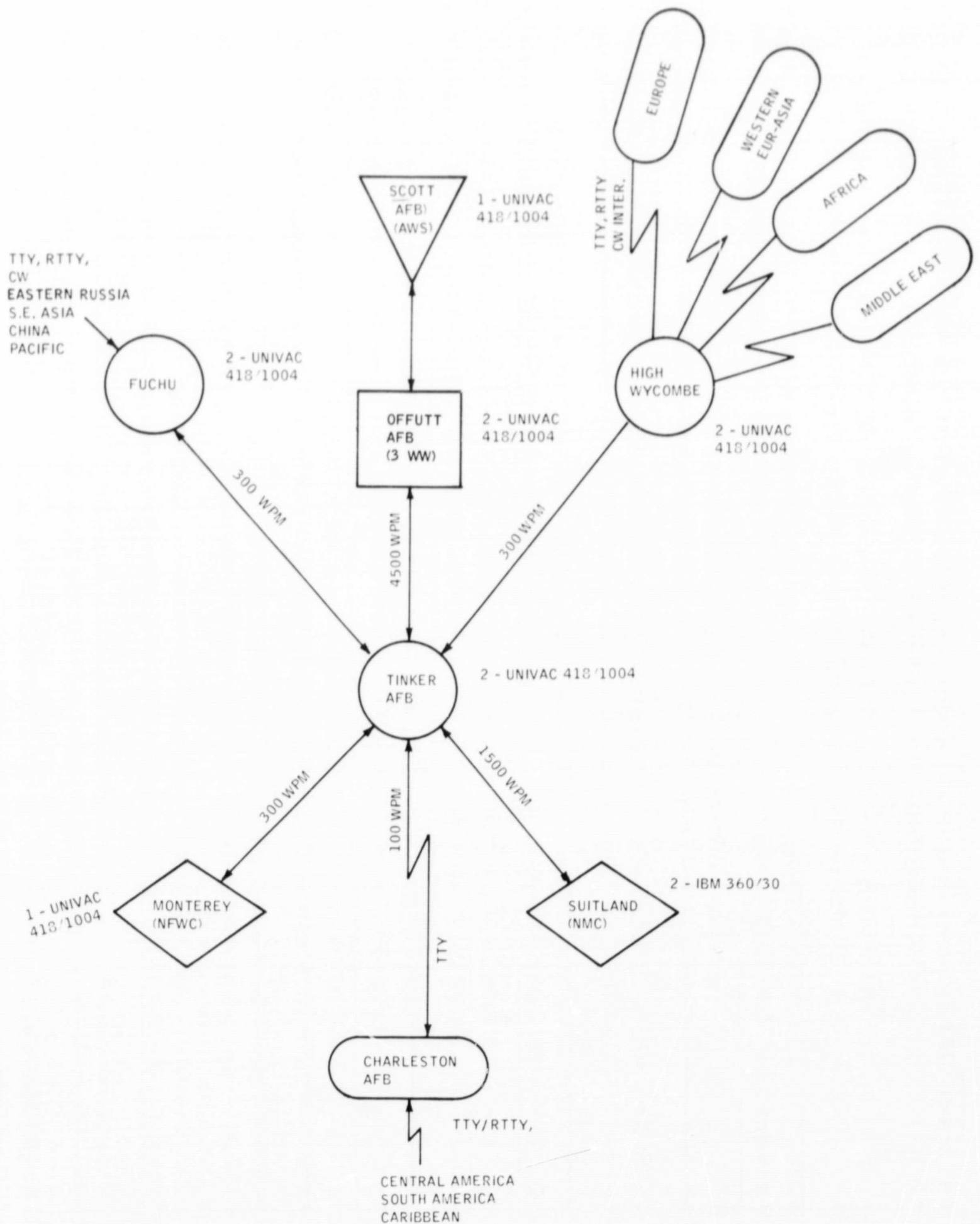


FIGURE 8. B. 4 The U. S. Air Force automated weather network.

