328/
6-2778

DR. 191

UCRL-52426

FEASIBILITY STUDY FOR COMPUTERIZED AUTOMATION OF EPA REGION II TECHNICAL SUPPORT BRANCH

MASTER

Fred B. Stephens, William F. Morris,
George W. Barton, Jr., and Eugene R. Fisher

February 9, 1978

Work performed under the auspices of the U.S. Department of
Energy by the UCLL under contract number W-7405-ENG-48.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California/94550

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

UCRL-52426

**FEASIBILITY STUDY FOR COMPUTERIZED
AUTOMATION OF EPA REGION II
TECHNICAL SUPPORT BRANCH**

**Fred B. Stephens, William F. Morris,
George W. Barton, Jr., and Eugene R. Fisher**

MS date: February 9, 1978

zB

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CONTENTS

Abstract	1
Introduction	1
Mission of Region II	1
How Region II Fulfills Its Mission	2
Planning	2
Preliminary Reconnaissance	3
Field Work	3
Laboratory Work, Data, and Reports	3
Function of the Technical Support Branch	3
Analyses	3
Division of Responsibility	4
Information and Data Flow, Chain of Custody, Records, and Reports	4
Approaches to Automation	4
Scope and Constraints	4
Goals of the Technical Support Branch	5
Instruments for Automation	5
Instruments Selected for Automation	7
The Study Plan, Job Scheduling, Coordination, and Automation of Sample Management Activities	7
Proposed Systems for Fulfilling the Requirements of the Technical Support Branch Laboratory	9
Option 1	11
Option 2	11
Option 3	11
Cost-Benefit Analysis	11
Introduction	11
Basis for the Analysis	11
Comparison of Costs and Benefits	11
Costs and Benefits Relative to Payout Time and System Life	13
Summary of the Cost-Benefit Study	13
References	14
Appendix A. Description of the Proposed Optional Automation Systems	15
Option 1: Standard EPA Automation System — Data General Computer	15
Computer and Peripherals	15
Laboratory-Instrument Interfaces	16
Software	17
Option 2: Standard EPA System with Communication to a PDP-11 SFC	17
Option 3: Laboratory Automation Using a PDP-11 with Communication to a PDP-11 for SFC	18
Appendix B. Details of One-Time Costs for Three Systems	19
Computer and Peripherals	19
Terminals	19
Site Preparation	20
Spare Parts and Test Equipment	20
System Installation	20
Instrument Interfaces	20
Software	21
Appendix C. Detailed Assessment of Automation Benefits	22
Instrumental Methods	22
Quality Control	23
Sample Management Tasks	26
Summary of Benefits	27
Appendix D. Breakdown of Added Operating Costs from Automation	28
Appendix E. New Personnel Skills and Capabilities Recommended for the Automated Laboratory	29

FEASIBILITY STUDY FOR COMPUTERIZED AUTOMATION OF EPA REGION II TECHNICAL SUPPORT BRANCH

ABSTRACT

Three options are presented for automating the laboratories at the Surveillance and Analysis Division, Environmental Protection Agency at Edison, New Jersey. We found each option to be cost effective. For two of the systems, existing EPA laboratory software would be used without (option 1) and with (option 2) data management. For the third system, laboratory and data functions would be implemented on a different computer (PDP-11) from those now installed. Option 2, the most favorable system, would make use of existing programs and data-management features now being developed; it would break even in 1.82 y and accumulate \$373,928 in the five years after installation.

INTRODUCTION

In this report we describe a feasibility study for the automation of the chemistry laboratories of the Surveillance and Analysis Division of the Environmental Protection Agency (EPA) Region II Office in Edison, New Jersey. The objectives of this study are to establish a comprehensive definition of the current and future automation requirements of the Technical Support Branch and to present a cost/benefit analysis of systems that will fulfill the requirements.

Specifically, we address the needs and objectives of the Region II Technical Support Branch, although these objectives also coincide with certain general objectives of the EPA. One of the current primary objectives of the EPA is to improve the reliability of data and reports generated by all EPA laboratories. To realize this, EPA is actively promoting the use of more quality-assurance checks and adopting optimized standard laboratory procedures. Because these endeavors add to the laboratory workload, automation techniques are being promoted to handle the workload and reduce

the probability of human errors.

Since 1973, the Environmental Research Center (ERC) at Cincinnati and the Lawrence Livermore Laboratory (LLL), in a joint project,¹ have specified, designed, and placed in operation three laboratory automation systems. These systems are located in the Environmental Monitoring and Support Laboratory (EMSL), and the Municipal Environmental Research Laboratory (MERL) in Cincinnati, Ohio and the Region V Surveillance and Analysis laboratory in Chicago, Illinois.

