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ON THE TRANSFER OF REMOTE SENSING TECHNOLOGY TO AN OPERATIONAL DATA SYSTEM

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ABSTRACT

The dynamics of transferring remote sensing technology to operational activities of a user agency are explored. The particular evaluation criteria of the Foreign Agricultural Service serve as the motivation for a framework which organizes information to provide a quantitative basis for management decision relative to technique and procedure acceptance for transfer.

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I. INTRODUCTION

Imagery obtained by satellite has been available in the ERTS and the LANDSAT programs for five years. Current use of the data is primarily confined to NASA development efforts, research centers, and technology transfer centers funded by NASA. Agencies charged with management of earth resources are not yet making day-to-day operational use of the data on a large scale. Unless successful applications of remote sensing can be made to operational systems, it becomes necessary to pause and ask very searching questions about the future of remote sensing investigations. The developers of processing technologies and data handling systems must examine the applications requirements of potential using agencies and act accordingly. Cost effective procedures and systems on which to base operational data systems must be developed for the processing of LANDSAT data. Potential users must develop methods to validate the usefulness of any proposed processing techniques when applied to an operational system. D. W. Mooneyhan, NASA/JSC, has pointed out, "It is easy for one technician to convince another that a new technology has application, the more difficult and time consuming part is convincing management, committees, and legislatures to adopt a new technology into their institutions."[1]

The terms "transfer" and "operational" activities require clarification. The technologies associated with meteorological and communications satellites provide the pattern of technology transfer. Requirements were developed for the satellites and ground data systems by NASA in cooperation with appropriate Federal agencies or private industry. The development of sensors, platforms and ground communication and data processing facilities was funded by NASA. Investigations were conducted in the agencies and private sector into the utilization of the new technologies for weather analysis and communications. The agencies and private industry assumed fiscal responsibility for the programs at a point in the process when the new technologies were deemed to be of use in the day-to-day activities of the user. The users have developed a routine dependence on the new technologies -- the ultimate form of transfer to operational activities.

Transfer of technology generally progresses through the following steps:

- Identification of User Requirements
- Assessment of possible remote sensing contribution
- Evaluation of existing data processing techniques and procedures
- Development of procedures and systems for cost effective data handling
- Demonstration of end-to-end system on limited basis
- Development of operational data system.

The United States Department of Agriculture (USDA) has worked diligently with NASA for several years to identify LANDSAT data and processing techniques to support the operational needs of the department. The USDA's support of the technology was evident in the 1971 Corn Blight Watch using aircraft imagery and is now evident in the intensive work of the Large Area Crop Inventory Experiment (LACIE) project which is jointly sponsored by NASA, USDA, and NOAA. Due to the promising results of the LACIE project, the USDA User Advanced Systems Design Group was formed to plan the transfer of remote sensing technology to USDA operations. The User Advanced Systems Design Group required a method to determine which techniques and/or implementation to transfer from research or developmental status to an operational system in an attempt to define a system optimized with respect to user performance criteria.

The purpose of this paper is to present some of the problems facing the USDA in evaluating data processing techniques for transfer to operational status and a framework for evaluation developed to provide insight into feasible solutions for the problems. A techniques validation framework has been developed to identify which techniques and/or implementations are preferred for application to an operational data system. The approach was developed initially to support management decisions which will face the USDA as the wheat production estimating systems, referred to as the Production Area and Yield Estimation System (PAYES), is developed. A feasible design incorporating LACIE techniques for the PAYES production environment was developed jointly by Ford Aerospace & Communications Corporation and the USDA working with NASA personnel at JSC during 1976. The objective of the evaluation methodology was to develop a scheme for quantifying cost/performance ratio improvements accruable to incorporation of various image processing techniques or modifications of techniques for the PAYES. The quantified results of the analysis are used to provide management information of the worth of a system change.

II. EVALUATION CRITERIA

The role of much of the research conducted in support of the LANDSAT program has been to determine the limits of accuracy of information which can be extracted from LANDSAT imagery. In such investigation the emphasis must be upon accuracy and repeatability of results. While these criteria are important to the operational environment other factors must also be weighted heavily. The PAYES will provide reports for routine reporting activities of the USDA Foreign and Agriculture Service. The reports should provide the basis for worldwide market analyses which become increasingly important relative to worldwide trade agreements. A report of great accuracy which is generated after a trade agreement is consumated is of no value to the negotiating parties. However, there exists a level of accuracy which can influence terms of a trade agreement if the report is available at the time of the agreement.

Correspondingly, the amount of dollars expended in generating the report must be traded against the value of the report. Even within the area of extrapolating costs, variables associated with budgetary cycles must be carefully considered. At one time funds for capital procurements may be more readily available than for additional manpower or skills not normally associated with the labor mix of the agency; in such a case emphasis must be placed upon techniques which reduce labor intensity. The guidelines provided by Foreign Agricultural Service (FAS) in support of the PAYES resulted in the following prioritization of techniques evaluation criteria:

- Timeliness of results
- Ease of development of the system
- Cost of operating the system
- Accuracy.