TABLE 8.B.1

FEDERAL PLAN FOR METEOROLOGICAL OPERATIONS AND SUPPORTING RESEARCH BY AGENCY
(in thousands \$)

	Operations			Supporting Research			Total		
	1967	1968	68 Change	1967	1968	68 Change	1967	1968	68 Change
AGRICULTURE				1,217	1,245	+28	1,217	1,245	+28
AIR FORCE	121,453	125,998	+4,545	6,278	5,334	-944	127,731	131,332	+3,601
ARMY	5,954	6,068	+114	9,933	12,815	+2,882	15,887	18,833	+2,996
AEC	1,429	1,477	+48	862	880	+18	2,291	2,357	+66
COMMERCE	102,167	111,307	+9,140	7,148	7,946	+798	109,315	119,253	+9,938
FAA	23,425	23,718	+293	1,017	1,526	+509	24,442	25,244	+802
HEW				1,274	1,450	+176	1,274	1,450	+176
ICSC	1,084	1,037	-47				1,084	1,037	-47
NASA	1,752	1,920	+168	36,259	52,150	+15,891	38,011	54,070	+16,059
NSF	351	320	-31				351	320	-31
NAVY	38,546	39,226	+680	1,515	1,565	+50	40,061	40,791	+730
TREASURY	6,462	6,873	+411				6,462	6,873	+411
TOTAL	302,623	317,944	+15,321	65,503	84,911	+19,408	363,126	402,855	+34,729

TABLE 8.B.2

FEDERAL PLAN FOR METEOROLOGICAL OPERATIONS AND SUPPORTING RESEARCH BY SERVICE
(in thousands \$)

	Operations			Supporting Research			Total		
	1967	1968	68 Change	1967	1968	68 Change	1967	1968	68 Change
BASIC	123,502	132,421	+8,919	41,587	58,023	+16,436	165,089	190,444	+25,355
AVIATION	117,021	120,527	+3,506	2,505	2,638	+133	119,526	123,165	+3,639
MARINE	11,856	12,854	+998	168	179	+11	12,024	13,033	+1,009
SPACE OPERATIONS	8,541	8,968	+427	2,018	2,040	+22	10,559	11,008	449
AGRICULTURAL	3,551	3,633	+82	1,236	1,285	+49	4,787	4,918	131
GENERAL MILITARY & GROUND FORCES									
SUPPORT	30,052	31,131	+1,079	15,853	18,416	+2,563	45,905	49,547	+3,642
OTHER SPECIALIZED	8,100	8,410	+310	2,136	2,330	+194	10,236	10,740	+504
TOTAL	302,623	317,944	+15,321	65,503	84,911	+19,408	368,126	402,855	+34,729

TABLE 8.B.3

AGENCY OPERATIONAL COSTS BY TYPES OF OBSERVATION
(in thousands \$)

	Surface Observations		Upper Air (Balloon) Observations		Upper Air (Rocket) Observations		Weather Reconnaissance Observations		Weather Radar Observations		Weather Satellite Observations		Total	
	1967	1968	1967	1968	1967	1968	1967	1968	1967	1968	1967	1968	1967	1968
AIR FORCE	5,597	6,274	5,824	6,375	2,759	4,158	13,212	13,648	1,638	2,323	250	258	29,280	33,036
ARMY			4,785	4,785									4,785	4,785
AEC	215	218	290	292	250	250							755	760
COMMERCE	10,157	10,646	8,190	9,109					5,527	4,580	21,223	25,405	45,097	49,740
FAA	1,927	1,295											1,927	1,295
ICSC	75	75	367	426					125	150			567	651
NASA	221	98	249	222	89	64	102	350	25	32			686	766
NSF	121	120	200	200									321	320
NAVY	6,562	6,602	1,548	1,621	758	803	4,170	4,195	648	711	826	831	14,512	14,763
TREASURY	689	728	5,472	5,821									6,161	6,549
TOTAL	25,564	26,056	26,925	28,851	3,856	5,275	17,484	18,193	7,963	7,796	22,299	26,494	104,091	112,665

B. Computer Processing of Satellite Cloud Pictures

INTRODUCTION

Preliminary efforts relating to the central processing of meteorological satellite data began in late 1958.* Early efforts were concerned mainly with the production of latitude/longitude earth locator grids, which were produced to fit the perspective of the individual vidicon camera images. Since multi-channel infrared radiometers were included in the early TIROS series, programs were produced for the archiving (on computer magnetic tape) of properly earth-located sensor data. With the advent of the Nimbus satellite series, major computer resources were made available for the operational processing of pictures from its advanced vidicon camera system (AVCS) and for the processing of other scanning radiometer data.

