Engineering Notes

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A System Analysis of Applications of Earth Orbital Space Technology to Selected Cases in Water Management and Agriculture

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THIS Note reports on a concept for a satellite-assisted information system to improve regional water management, wheat crop management, and wheat rust control. Examples are presented for the water management case to illustrate a number of relevant points. The concept employs "user decision models," and particular attention is focused on a technique of dynamic sampling that appears to make the system much more feasible, given the current state-of-the-art.

After preliminary investigations of various regional water systems within the United States, the Columbia River system in the Pacific Northwest was selected for analysis. It represents a geographically and administratively viable region for this purpose. The Columbia Basin covers parts of four states and Canada and contains one of the most sophisticated and complete dam and reservoir systems in the world. This watershed covers about 260,000 square miles. The machinery for cooperation between the three principal water management participants—the Bonneville Power Administration, non-Federal power producers and the Army Corps of Engineers—is formalized in the Pacific Northwest Coordination Agreement. A committee established by this Agreement prepares an annual system-wide operation program. Other agencies, because of their operating mandates or interest in regional water management policies, actively participate in the decision process. They include the Bureau of Reclamation, Weather Bureau of the Department of Commerce, and various local and regional groups. The cooperation of all of these parties was solicited for this study.

The Management Problem

The dam system in the Pacific Northwest is typical in that it must satisfy various needs; power generation is the prime objective of one group, flood control that of another, and so on. The situation would be greatly simplified if the annual flow of water through the Columbia Basin were essentially stable. Human affairs and the decision process become much more complicated in the face of largely unpredictable fluctuations in nature. Figure 1 shows the fluctuations in annual flow at Grand Coulee Dam over the period 1914–66. Moreover, seasonal timing of the flow is an important element in water management. To cope with these irregularities, three types of dams are used: 1) the Annual Dam, whose reservoir regularly fills each year; 2) the Cycle Dam, whose reservoir may or may not fill in any given year; and 3) the Run of the River Dam, which has no reservoir. Each contributes in different ways to the multi-purpose system serving navigation, recreation, flood control, power generation, and irrigation.

System Analysis and Dynamic Sampling

The management approach described herein begins with the user needs or user decision models which, in turn, determine requirements for other elements of the system such as sensor choice, payload components, orbital parameters, and data system needs. It was also found useful to employ "dependency matrices." Figure 2 is a snapshot of the system analysis undertaken in the wheat rust control case. Individual competence tends to be limited to one elbow of the matrix; e.g., the individual familiar with forecasting and/or elements of management decisions may be less familiar with the measurements required for these forecasts and may be unacquainted with remote sensor, aircraft and/or satellite performance. The dependency matrix allows the various experts to get a quick overview of the system and to ask more penetrating questions about system operation.

Problems could arise because of the volume of data generated. Continuous global observations from a four-satellite system yielding 6-hr coverage over any one spot envisaged in the present study would swamp the system and seriously tax state-of-the-art capabilities. (The characteristics of the multipurpose system conceptualized for the three case studies are found in Ref. 5. The sensor package included a multispectral scanner, TV, and radar.) A dynamic sampling technique, tailored to the decision-making process involved in each operational case studied, can greatly reduce data volume, hence data processing and human interpretation activities, although simplifying the telemetry data transmission process, increasing sensor operating life, reducing power requirements, lowering heat outputs, and permitting simplification and reduction of vehicle structure. The dynamic sampling concept is based on the notion that, for various practical purposes, nature need not be considered as in constant change. Rather, various states of nature tend to persist or change in a predictable fashion. Thus, it is practical to schedule less than continuous observations over the area of interest.

The discontinuous change in states of nature is graphically illustrated in Fig. 3. The snow pack is laid down in the fall and winter months during major snow storms. Then, except for a couple of cold periods in the spring months, estimates from climatic data on degree-days might well be used to estimate its melt-off. The sensors become critical in observing

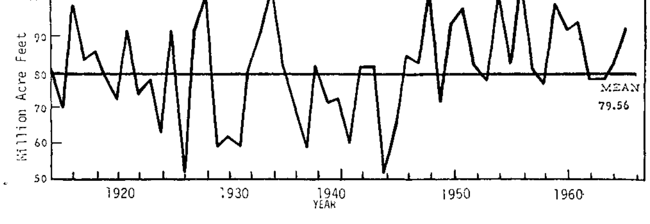

Fig. 1 Annual flow at Grand Coulee Dam, 1914–66.