These systems have been designed with the EPA primary objective in mind. At the same time, the systems have evolved into a powerful common design that meets the special needs of water analysis laboratories. This common design represents a substantial investment (\$500,000) by EPA in terms of specifications, fundamental systems design, hardware interface design, and software. Thus, this design should receive primary consideration as a proposed system for automation of a candidate laboratory such as the Region II facility.

MISSION OF REGION II

Region II is a field operations unit of the EPA whose area of operations includes New York State, New Jersey, and Puerto Rico. The main laboratory facilities are located at Edison, New Jersey with a

small field laboratory at Rochester, New York. The primary purpose of the laboratories is to provide surveillance and analytical information, which are transmitted to the data storage and retrieval

(STORET) function of the Water Quality Control Information System of the EPA in Washington, D.C. The Edison facility is required to respond quickly and reliably to emergencies, to aid other regional offices when necessary, and to provide assistance to states in their efforts toward environmental protection.

The mission of Region II is coordinated through three main branches under the director of the Surveillance and Analysis Division: (1) the Emergency Response and Inspection Branch, (2) the Surveillance and Monitoring Branch, and (3) the Technical Support Branch. The Technical Support Branch is responsible for the technical field and laboratory studies of the laboratory. This branch consists of the microbiology, biology, chemistry, and pesticide laboratories (at Varick Street, New York City), and the Operations and Review Section. The Region II Office receives some data management (STORET) support from the Data Systems Branch in New York City.

Region II is primarily concerned with water pollution and is moderately involved with surveys for compliance to lead standards in gasoline. Region II also undertakes some air pollution studies and surveys.

The Laboratory's main water-study activities include ocean dumping surveys and inspections of applicants facilities for National Pollutant Discharge Elimination System (NPDES) permits. This includes the inspection of municipal, federal, and industrial waste treatment plants. Region II also provides surveys of municipal water supplies for compliance with drinking-water standards.

On the average, the effort of Region II is divided among five studies.

- 70% NPDES water enforcement.
- 20% ocean-dumping enforcement.
- 5% water enforcement (water supplies and other).
- 3% gasoline compliance.
- 2% miscellaneous.

HOW REGION II FULFILLS ITS MISSION

Independent of the type of samples that Region II processes, there are certain common procedures to every investigation that require the cooperation of all branches and form a basis for describing how Region II carries out its mission.

A typical study embodies six phases: (1) planning, (2) preliminary field reconnaissance, (3) field work, (4) laboratory work, (5) evaluation and interpretation of data, and (6) reports.

Although all branches cooperate in all phases of a study, not all will contribute proportionately in each of the six phases; rather, they will contribute when or where their expertise is needed. For example, when conducting preliminary field reconnaissance, the Surveillance and Monitoring Branch contributes substantially to the planning phase. The Technical Support Branch also inputs to the planning phase although performing the laboratory work is its main function. Field work is a coordinated effort by Surveillance and Monitoring and Technical Support with participation by Emergency Response and Inspection. Final reports are compiled with contributions from all of the branches involved.

Planning

Before conducting an on-site investigation, survey, or study, a mandated work plan from EPA Headquarters in Washington, D.C. (a product of a resource-planning meeting) is matched with Region

II work schedules. Background information is then compiled. The division or laboratory (or both) maintains a data base upon which to plan a survey, when data are available. Water-enforcement study runs are generally based on permit requirements, but actual concentration data are often limited. For ocean surveys, the laboratory has accumulated a sufficient data base for useful planning analyses. Because of the difficulties in accessing analytical data from previous runs, little data are generally retrieved in the survey planning stages, a deficiency that makes analytical planning more difficult. The information is evaluated to establish whether a preliminary site reconnaissance (survey) is needed, and to design a study plan that includes an adequate sampling program within a reasonable time to carry out the field and laboratory investigations.

A study coordinator from each involved branch coordinates the activities of that branch relative to the survey. Preparations are then made to insure the availability of resources including personnel, field and laboratory testing capabilities, and available equipment and supplies.

Before going into the field, there is a briefing session to review all aspects of the survey. For example, Technical Support will review the nature and numbers of samples, the parameters to be determined in the field and in the Edison laboratory, the holding times of samples, any unusual tests to be made, time schedules relative to sampling, their

shipment from the field, expected arrival at Edison, chain-of-custody procedures, and reporting of results.

Importantly, the tasks may differ in scope from survey to survey, and sometimes require application of a completely new set of tests.

Preliminary Reconnaissance

A preliminary reconnaissance is usually made by the Surveillance and Monitoring team to validate background information and data to be used in the study. This often consists of a plant walk-through to check the number, location, and flows of plant discharges for sampling purposes, any operational problems, possible locations for mobile laboratories, and other information to aid in planning the study.