The TIROS Operational Satellite (TOS) System resulted in a reconfiguration of specialized electronic equipment in order to process data from the new (wheel-configuration) spacecraft. The operation was activated with the launch of ESSA-I—the first spacecraft in the new TOS series. By October 1966 the global mapping of video data had become a daily routine. Since that time, basic mapped video products have improved, and a beginning has been made toward a hierarchy of derived products.

DATA ACQUISITION

Responsibility for command and operational control of the satellites in proper mission mode rests with the Satellite Operations Branch at Suitland, Maryland. Instructions are transmitted to the ESSA Command and Data Acquisition (CDA) stations at Wallops Island, Virginia, and near Fairbanks, Alaska. Since the satellite has been injected into a sun-synchronous orbit (same local sun time at each equator crossing), the planning of picture taking under proper illumination is a straightforward process. Once the positioning of the 12-picture sequence for an orbital pass has been decided upon, commands are made up to activate the satellite. The satellite's programmer logic starts the picture-taking sequence by counting down a specified number of spin counts. As the camera shutter is activated, the vidicon scan response is stored on the satellite's videotape recorder.

Once the pictures are stored (in intermittent 8-second bursts), a readout command delivers a 12-frame sequence to the CDA stations' analog tape recorder in about 1-1/2 minutes. Pictures recorded at the CDA stations are next relayed to Suitland via microwave (48Kc Telpack B) communications facilities. Since the microwave facility is substantially narrower in bandwidth than the direct satellite-to-ground CDA links, the relayed video is transmitted on an eight-to-one slow-down basis.

*Most of the material in this section is from ESSA Technical Memorandum NESCTM-3 by C. L. Briston (April 1968).

Within the ESSA National Environmental Satellite Center (NESC) in Washington there is a sizable hardware complex for the processing of video data. Many man-years of software investment also support this processing. Apart from the raw input signals, a considerable number of collateral input items are required. The serially received (FM/FM) video signal arrives at the data-processing facility, is properly discriminated, digitized, and made available to an on-line computer (see Figure 8. B. 5). This raw digital video signal is presented as a sequence of 6-bit brightness bytes, along with frame-start and line-start interrupt signals, so that the 800 samples along each of the 800 scan lines can be properly identified within the computer.

During the time in which the picture is being stored on the satellite's tape recorder, a 20-bit relative (half-second) time count is being recorded on another telemetry channel. With knowledge of the real time at which this counter was reset, the picture shutter-time may be deduced. This is made available to the computer through a time-code formatting device. The raw video ingestion program receives the above two inputs and creates a properly formatted raw digital videotape for further processing.

Picture sequences must be planned and the satellite commanded on the basis of proper illumination and other operational constraints. Since satellite command logic requires relating picture-taking to spin revolutions, the spin rate is evaluated very precisely. Calculation is then performed so that spin count passed to the satellite at command time, when counted down, will provide pictures at the proper time. With auxiliary information converting the reset of the 20-bit time counter, the program which computes spin revolutions may also convert the projected shutter times into the equivalent 20-bit time code. By this means it is possible to verify that pictures obtained are indeed taken at the planned times.

EARTH LOCATION

Proper earth positioning of each picture, as shown in Figure 8. B. 6, requires substantial added information. Although the camera is mounted in the satellite at a precisely known angular position, the exact location of each picture element on the image plane requires knowledge of distortions produced within the camera system. Pre-launch pictures of test targets provide such information. This information is prepared in tabular form and made available to the computer. These distortions arise from the optics and the electronic characteristics of the camera system. Shifts in distortion characteristics can be checked after launch by means of fiducial marks, which are permanent features of the vidicon-image face. If raster shifts are permanent and stable, the coordinate shifts can be incorporated as corrections to the distortion tables.

Since the video processing is a real-time operation, orbital information related to the pictures is produced on a predictive basis. A modified version of a NASA (Nimbus Project) program is used for this purpose. With proper orbital elements, this package produces subsatellite-point latitude and longitude together with satellite attitude, all as a function of a specified shutter time.