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MANAGEMENT AREAS/BENEFITS

Legend:

1. Sufficient
2. Major Contribution
3. Contribution
4. Slight to No Contribution

A. Too low a spatial resolution
B. Can detect but not quantify
C. On the basis of area extent only
D. On the basis of low resolution shape information
E. Insufficient resolution for identification by shape and insufficient spectral information
F. Would be excellent if sufficient spatial resolution were possible

MEASUREMENTS	CROP IDENTIFICATION	CROP AREA AND LOCATION	CROP VIGOR	STRESS IDENTIFICATION	STRESS SEVERITY	STRESS LOCATION	INFECTION PROBABILITIES	TV	MSS	RADAR	Microwave Radiometer	IR SCANNER
INCREASED YIELDS	3	3	2	2	2	2	2					
MINIMUM DAILY TEMPERATURE	4	4	3	3	3	3	2					
MAXIMUM DAILY TEMPERATURE	4	4	3	3	3	3	2	4	1/2 (H)	4	4 (A,H)	1/2 (H)
RAINFALL	4	4	2	4	4	2	2	3(B,C,I)	2 (B,C,I)	1/2 (B,C,I)	2/3 (A,B,C,I)	2/3 (B,C,I)
SOIL MOISTURE	4	4	3	3	2	?	2	3(B,C)	2 (B,C)	2 (B,C)	2/3 (A,B,C)	2/3 (B,C)
PLANT TEMPERATURE	2	2	2	2	2	2	4	4	1/2 (A,F)	4	3/4 (A)	1/2 (A,F)
RESPIRATION	3	3	3	2	2	2	2	4	4	4	4	4
EVAPOTRANSPIRATION	3	3	2	2	2	2	2	4	2 (A,J)	4	3/4 (A,J)	2 (A,J)
ACRES OF WHEAT	1	1	4	4	4	4	4	2(D,G)	2 (F,G)	2/3 (D,E)	3/4 (A)	3 (E)
WIND (DIRECTION AND VELOCITY)	4	4	4	4	3	2	2	4	4	3/4	3/4	4
AIRCRAFT SYSTEM A												
AIRCRAFT SYSTEM B												
SATELLITE SYSTEM A												
SATELLITE SYSTEM B												

G. On the premise of spectral recognition

H. High frequency observation required

I. After fall of rain

J. Depending on time of diurnal cycle, transpiration controls plant temperature

Fig. 2 Wheat rust dependency matrix.

the discontinuities in this process, which are averaged out in the climatic data.

Obviously, states of nature tend to persist when we look at various phenomena. Thus, a realistic observation schedule would not require frequent sensings of some phenomena. Efficient sensor management in turn means extended equipment life, as noted above, or alternatively, the opportunity to use the payload for additional missions. A formalistic quantification of all the parameters and the changing interrelationships with shifting states of nature proved beyond the scope of the time and resources available. However, a semi-quantitative approach ordering a set of representative events in scenario form proved effective in developing the concept of the total system. For example, precipitation is dropped in the Pacific Northwest by major storms that originate in the Gulf of Alaska and release their moisture as they cross the Coast Range, Cascades, or Rocky Mountains. As the storm moves over the Pacific Ocean, it need not be observed every 6 hr, which would be possible with the conceptualized satellite system. It will be useful to observe the storm as it dumps its moisture. The height, direction, and other characteristics of a given storm may mean that it can only dump its load as it reaches the Rocky Mountains. Observing the time of precipitation constitutes a specific requirement on the system. However, a check on the results in the form of increased snow pack or moisture on the ground can often be done in a more leisurely fashion.

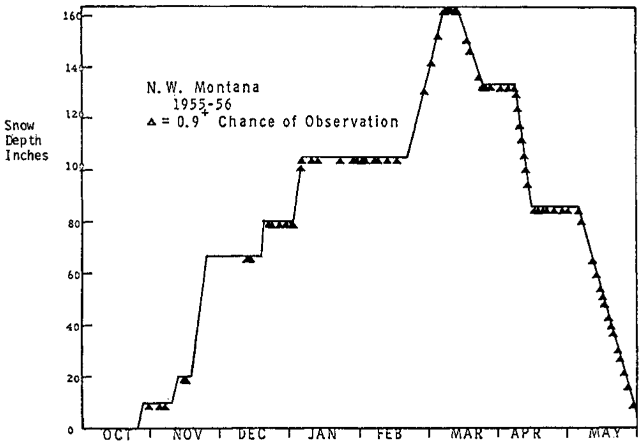

Fig. 3 Potential satellite observations over Northwestern Montana stations.

The objective of the dynamic sampling technique is to manage the required sequence of sensor observations. The duration of the various states of nature can be conservatively estimated. A given storm originating in the Gulf of Alaska will not reach the Pacific Northwest for 3 to 4 days at porjected speeds and routes. Care must be taken to allow for cloud cover, if it is relevant, in projecting the availability of unobscured sensings for decision-making purposes. Each unobscured sensing of a given state of nature tends to cumulatively reduce the probability of false identification. (Reference 5 cites a number of other ways in which the confirming and reconfirming aspects of the system emerge from the scenario analysis to increase over all confidence in the total effectiveness of the system.)