Field Work

Field work is not the same for each branch. The overall goal is to conduct a well-coordinated survey. Unique tests from the chemistry and biology laboratories, many of which are made in mobile field laboratories, support the Surveillance and Monitoring Branch. Because each study or survey may be different, much effort is needed to set up and equip the laboratory and schedule the required survey tests. For example, when the Technical Support Branch field team arrives at the study site, they will set up the mobile laboratory, prepare reagents and glassware, and run preliminary standard tests

to be certain that the methods and instruments are functioning properly. Region II maintains one Mobile Laboratory at Edison and one at Rochester that are used on-site to monitor bacteriological changes, biological oxygen demand, pH, total suspended solids, and other time-sensitive tests. There is also an Air Mobile Laboratory at Edison containing instruments for the analysis of SO₂, NO₂, oxidants, methane and nonmethane hydrocarbons, CO, and a tape sampler for particulates in air. The data is collected on a Wang 600 and reduced from the tape on a second Wang 600 for printout of hourly averages and other data on a typewriter.

Laboratory Work, Data, and Reports

Field data is entered on the Field Data Sheet, which corresponds to a laboratory number attached to the test sample. Sample numbers are matched against the descriptors and parameters in the field, on receipt at the laboratory, and by each analyst. Preliminary reports are issued to the originator of the study if, due to backlog, a parameter will not be tested until later.

Most data is forwarded on the "Form for Storage of Water Quality Data" for entry into the STORET system. Essay-type reports are prepared for oil identification or other qualitative data. Data for gasoline lead is entered on the prenumbered "Inspection of Retail Gasoline Outlet" report. Biology reports are usually essay type. The results are stored in the Laboratory Data file with the quality-control data for an indefinite period.

FUNCTION OF THE TECHNICAL SUPPORT BRANCH

The Technical Support Branch participates in all six phases of a typical survey. The primary functions of the branch are to provide reliable data as quickly as possible in the field and laboratory.

The activities within the Technical Support Branch differ from those of the other branches. This is because much of the time must be spent on complex chemical analyses (e.g., tests using Auto-Analyzer, atomic absorption, chromatographic, and gas chromatographic-mass spectrometer methods) of water and gasoline surveillance surveys, and quality-control records.

Analyses

Many different variables are determined in the Region II Edison laboratory for the most part by instrumental techniques. Some of the more frequently

used instruments are: atomic absorption, Technicon AutoAnalyzer Systems; optical-emission, visible, and ultraviolet spectrometers; gas and liquid chromatographic and GC-MS instruments; and carbon analyzers. Manual multistep tests like biological-oxygen-demand analyses are also used.

Surveys differ markedly in the type and number of requested tests. In some surveys, the requests may distribute the workload over the full range of analytical methods, while other surveys may concentrate on only a few methods.

This varying workload distribution requires that the Technical Support Branch maintain personnel, expertise, and equipment to respond to the many different requests that are made throughout the year; the branch must also be capable of responding to an intensive workload in a specific area of expertise.

Division of Responsibility

The Surveillance and Analysis Division director is responsible for the surveys, studies, case preparations, and other activities made at the Region II facility in Edison. Generally, work is scheduled on the basis of the weekly work plans submitted to the chief of the Technical Support Branch after consultation of the chief chemist and microbiologist about laboratory resources. The section chiefs assign the test to be made to members of each section through the Official Sample Control And Repository (OSCAR). The analysts set up their schedule of work on the basis of this guide. The OSCAR coordinator must keep the laboratory supervisors and key personnel informed of any changes in the work plan, especially about the numbers and kinds of samples to be taken and the time the results are needed. Decisions must be made about recommended maximum sample holding times and the resources and time available to test the samples in the field and laboratory. Throughout the course of the study, the OSCAR coordinator must insure that the identification and integrity of the samples and data are maintained and documented according to the chain-of-custody procedures.

Information and Data Flow, Chain of Custody, Records, and Reports

Samples are labelled in the field with a station identification, sample location, a laboratory number taken from a prenumbered "Field Data Sheet", date and time of sampling, and sampler's name or initials. For samples originating from other sources, the Field Data Sheet and laboratory number is completed and assigned in the laboratory.