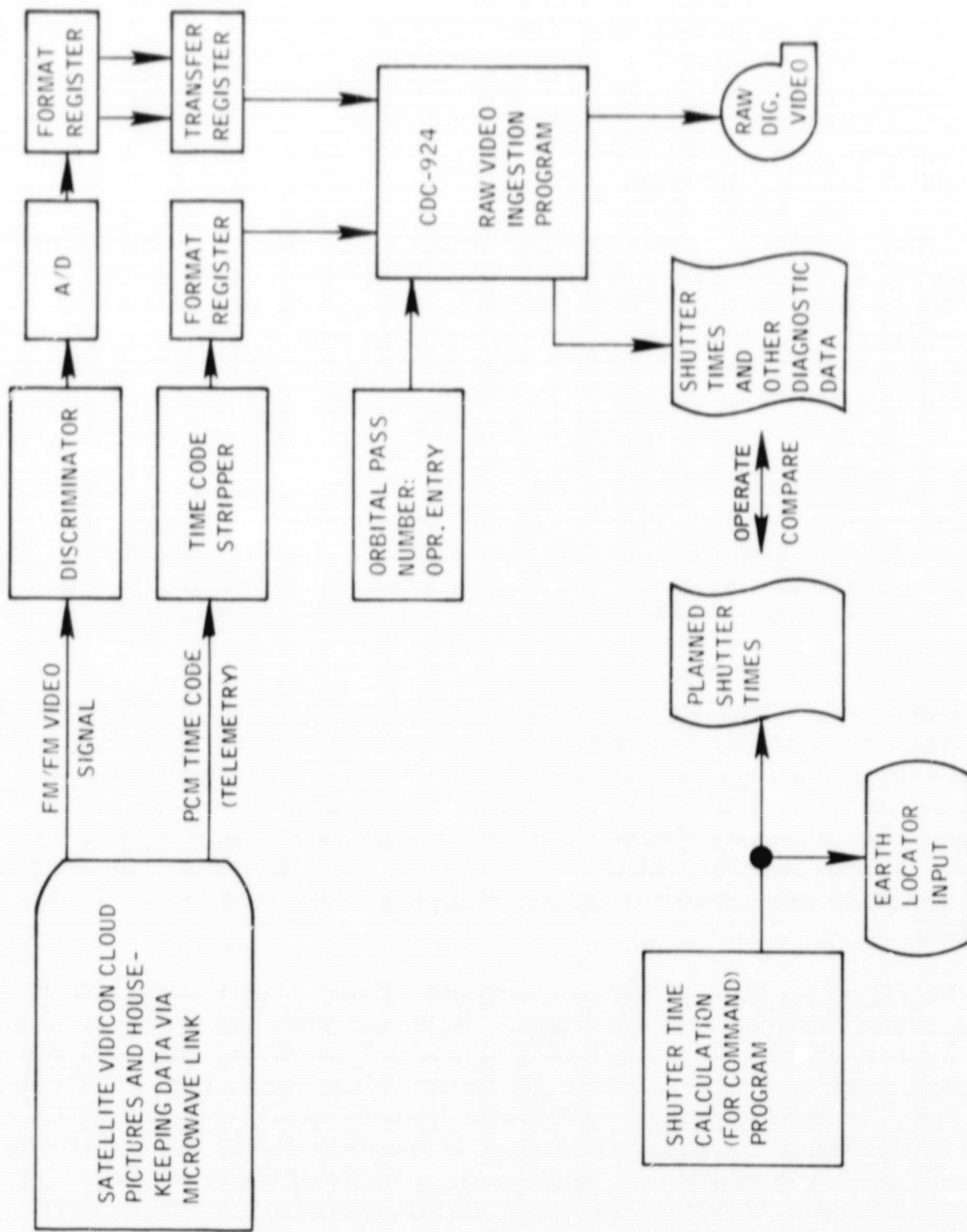


FIGURE 8. B. 5 Input data processing.

Despite the fact that vidicons have not been constructed with strong quantitative design specifications, a considerable effort has been expended toward quantitative use of the picture data. Digital sampling of pre-launch pictures, taken under a variety of controlled conditions, reveals a strong vignette effect toward the edges of the frame. Correction for such attenuation permits comparison of brightness response throughout an image, and with overlapping portions of adjacent images. In the case of mapped video, there is also interest in comparing brightness responses over large geographical regions where pictures are taken under varying sun angles. Programs which apply such corrections do so in an approximate sense, since only the sun/satellite position trigonometrics are considered. Additional diagnostic software utilizes saved response samples from each picture in order to check for in-flight response changes.