The early season foreign commodity estimates require a timely reporting capability. Other USDA agencies which have crop reporting problems may require a solution from a system similar to PAYES which emphasizes accuracy. For example, Agricultural Stabilization and Conservation Service (ASCS) would require accurate estimates for relatively small geographic areas to determine compliance within support program guidelines. Both ASCS and Federal Crop Insurance Corporation (FCIC) would require accuracy and timeliness in estimating crop damage due to some natural disaster or widespread crop disease. Payment to farmers as well as budget activities would be supported by having accurate estimates. Even within these two agencies, however, timeliness has a different definition. FCIC would require a more timely report in order to perform farm inspection with adequate time remaining to allow the farmer to replant his fields. ASCS would not require as timely a report due to the longer term nature of the support program payment schedules.

III. DATA PROCESSING FLOW VARIATIONS

The LACIE project has demonstrated that technology for classifying LANDSAT imagery has developed to the point that definite plans for transfer of technology to the USDA have been made. However, within LACIE operations techniques are under continuing review and new techniques are being developed and evaluated. Given the basic technology, the USDA can be expected to incorporate new techniques and develop procedures which best fit their operational requirements.

Of particular interest to the USDA are the major transitions in LACIE. A highly simplified presentation of recent transitions in techniques utilization in LACIE is given in figure 1. The illustration depicts processing sequences for LACIE Phase I, LACIE Phase II and Procedure 1 which will be used in LACIE Phase III in mid-year 1977. The primary variation in processing between Phase I and Phase II was based upon experience gained during LACIE Phase I. In Phase I the

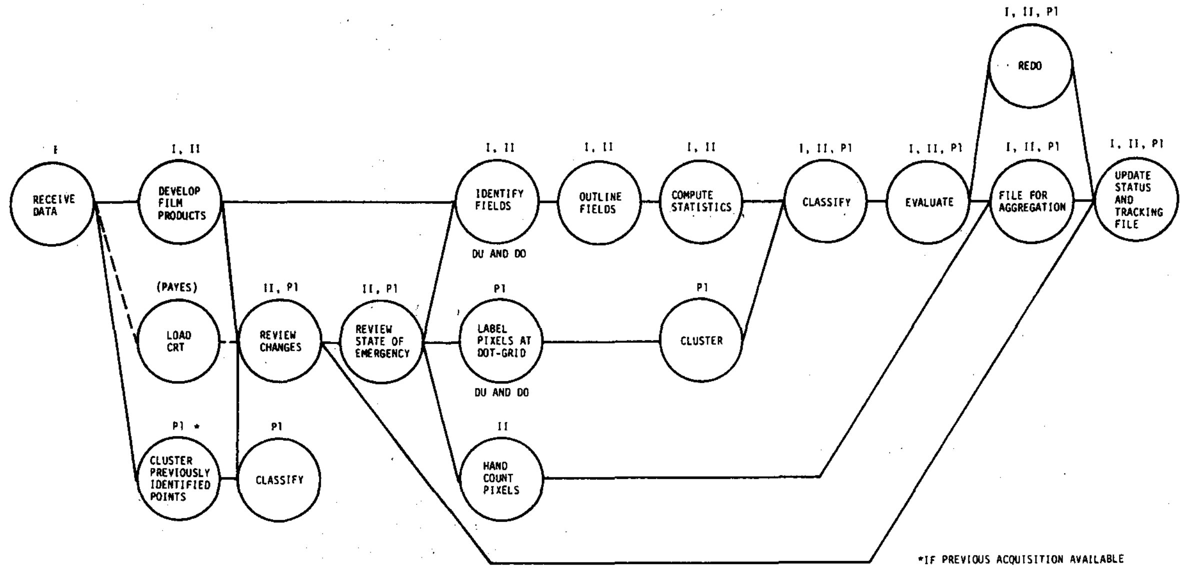

Figure 1

procedure was to classify all sample segments. In Phase II the determination that in instances of low level emergence, hand counts of pixels was a more rapid form of classification than performing the tasks associated with automatic classification. Furthermore, acreage estimates for a given sample segment tend to stabilize and examination of imagery for changes precluded the need for further processing in many instances.

The latest transition in LACIE procedures is Procedure 1 which is the result of extensive analysis which has demonstrated that results comparable to those obtained in Phase II can be obtained without the need for field boundary definition which consumed resources and was a throughput bottleneck in Phase II. Under Procedure 1 the analyst labels the pixels associated with the intersection of regularly spaced horizontal and vertical lines. Within each labeled class cluster analysis provides subclass statistics which serve to train the classifier. After the initial successful acquisition is processed the analyst will routinely be provided with clustering and classification maps derived from labeled pixels from previous acquisitions. Also, the analyst is provided the previous maps and summary statistics to aid in the change determination process. The USDA will review LACIE procedures on a continuing basis to identify likely procedures and techniques which result in cost effective improvements in PAYES performance.