Upon receipt at the laboratory sample receiving station (OSCAR), the sample label and samples are checked for agreement. A chronological "Incoming Samples and Inventory" log and "Sample Record" is maintained at OSCAR. A "Form for Storage of Water Quality Data" is filled out by OSCAR personnel; this form provides the station identification,

sampling date and time, sample type, depth or location, lab number and parameters. Parameters are taken from the "Analysis Request" form filled out, and approved by the chief of the Technical Support Branch or his designate. The appropriateness of containers, preservative, and holding times is also checked by OSCAR personnel before the respective samples are distributed to the analysts. The "Form for Storage of Water Quality Data" is placed in the chemical conference room to be completed by the analysts. A "Chain of Custody Record" for enforcement samples is completed by the originator of the "Analysis Request" form and signed by the chief chemist, who assumes responsibility for the samples while they are in the laboratory. Samples are generally consumed during the analyses or discarded after the data has been checked.

Each analyst who participates in a study refers to a copy of the work plan to schedule his work. For example, if the analyst specializes in metals analysis by atomic absorption spectroscopy, he will refer to the plan, determine the samples that fall into his analysis category, select the samples, make the analyses, calculate the results, and enter his results on the "Form for Storage of Water Quality Data."

The data are reviewed by the laboratory supervisor and then by the Technical Support Branch chief, who forwards a copy to the survey investigator. Also, a copy (with quality-assurance data) is sent to the quality-control officer, who will examine the replicate analyses and the Quality Assurance (QA) data to determine whether precision and accuracy criteria have been met. The statistical data are also examined by Shewhart control chart procedures to assure the data are within acceptable control limits. If these limits are exceeded, steps are taken to identify and correct problems in the analytical method.

The quality-control officer also checks the data for approved reporting units and for STORET compatibility. A copy of the report is then sent to the Data Systems Branch in New York for STORET keypunching.

APPROACHES TO AUTOMATION

Scope and Constraints

Laboratory automation systems have been designed and installed in three EPA water-analysis laboratories: the Environmental Monitoring and Support Laboratory (EMSL), the Municipal Environmental Research Laboratory (MERL) in Cin-

cinnati, and the Region V Laboratory (CRL5) in Chicago. They accommodate the operation of several of the same instrument types that are used by Region II for water-sample analyses. The systems represent a large EPA investment in hardware and software, and it is imperative in this

study that they receive primary consideration relative to the needs of Region II.

In the preceding sections, we have described the overall mission and functions of the Region II facility. All branches could greatly benefit from an in-house computer system. This feasibility study considers only a computer system that fulfills automation of laboratory instruments, data reduction, and other closely related operations allowing it to handle a greater laboratory workload quickly and reliably. Nevertheless, the above constraints do not necessarily preclude future expansion to accommodate other Region II needs at Edison.

Goals of the Technical Support Branch

The goals of the Technical Support branch can be reduced to two fundamental objectives: (1) respond quickly to analysis requests, and (2) make the analyses reliably. These are continuing goals that have been met in the past by new analytical instruments and by improving existing methods and techniques. Further improvements appear to be possible through the use of computer automation in the laboratory. The objectives are to provide the means to the following.

- Link individual laboratory instruments into a system that will acquire and process data for quality-control tests, and store the data for subsequent recall for compilation of a summary-analysis report.
- Determine quality-control results during the time samples are run.
- Perform quality-control studies to establish the data acceptability.
- Assure the integrity and retention (back up) of the analysis data such that no data can be altered or lost.
- Track chain-of-custody of the samples as they move from one person to the next.
- Lessen the number of data transcriptions and make calculations more rapidly.
- Reduce or eliminate possible errors made in these steps.
- Enter data off-line from low-use and non-automated methods.
- Log in samples, their identity, descriptions, the analysis requested, changes in the study plan, and other information pertinent to the analyses and eventual report.
- Determine the status of individual or groups of samples and the parameters completed relative to the study plan.
- List work schedules of samples or variables to be tested.

Many analytical determinations are made in mobile laboratories in the field, especially some

time-sensitive determinations required for some water-sample studies. The procedures for these determinations require numerous data transcriptions, calculations, and the maintenance of record sheets. Where appropriate, the data from these tests must be included in the Region II databank to make available comprehensive computer-generated reports.

Instruments for Automation

Some of the instruments used in the Technical Support branch laboratories are the same as those already automated in other EPA laboratories. They are the best candidates for automation because most of the software has been developed and the hardware interfacing designed. The only cost incurred by Region II would be that of fabricating the interfaces. The instruments that fall into this category are:

- Perkin-Elmer AA spectrometer 403 (2 instruments).
- Perkin-Elmer Automatic Sampler AS-1.
- Technicon AutoAnalyzer II (2 instruments).
- Technicon AutoAnalyzer II (2 units, modified CSM-6).
- Technicon sampler IV.
- Beckman Model 915 carbon analyzer.
- Mettler electronic balance.
- Jarrell-Ash ICP emission spectrometer.*

Instruments that do not fall into these categories, but require some additional automation or modification to already existing automation development are:

- Perkin-Elmer Model 460 with HGA 2100 furnace.
- Finnigan chemical ionization GC/MS system.
- Finnigan electron ionization GC/MS system.
- Oceanographic International total carbon analysis system.
- Perkin-Elmer Model 202 UV/visible spectrophotometer.