The presentation of earth-located imagery is considerably enhanced by the implanting of coastlines and other important land-form features. The program which provides such information utilizes large tables which contain latitude/longitude points along all such desired line features. These tables have been prepared from detailed navigation charts--the selected points having been estimated to tenths of degrees by eye, and entered on punched cards.

PICTURE MAPPING

Despite the convenience of grids, automatically combined with pictures, the analyst must still cope with problems of perspective and overlap between frames. Since October, 1966, NESG has provided mapped imagery on a daily global basis.

The same earth-locator information (Figure 8. B. 6) is used to determine the latitude/longitude of each digital-brightness sample. If these locations are transformed through map-projection geometry, a digitized picture can be replotted on standard Mercator and polar stereographic maps for handy comparison with other environmental data. A fine-mesh (4096 x 4096) map-array area is reserved on computer disks for each polar hemisphere, and a separate space is reserved for an overlapping Mercator equatorial map array (40N to 32S).

A substantial amount of large-computer time is utilized each day in producing these mapped video arrays. Raw samples are brightness-normalized for non-linearities in vidicon response, are adjusted for inequalities in solar illumination, and then mapped into the polar Mercator arrays. Overlap imagery from frame-to-frame and from pass-to-pass is reduced by cropping unwanted redundancy. Global coverage is maintained in the polar-map disk arrays. As new information is acquired, a "forward erase" logic ensures that the most timely 24-hour coverage is maintained. A slight forward gap is created to demark the shifting 24-hour discontinuity line.