To date the LACIE project has relied upon film products to support analyst interpretation activities. The USDA will evaluate the cost effectiveness of using high fidelity color CRT displays for some interpretation work in an attempt to reduce the number of film products generated. All currently manual functions will be under continuing review to determine if automatic procedures are available which support or replace manual functions using the current (at the time) USDA evaluation criteria. Once again, it should be noted that the objective is not necessarily to duplicate LACIE accuracy but to transfer techniques and develop procedures which satisfy a weighting of the evaluation criteria. The framework for evaluation which will be applied is presented in the following section.

IV. FRAMEWORK FOR TECHNIQUES VALIDATION

The validation approach developed for the PAYES is based on a model for selecting from alternate system elements during design tradeoff analysis.[2] Results of experiments with new techniques will be quantified by research analysts as to expected, pessimistic, and optimistic performance capabilities in the same manner as production managers provide inputs for classical PERT scheduling.[3] This allows expected performance results to be assumed statistically independent. Statistical independence allows linear summation of expected performance of techniques in order to obtain expected system performance. New or modified techniques suggested as feasible for the operational system can then be analyzed in a system tradeoff analysis. The evaluation is sensitive to the cumulative effects of quantifications by analysts, but as demonstrated by experience with PERT and CPM techniques the accuracy of estimates improves as the worth of the activity is demonstrated.

An operational data system, such as the PAYES can be described as a sequence of stages of processing. At each stage of processing a next technique or set of techniques is applied to the data. Alternate techniques which may be used to process any stage are defined as the possible states of the system at each stage. Utilizing the theory of optimizing systems by dynamic programming methods it is possible to select from the alternate techniques for each processing function, or stage of processing, a technique which optimizes the system with respect to the evaluation criteria. The cost/performance of an operational system is a linear function of the defined user performance criteria and special constraints. Weighting coefficients reflecting the user's priorities on the performance criteria and cost factors are used to simplify the cost/performance function to a scalar.

The approach considered for application to PAYES assumes that processing of LANDSAT data is a set of processing functions. The "state" of the system, as defined in the model, reflects the set of sequential functions accomplished no matter which technique may be used to process the function. The system life is considered to be a set of sequential states and a network of processing functions of the form in figure 1. The cost (C) of following a specific branch is determined as a linear combination of development, implementation, and operations costs. Throughput, ease of use, accuracy, and repeatability of results are combined to obtain the performance (P) of each technique. The cost/performance ratio (R) can be expressed as:

$$R = \frac{W_c \cdot C}{W_p \cdot P}$$

with W_c and W_p vectors of weighting coefficients with elements which reflect the degree of sensitivity desired for the respective cost of performance element. The probability of using a given path is used to predict the number of units per path. For analysis the probability of using a given path, or technique, is derived emperically from analyst experiences with the new techniques during development. The system throughput cost is then a function of the number of units processed on each feasible path through the system, the expected value of the respective path cost/performance and the path constraints.

As an example, consider the simple system of figure 2. The baseline technique is presented graphically by path A-B-C-F. The throughput time is defined by experiment in an operational environment. A proposed processing modification would add techniques D and E with resultant possible sequences of A-D-C-F and A-D-E-F. The throughput time is developed probabilistically from inputs provided from an analyst working on the development. The analyst provides an expected, a pessimistic, and an optimistic throughput time for the suggested new techniques. The experiments in developing the technique are analyzed to determine the relative frequency of taking a particular path assuming the current state allows the option, for example, when finished with A the system was such that 80% of the time D could be used if available.

The frequency of using a given technique is shown on the lines of the network. Table 1 reflects the performance data for the system. The performance analysis date in in table 2.

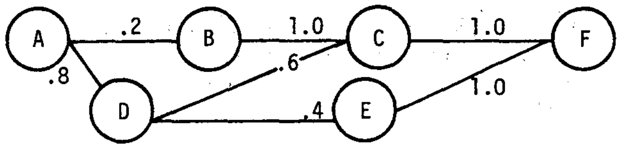

Figure 2

Function	Most Likely Time	Pess. Case	Optim. Case	Expected Time	Variance
A	151			151	0
B	83			83	0
C	74			74	0
D	76	60	87	75.16	4.5
E	65	50	95	67.5	7.5
F	52			52	0

Table 1

Path	Expected Cost in Time Units	Variance
1. (A-B-C-F)	360	0
2. (A-D-C-F)	352.16	4.5
3. (A-D-E-F)	345.66	12.0

Table 2

Path 2 provides an expected gain of 7.84 units. The probability that the time is less than the original 360 units is 95.91.

Path 3 provides an expected gain of 14.34 units. The probability that the cost is less than the original 360 units is 88.5.

In addition, the path use probabilities yield the following expected time for the modified system:

$$A + .2(B+C+F) + .8[D+.6(C+F)] + .4(E+F) = 351.64$$

an expected gain of 8.36 units to the system.

V. CONCLUSION

Transfer of a particular technique to an operation system requires the expenditure of resources such as manpower, system downtime, and budget. The benefit of a proposed technique for an operational system should be defined in terms of user specific evaluation criteria on performance and costs. Traditionally, management personnel have based decisions on intuition and results from often isolated sources. The framework for evaluation which has been described organizes the evaluation process and assures, at the very least, that the right questions are asked of technology developers.

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