*The Jarrell-Ash ICP emission spectrometer contains its own computer for data acquisition, reduction, and individual-sample report generation with data output by means of punched paper tape.

The use of the ICP emission spectrometer by Region II is not included in this analysis; however, experience at other laboratories indicates that additional data handling capacity is required to store data and manipulate results for multiple samples. Work is underway to develop efficient means of transferring data to the laboratory automation system to facilitate the additional data-reduction capability. The dollar value of this benefit and the costs to implement it cannot now be determined.

These instruments, the measurements taken, and the maximum workloads per survey are briefly described in the following sections.

Atomic Absorption Spectrometer

The atomic absorption spectrometer is used to determine the levels of metals in water samples. The instrument contains a characteristic atomic-line source (hollow cathode lamp) of the metal to be determined, a flame or furnace source for exciting metals in the sample, a monochromator to select light of the appropriate wavelength, and a photomultiplier tube to detect the light. Water samples are aspirated into the flame or injected into the furnace, which is positioned between the hollow cathode lamp and the monochromator-detector. Neutral atoms of the metal of interest absorb the characteristic light from the hollow cathode, and the instrument detects and measures decrease in light energy (absorption). The value can be read on a digital display in absorbance units or directly in concentration, which is proportional to absorbance.

Two Perkin-Elmer spectrometers (models 460 and 403) have been used to determine approximately twenty different metal elements in water samples. Model 406 has an AS-1 automatic sampler as an integral part of its system.

Technicon AutoAnalyzer

The AutoAnalyzer performs continuous-flow, multiple-chemical analyses. The system aspirates samples in sequence, brings sample and reagent together for reaction to form a colored solution, and continuously moves the sequence of samples through predetermined analysis steps. The analyzer moves the colored solution through a colorimeter where its light absorption is measured. The concentration, which is proportional to absorbance, can be presented on a recorder or digital tape. A six-channel Technicon CSM-6 analyzer (modified as two TAA IIs) and two Technicon AutoAnalyzer IIs are used for the determination of analytes such as phenol, Kjeldahl nitrogen, NH_3 , $\text{NO}_3\text{-NO}_2$, and various forms of phosphorus. The analyzers have automatic samplers as integral parts of the system.

Mettler Electronic Balance

The Mettler balance to be used will be the recent Model HL52 electronic analytical balance. The balance is used most often for weighing total suspended solids in water and for organic and bottom-sediment analyses. The number of weighings on the electronic balance will be high: about 1,000 suspended solids analyses requiring two weighings each, and 500 to 600 organic and bottom sediment analyses requiring six weighings each will

result in approximately 5,000 to 5,600 weighings annually.

ICP Optical Emission Spectrometer

Multielement determinations of trace metals in water samples and residues are made using a Jarrell-Ash optical spectrometer equipped with an inductively coupled, argon-plasma excitation source. The sample is nebulized to an aerosol in high-temperature argon that is heated as the gas passes through a radio-frequency field. Radiation from the plasma that is characteristic of the excited argon and impurity atoms is dispersed in the grating spectrometer and focused on separate slit-photomultiplier tube assemblies (channels) precisely arranged along the focal plane of the spectrometer to detect each element of interest. The signals for individual samples detected in each channel are processed by a minicomputer and typed out directly in concentration units for each element. The minicomputer is an integral part of the spectrometer.

The optical emission spectrometer is currently being used for the determination of metals on unregulated samples. It has high precision and accuracy, equivalent to atomic absorption for many elements, but can process more samples in time.

Total Organic Carbon Analyzers

Total organic carbon is determined by combustion of organic matter to convert the carbon to carbon dioxide which is detected as it passes through an infrared analyzer. The two instruments that are used for this determination are the Beckman Model 915 Carbon Analyzer and the Oceanographic International Total Carbon System.

With the Model 915, a measured volume of the test solution is injected into a combustion furnace where a continuously flowing stream of oxygen converts the water to water vapor and organic carbon to carbon dioxide. The water vapor is condensed and trapped as the gases are carried out of the furnace, and the carbon dioxide is carried through the infrared detector and released to the exhaust. The infrared detector generates an electrical signal that is converted to a voltage proportional to the amount of carbon dioxide passing through the detector. The voltage is recorded on a strip-chart recorder, and the amount of organic carbon present in the injected solution is calculated by comparing the recorded voltage with that for a standard solution containing a known amount of organic carbon.