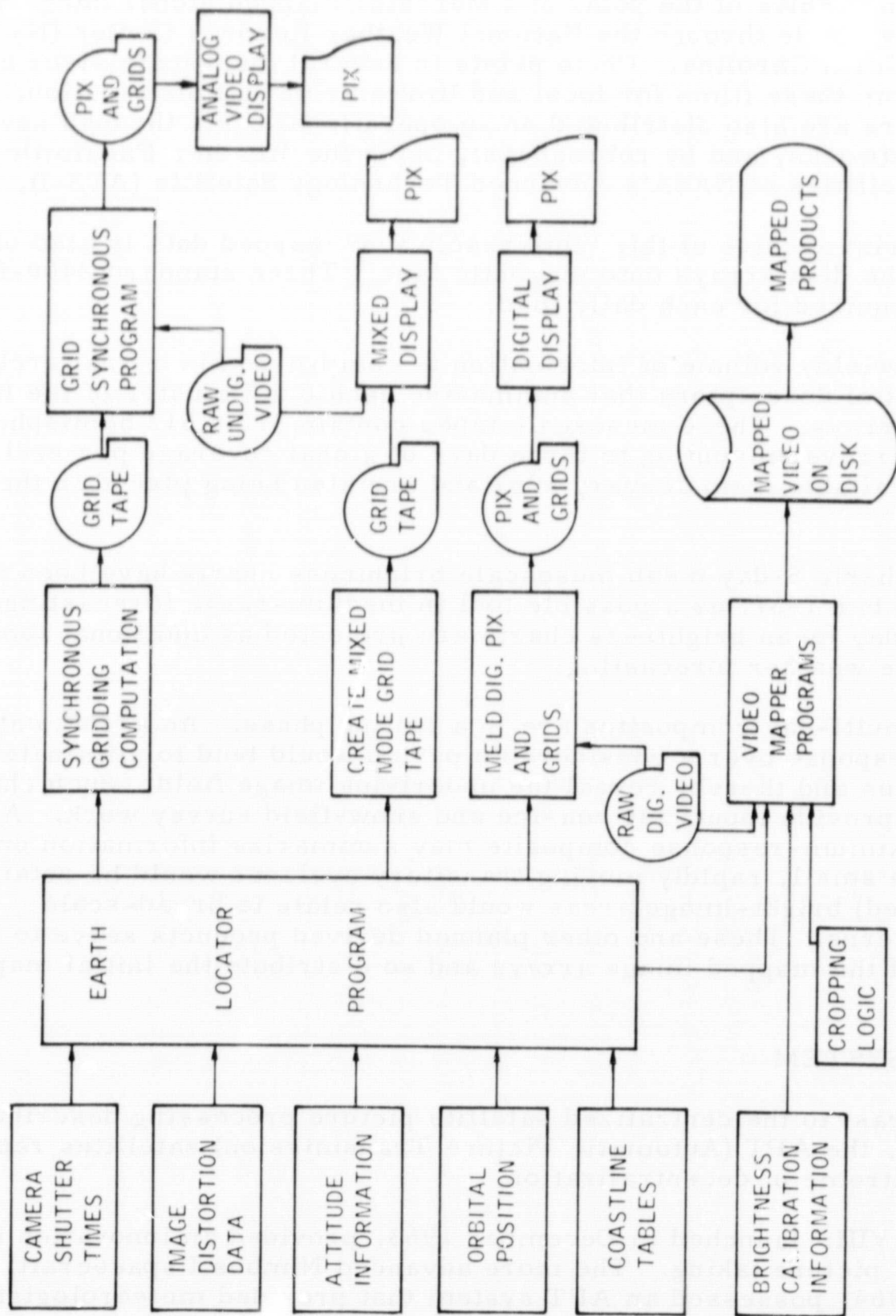


FIGURE 8. B. 6 Earth location processing.

COMPUTER PRODUCTS

Once images have been mapped, the disk-file arrays are available for a variety of products. Sixteen 35-mm film chips are produced daily in order to provide an archive of the polar and Mercator mapped global imagery. These are available through the National Weather Records Center (NWRC), Asheville, North Carolina. Photo prints in several map-scale sizes are also produced from these films for local and limited external distribution. Many image sectors are also distributed on an operational basis through several facsimile networks, and by rebroadcast, using the Weather Facsimile (WEFAX) facilities of NASA's Advanced Technology Satellite (ATS-I).

An interim archive of this "full-resolution" mapped data is also obtained by copying the disk arrays onto magnetic tape. Three standard 2400-ft tape reels are required for each daily load.

This unwieldy volume of information is compressed in a final archive by storing a set of descriptors that summarize each 8 x 8 cluster of the full-resolution arrays. These mesoscale tapes contain 512 x 512 hemispheric descriptor arrays amounting to three days of global coverage per reel. Such tapes are available from January 1967 and are also being placed in the NWRC archive.

Hemispheric 5-day mean mesoscale brightness charts have been produced since November 1967, as a possible tool in medium-range forecasting. Similar 30-day mean brightness charts are projected as additional tools for longer-range weather forecasting.

Other multi-day composites are in a testing phase. An accumulation of minimum response over a considerable period would tend to eliminate moving cloud regimes and thereby reveal the underlying image field. Such charts are expected to provide inputs for sea-ice and snow-field survey work. A similar maximum-response composite may summarize information on storm tracks since small, rapidly moving transitory cyclones would be retained. The (smeared) bright-image areas would also relate to broad-scale rainfall patterns. These and other planned derived products serve to broaden the utility of the mapped image arrays and so distribute the initial mapping cost.

THE APT SYSTEM

In contrast to the centralized satellite picture processing described in the last section, the APT (Automatic Picture Transmission) satellites represent the other extreme of decentralization.

TIROS-VIII, launched in December 1963, provided an innovation in satellite TV picture taking. The more advanced Nimbus I spacecraft, launched in August 1964, possessed an APT system that provided meteorologists in all parts of the world with cloud-cover pictures by direct readout from the satellite. At present, the ESSA-II satellite is providing this service. Unlike the standard TV system carried on the Tiros satellites, APT transmits

pictures on a slow-scan principle, similar to that used to send radio photographs. A picture covering about 1,000,000 square miles is taken and transmitted every 352 seconds.

Depending on the satellite's elevation angle above the horizon, each APT ground station can receive up to three pictures during each pass. There is no data storage assumed in the APT except for the short-term storage in the video system during the readout of a picture.

The APT concept has been very popular with meteorologists around the world. There are over 400 independent APT stations now in existence, with many more planned. The importance of these cloud-cover photographs to meteorologists in remote locations with little normal coverage is hard to overemphasize. The United States has entered into international agreements promising not to change the ground-station receiver requirements without several years' advance notice as to the details of the change.

The estimated cost of an operational APT station is around \$57,000 for a complete receiver set including installation and spares. If the useful life is figured at five years, and an annual operation and maintenance cost of \$15,000 is added, then the annual cost of a full APT station is about \$26,400.

Of course, many APT stations have been built for much less than this, including some built by amateurs costing only a few hundred dollars; however, the above figure is reasonable for an operational installation.