Since it is possible to incorporate a feed-back loop comparing the cumulative reduction to the acceptable operating level of false identification, it is practical to propose a continuous adjustment in sensor observing management. Dynamic sampling management would cover the time, parameter measured, sensing instrument and area involved. A computer program to manage the mechanics of the telemetered command and control routines can be readily imagined.

Conclusion

A standardized over-all methodology for establishing system requirements of a satellite-assisted information system for resource management permits meaningful cost/benefit comparisons across various resource areas and an effective integration of the various resource management information requirements into a multipurpose satellite system. Dependency matrices are useful in portraying a snapshot concept of a completed system to permit expert review and analysis. The application of a dynamic sampling concept appears to reduce data requirements significantly, with the obvious benefits relative to system complexity and requirements to advance the state-of-the-art. Finally, the scenario method of organizing the many events involved in the total system helped to develop the concept of the system and suggested the way to sequence the various sensors and other elements of the operational system.

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Apollo Spacecraft Certification Test Program

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TESTING played a vital role in the development and maturity of the Apollo spacecraft hardware. The four elements paramount to achieving the present high degree of reliability demonstrated in flight by that hardware were adequate design redundancies, exhaustive testing, control of configuration changes, and a thorough understanding of all discrepancies. These elements played a significant part during preflight ground tests in demonstrating the capability of the Apollo spacecraft hardware to withstand the rigors of lunar flight and the return to Earth.

The role of the certification test program can be clarified by considering its relationship to other aspects of the total Apollo spacecraft test program. The purpose of this test series was to ensure that the hardware design was adequate for the performance of specified functions for the time and under the spectrum of environments that were expected for a like piece of hardware during the combined ground and flight life of the hardware. The hardware was used solely for testing and, as such, was not used for flight.

The certification concept selected for the Apollo Spacecraft Program was an integrated test and analysis program in which, nominally, two production units of hardware were used; one unit for design-limit testing, and the second unit for mission-life testing. This program was designed to not require an excessive amount of hardware and to demonstrate the capability of the hardware to withstand the spectrum of environmental magnitudes and durations with margins of safety greater than those expected in flight. This test program permitted more test articles for testing of certain critical items such as those in the propulsion system and for testing of high-usage hardware such as switches and relays. Although a statistical demonstration of the reliability of the hardware would not be obtained, this approach would provide a significant degree of confidence in the design.

A total of 712 certification tests for the command and service module (CSM) and 505 certification tests for the lunar module (LM) were required to be completed successfully before flight. Complete subsystem and vehicle-level tests were included in the program to demonstrate the design capability of the interfaces between hardware elements (125 tests for the CSM and 175 tests for the LM).

Although certification hardware was required to be tested for the equivalent of one complete ground-operating cycle and two complete flight-duration cycles, most of the certification hardware was exposed to considerably more testing than this ground rule indicates. Additional testing occurred, in part, because significant design changes were incorporated into the certification units, and the complete test or major parts of the test were repeated. In addition, some hardware, such as switches, were used in a hybrid test program that resulted in the accumulation of additional test hours.

The multitude of certification tests to be conducted, the numerous locations across the country at which the testing was done, and the large number of persons involved necessitated a thorough management control system. Although the successful development of spacecraft hardware cannot be reduced to a specific formula, a series of specific requirements was used to manage the certification test program.

Testing was the primary method for the demonstration of hardware capability under environmental stress and was undoubtedly the key to the success of the certification test program. The "show me by test" attitude was dominant in the organization that managed the test program.

The use of production hardware, whereby the test article was produced under the same design manufacturing processes and controls as the flight hardware, ensured that the minor, and sometimes subtle, design or process changes (from which new failure modes can be introduced) were adequately tested.

Units were tested at the highest practical level of assembly to ensure that as many of the interface problems as possible would be uncovered. Although this procedure was often

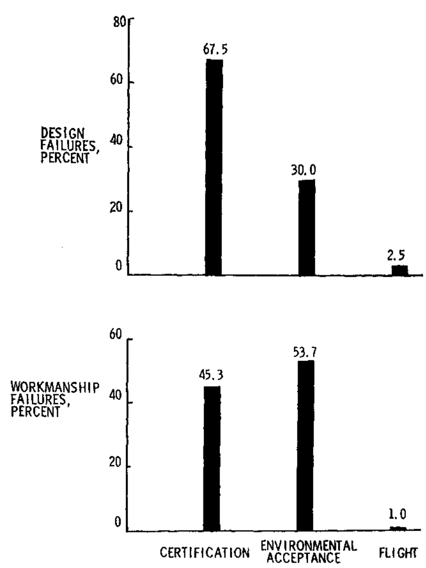

Fig. 1 Distribution of Apollo design and workmanship failures to three test categories.

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