The Oceanographic International carbon analyzer consists of a sample preparation and analyzer unit. Up to 10 ml of sample are placed in a borosilicate ampule, and potassium persulfate is added. To remove pre-existing carbonate, the mixture

is acidified and purged with oxygen. The ampule is then sealed, and the organic matter oxidized to CO₂. The ampule is then transferred to the analyzer unit where the seal is broken, and the quantity of carbon as CO₂ is measured with a nondispersive infrared analyzer.

Ultraviolet and Visible Spectrophotometer

A Perkin-Elmer Model 202 UV/visible spectrophotometer is used. The spectrophotometer consists of interchangeable, tungsten-filament (visible) and hydrogen (ultraviolet) source lamps, sample-solution cells, a monochromator, and a detector. The solution cell containing the sample is placed in the light path between the source lamp and the monochromator-detector. Light passing through the solution is absorbed by the analyte over a wavelength band characteristic of the analyte. Measurements are made in absorbance units; absorbance is proportional to concentration. Phenol, cyanide, and MBAS are the most frequent spectrophotometric determinations made.

Automation of the Perkin-Elmer 202 is not included in this study because it is used so infrequently at the Edison facility.

Other Instruments

The chromatographic and Finnigan GC-MS instruments are integrally automated or semi-automated, and therefore further automation linked to a laboratory automation system is not now justified. Additional software and hardware to link the data output of these instruments to the central data system is possible, but not included in this study.

Other instruments are used in the laboratory such as sulfur analyzers, automatic titrators, ozone analyzers, nitrogen oxide analyzers, pH meters, and a polarographic analyzer. The workloads on these instruments are not sufficiently high to warrant the development of hardware and software for their automation. If desired, analytical results from them can be manually entered into the computer data base, which would require some additional software.

Instruments Selected for Automation

For this feasibility study the following instruments (number available) have been selected for automation at the Region II Edison facility:

- AutoAnalyzer II unit with Technicon Sampler IV (4).
- Perkin Elmer Model 460 AA spectrophotometer with HGA 2100 furnace and PE AS-1 sampler (1).
- Perkin Elmer Model 403 AA spectrophotometer (2).
- Beckman Model 915 carbon analyzer (1).
- Oceanographic International total carbon system (1).
- Mettler electronic balance, Model HL52 (1).

Study Plan, Job Scheduling, Coordination, and Automation of Sample Management Activities

For each study, a work plan is devised as described previously. This plan includes sampling schedules along with the parameters to be determined and will establish a data base into which will be placed the data from chemical tests made in the field and at the Edison laboratory. The study plan provides the schedules by which the Technical Support branch can plan its work, determine the status of a survey, fulfill changes therein, and generate reports.

Throughout the course of the survey, there are many transcriptions of information and data in the field and the laboratory (Fig. 1). Records of information and data maintained by all of the laboratory participants are numerous, and must be compiled into a unified report. The present system requires much coordination and diligent rechecking to ensure that the information and data flow are correct and proceed smoothly within the time constraints set by the study plan. Establishing a sample data file could be made more efficient and reliable if data acquisition, information and data transcriptions, and record keeping were minimized. This would apply throughout the survey from sampling log-in, analysis, data logging, calculations, data compilation, and generation of reports.

In this study, Sample File Control (SFC) is defined as an automated system to create and allow interaction with a sample data file. Such a system would facilitate the determination of the momentary status of any given sample or group of samples. The following is a list of minimal SFC functions that are candidates for automation.

Water Quality Data File

A water quality data file is created that will be available in one or more computer files to be accessed for local laboratory work schedules and to determine the status of the work plan relative to parameters in samples completed. The file also provides hard copy.

Water Quality Data File Update

Provisions are made for updating the computer files with analysis-results and changes in the work plan.

Fig. 1. Survey information and data flow.

Sample Reruns

The means are provided to amend the water quality data file with approved results from samples that have been rerun.

Completed Samples

The means to review all analysis results of completed samples are provided for the purpose of approving the final analysis report as being ready for STORET. Hard copy is also provided along with the means to transmit these data to STORET.

Samples in Process

A means to list all samples having incomplete data with hard copy is provided.

Laboratory Work Schedule and Analysis File

A local analysis file is made available by listing samples to be run according to a common-parameter test. Hard copy is also provided.

Laboratory Analysis File Update

Provisions are made for updating the local analysis file with results as they are generated.

Analyst's Report

The means to list an analyst's completed analyses and quality controls is provided with hard copy. The hard copy can be dated and signed by the analyst and QC officer and retained as litigation backup evidence.

Chain-of-Custody

A file for recording sample chain-of-custody with hard copy is provided.