WHAT IS THE FUTURE OF APT?

A number of possible extensions of APT have been discussed. One of its main shortcomings-no storage of data-has been partially overcome within the United States. The ESSA-II APT signals received by the San Francisco receiver are routinely transmitted in real time via the GF-10205 circuit to a recorder in the National Meteorological Center in Suitland, Maryland. The quality of pictures resulting from this long-distance transmission is practically indistinguishable from those received locally by the Suitland receiver. The Suitland and San Francisco signals together provide picture coverage for all the United States, about half of Canada and Mexico, plus strips of both the Atlantic and Pacific Oceans near them. The gridded pictures of this huge area are pieced together into a mosaic every day.

It is possible to consider extending this solution to other parts of the globe where high-speed data links exist. The possibility of using communications-relay satellites has also been suggested, to make the coverage nearly global.

There have been frequent suggestions by other countries for digitizing the APT signals on the ground for possible entry into computer models. The same has been proposed for the geosynchronous ATS scanners.

U. S. experts feel that the APT concept as presently implemented is too restrictive. Natural extensions, such as to multi-spectral scanners, will

be hard without a shift in transmitting characteristics, which would probably make existing ground receivers obsolete.

The APT system thus shows all the classic strengths and weaknesses of a decentralized system. It has given a great advance to many isolated users who were able to enter the system at relatively low cost. Now that the system is entrenched, institution of any significant upgrading that would force all users to change equipment will be difficult.

APPENDIX C

GEOLOGY AS AN ILLUSTRATIVE SUBJECT

PROBLEM

During the last decade the extractive industries have had increasing difficulty in discovering new reserves in North America at a rate equal to consumption. Without increased exploration capability the trend will probably continue.

TECHNICAL ASPECTS

Natural resources such as sand, gravel, salt, sulfur, minerals for fertilizer, metallic ores, and petroleum are the continuing object of search by exploration geologists and geophysicists. Search methods are frequently rules of thumb, with little scientific basis. They are often based on individual experience, and may apply over a very limited geographic area only. The products of the extractive industries are found by using ideas in the heads of men. These ideas are models of the natural processes leading to the accumulation and concentration of some resource and the observable geophysical, geochemical, and geologic features associated with the resource accumulation. Examination of the surface of the earth is a time-honored and historically successful method of exploration. However, the models that associate subsurface resource accumulations with surface observables are unsatisfactory. Whereas methods for detailed exploration after the explorationist has been directed to a small, highly prospective area are relatively well developed, reconnaissance methods to direct the explorationist to these small highly prospective areas are in a far more primitive state. The study of carefully selected, high-altitude imagery of the earth's surface in synoptic, orthographic form, with ancillary spectral information, is a research activity that may produce new models of the geological and geophysical processes that have led to the present surface character of the earth. Given these new models of geologic and geophysical processes, new correlations between surface observables and subsurface resource accumulations may become apparent. This is in every sense a research activity, because there is no certainty that the postulated process and accumulation models will be attained. However, since geologic surface methods should be based on geologic models and since such models offer both economy and speed in reconnaissance exploration, a research program of reasonable scope is recommended.

The relative merits of very high-altitude aircraft and satellite imagery must be evaluated by other competency. If satellite surface-imagery is preferred, the following first-generation research program is feasible.

RESEARCH PROGRAM

1. Hard-film coverage of North America, including Alaska and as much of Central and South America as can be included within budget constraints, should be programmed. If the availability of high-resolution multi-spectral hard-film imaging equipment with satisfactory registration is probable at the expected time of flight, it is the preferred mode of photography. First priority should be given to the portions of North America where extensive ground-truth information exists or may be obtained with relative ease. This maximizes the probability of establishing new reconnaissance methods as rapidly as possible. Second, and of almost equal priority, is imagery over large areas that are considered prospective for resources and are relatively unexplored. This coverage should allow rapid evaluation of any new reconnaissance methods in potentially profitable and politically secure areas. Alaska and selected portions of Canada are probably the top candidates.

One spectral band of stereo coverage is recommended. The trade-off between reduction of satellite-orbit height to obtain stereo coverage, and the potential loss of areal coverage, must be evaluated. The inclusion of Ektachrome infrared imagery is also recommended. There is no backlog of experience that justifies full-color stereo coverage at this time.