Entry of Field Analyses

A means is provided for entering field data into the water quality data computer file.

PROPOSED SYSTEMS FOR FULFILLING THE REQUIREMENTS OF THE TECHNICAL SUPPORT BRANCH LABORATORY

We propose three optional automation systems, briefly described below. More details about these three options are presented in Appendix A; the configurations are shown in Fig. 2; the one-time system costs are listed in Table 1 and Appendix B. In this table, the costs pertain to the computer and peripherals, the hardware interfaces, the software, site preparation, spare parts, test equipment, and system installation. Also included for options 2 and

3 are the costs for communications hardware and software that allow the laboratory automation system to communicate with a remote (regional) management system for the SFC functions listed in the previous section. The management computer system (DEC PDP 11/70, proposed) presumably will have been justified separately for regional management needs and will not be a cost incurred by Region II Technical Support Branch.

Table 1. Summary of costs for the proposed optional computer automation systems.

Item.	Option 1: data general lab., automation only	Option 2: data general lab., automation + communication with SFC	Option 3: digital equipment lab., automation + communication with SFC
Computer and peripherals	\$82,866	\$119,406	\$180,674
Terminals	22,000	31,800	31,800
Site preparation	15,000	15,000	15,000
Spare parts and test equipment	10,900	10,000	10,000
System installation	40,000	40,000	40,000
Instrument interfaces	34,300	34,300	40,041
Software	No cost ^a	20,000	181,500
Total one-time costs	\$204,166	\$270,506	\$499,015

^a Assuming no modifications required to existing software now being used with the standard EPA Automation package.

Fig. 2. Three proposed options for automation of EPA Region II laboratory.

Option 1

The first option is based on the EPA standard laboratory automation design currently installed in water-analysis laboratories in Cincinnati and Chicago. The system incorporates a Data General computer with the MRDOS operating system and Basic language programming capability. The ECLIPSE S/230 was chosen for costing purposes. The choice of the computer should be deferred until the implementation design phase because other computers may become available for the agency-wide system. The EPA system also includes laboratory instrument interface designs and BASIC language programs with assembly language routines for operation of the automated laboratory instruments. Descriptions of the computer hardware, the interfaces, and software comprising the system are given in Appendix A. Although the proposed system embodies the current EPA design, the computer hardware differs from the currently installed systems in that more recent designs of the central processor and peripheral devices are proposed. The

new generation equipment remains largely compatible with the analytical instrument hardware interfaces and applications programs developed for the standard system.

Option 2

The second option is an outgrowth of the EPA decision to adopt the PDP-11 system (Digital Equipment Corporation) for decentralized processing by regional offices. This option includes the standard EPA laboratory automation system (same as option 1) with added hardware and software to communicate with a host PDP-11 (in the regional office) for SFC functions.

Option 3

Option 3 also considers the EPA commitment to PDP-11 computer systems to automate the laboratory. This option would include hardware and software to communicate with an additional PDP-11 for SFC functions.

COST-BENEFIT ANALYSIS

Introduction

Three optional systems have been proposed to fulfill the needs of the Region II laboratory. We must now show the extent to which Region II can justifiably incur the costs against the benefits it can expect to derive from these proposed systems. It is the purpose of this analysis to place a dollar value on the benefits vs the dollar costs.

Basis for the Analysis

To analyze this problem, we used the workload derived from Region II data for 1976 and the projected estimate for 1977 based on the actual workload through May 1977. We compared the effort and operating costs required to meet the load with and without automation.

The data shown in Table 2 are based on the determinations made at the Edison facility and do not include field determinations. The numbers given for the total determinations per year are exclusive of determinations made for quality control.

The effort of the Technical Support branch personnel can be broken down into three categories: (1) administrative and supervisory tasks, coordination and collation of studies, and summarizing of analysis data; (2) laboratory work; and (3) quality control. The present expenditures are shown in Table 3 in amounts of full-time employees (FTE)

required (i.e., 0.5 FTE is half of a full-time employee's time).

Quality-control standards are run to check all analytical methods. The time devoted to their preparation and running is not included in the effort of the quality-control officer, but in the laboratory personnel's effort. The tasks of the quality-control officer are to make certain that quality-control procedures are followed and criteria are met.

Our intent in this study is to estimate the benefits that will accrue to the Technical Support branch in the best areas for automation. Briefly, these include on-line automation of the Technicon Auto-Analyzers, atomic absorption spectrometers, electronic-balance operations, and total organic-carbon analyzers. The other prime area for automation includes study-coordination and sample-file-control functions such as log-in and work scheduling.

Comparison of Costs and Benefits

To assess the cost benefits to Region II as a result of automation, we compared the effort that will be expended in the instrumental analyses, sample coordination, and management areas by manual methods to the expected effort by computer-automated methods.