2. If possible, film should be processed by existing capabilities. Processing should include rectification and reduction to orthographic imagery. Precision-grid or location information should be superposed on the imagery. If no existing high-quality government facility can furnish this service, established commercial mapping services should be investigated prior to establishing a new government facility to furnish the needed processing for this research project. Experience during the research project should aid in establishing the need, technical requirements, and timing for a full-fledged earth-resources processing facility.

Distribution of analog- and digital-tape representation of the imagery should be provided upon user request. Because of the limited number and diversity of potential tape users, automatic distribution of imagery in tape form is probably not justified. Analog tape may be a byproduct of the rectification and gridding step in photo processing. Uniform tape formats and characteristics should be specified in order to simplify later processing by various users with differing computer configurations.

3. There is a very limited capability in the university and industrial communities for special data-processing functions such as image enhancement and frequency and threshold-filtering. These services should be available upon request to researchers and interpreters from the film-processing capability or some other appropriate agency.

4. If the geological research program is associated with other satellite programs, a small central research and development group, in close association with the film-processing and data-processing facilities, should be engaged in producing techniques for increasing ease and capability in interpretation and display of earth-resource information. Their activities should be strongly user oriented, which implies explicit knowledge of user goals and problems. This function might well be provided for the geological research program by a U.S. Geological Survey team operating within the central R&D activity.

5. In order to maximize the interpretive potential associated with the imagery, research in specific areas such as rock-signature analysis, false-color uses, and specific data-processing techniques should be funded at a level of about \$1 million per year. It is assumed that most of this funding would go to the university community. This research should be problem-oriented, i. e., specific interpretive needs should be specified and means to achieve these needs should be sought. Purely academic research has a low probability of fulfilling these specific needs. This does not imply that non-committed research is not desirable. However, the funding of such research is a separate consideration that should be based on estimated capability and need.

Given modest support in research data-processing activities, paid for at cost or a reasonable cost-plus level, the extractive industries will be able to make a substantial contribution to the research program in interpretation of high-altitude exploration-oriented imagery. It is not unreasonable to assume that the research effort by the extractive industries in exploiting this new information source might exceed that of the government.

6. The value of radar imagery is a subject of controversy. It appears that airborne-radar imagery, for unclassified applications, would best be obtained during the next few years by aircraft. The major problem in recommending a radar-imagery program in conjunction with optical and infrared imagery is the dearth of knowledge, in the unclassified areas, of what may be expected from radar imagery. It has been demonstrated that radar produces useful imagery in areas that are permanently under cloud cover. Multi-false-color radar imagery produces spectacular color separations that are associated with different rock types where sufficient ground truth is available. For operational purposes, consistency of radar color and rock-signature information with geologic features must be demonstrated. This leads to the recommendation that initial expenditures should be devoted to R&D, exploring and hopefully demonstrating the capability of aircraft radar imagery for answering useful geologic questions. There is a good probability that sufficient radar imagery exists now for conduct of the needed R&D.

Given sufficient imagery in existence, the incremental increase in interpretive capability from associating radar imagery with visible and infrared imagery is a valid and important R&D activity. If unclassified imagery is insufficient, supplementary imagery can be obtained from existing aircraft-radar systems. The R&D activity should also be charged with

determining what information is produced by what type of radar imagery. This information is essential for laying out equipment specifications and flight plans for future large-area synoptic coverage.

At this time the expected value of shallow-penetration radar imagery is practically nil for geologic problems. Given shallow penetration of 1 to 10 meters, the interpretive art is nonexistent. Again, R&D on the use of radar-penetration information is needed prior to specifying and embarking upon large-scale flight programs.

APPENDIX D

BIBLIOGRAPHY

A substantial amount of material details the issues surrounding the subject examined here. Particularly pertinent are articles concerning handling of images (3, 4, 10, 33, and Appendix B of this report), collection of data from distributed sensors (2), and automatic interpretation (12, 16, 17). In addition, a study conducted by RCA (43), appearing after the completion of this Summer Study, contains a substantial expansion of detail beyond that discussed in the present panel document; the panel benefited significantly from an early review of the RCA findings. We are also particularly indebted to the Forestry, Agriculture, and Geography Panel, and to the Sensors and Data Systems Panel of the 1967 Space Applications Summer Studies for their thoughtful reports and guidance (6).

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