The increased efficiency after automation can be expressed as full time employee (FTE) effort made

Table 2. Analysis methods and percent of determinations performed.^a

Method	Number of samples/y	Number of parameters/sample	Total determinations/y	Determinations of total, %
Atomic absorption	570 (H ₂ O & sediment)	7	4,000	17
Atomic absorption	3,000 (gasoline)	1	3,000	12
AutoAnalyzer	860 (nutrients)	7	6,000	25
Emission spec	225 (metals)	18	4,000	25
Total organic carbon	2,000	1	2,000	9
GC/MS	600	5	2,500	11
Gravimetry	1,000	2	2,000 ^b	9

^aBased on average 1976 and projected 1977 data.^bRepresents approximately 6,000 weighings.

available for other tasks such as making more analyses or surveys. Benefits, expressed as increased efficiency, are summarized in Table 4. Details of this assessment are given in Appendix C. On-line instrument automation and quality control (QC) will

make available 3.36 FTE, while sample management automation will free another 2 FTE. Because the laboratory's expected average annual cash output per employee is approximately \$45,600,* the savings attributable to laboratory automation and QC is equivalent to \$153,200/y. The savings in management effort is equivalent to \$91,200/y. Thus, the total savings accrued to Region II is \$244,400 annually.

The one-time costs for each of the three proposed optional automation systems are listed in Table 1. In addition to these costs, it is essential to include

Table 3. Full-time employee (FTE) expenditures for the Technical Support Branch.

<u>Administrative tasks</u>	
Branch supervisor	0.1
Chemistry supervisor	0.5
Biology supervisor	0.2
Secretary	0.5
Log-in station (OSCAR)	0.8
Chemist administrative duties	0.5
Total	2.6
<u>Laboratory tasks</u>	
Metal analyses	2.8
Organic analyses	3.8
TOC and inorganic analyses	2.9
Miscellaneous analyses	0.2
Total	9.7
<u>Quality-control tasks (supervisory)</u>	
Quality-control officer	1.0
Other operations & review	0.25
Total	1.25

*This assumes a median salary level of \$21,000/y multiplied by 1.3 and 1.67 to account for benefits and overhead, respectively.

Table 4. Summary of benefits.

Candidate area for automation	Effort efficiency from automation, FTE
Instruments	2.41
Quality control	0.95
Subtotal	3.36
Sample management	2.00
Total	5.36

the annual maintenance and operating costs of the proposed systems. These costs, which are above any current annual costs, are \$30,000 for option 1, \$58,400 for option 2, and \$65,700 for option 3. Option 2 and 3 costs are higher than option 1 costs because of the maintenance and operation of communications with SFC. A description and breakdown of these costs for the three options are given in Appendix D.

Costs and Benefits Relative to Payout Time and System Life

To determine whether it is feasible to automate the Region II Laboratory, the benefits derived from automation must be weighed against the costs of the automation system. In this analyses, we use the accumulated benefits at five years' of system service and the payout time of the system as two criteria for measuring feasibility. We calculated these criteria for each of the three options. However, option 1 includes a laboratory automation system only, and does not provide communications with a laboratory management (SFC) computer. Therefore, only the savings derived from on-line instrument automation and quality control (3.36 FTE, equivalent to \$153,200/y) can be considered for the first option.

Also, the annual savings for the three options must be balanced against the added operating costs incurred as a consequence of each automation option.

The first feasibility criterion, the accumulated balance at five years service, ² is calculated using the formula ³:

$$B = b/i[1 - 1/(1+i)^n] - C, \quad (1)$$

where,

B = balance after n years,

b = net benefit per year,

i = interest rate, 10% per year = 0.1,

n = number of years = 5

and

C = one-time investment cost of the system.

The second feasibility criterion, the payout time, is that time when the one-time costs will have been balanced by accumulated benefits. Thus, B in Eq. (1) may be set to zero and the payout time n can be solved by:

$$n = -\log(1 - iC/b)/\log(1 + i).$$

Summary of the Cost-Benefit Study

From a cost/benefit point of view, all options of the proposed automation are economically justifiable. Net equivalents in increased-effort efficiency of \$262,859 (option 1), \$373,928 (option 2), and \$117,746 (option 3), will be accrued by Region II over an expected 5-y system-service life. Also, the original investment costs will have been paid up in 1.90 y (option 1), 1.82 y (option 2), and 3.84 y (option 3).

There are other benefits of automation that will accrue to Region II that will directly influence its mission to respond quickly to emergencies. On-line automation in the laboratory and a link with a sample management system will allow the laboratory to complete a study or survey at least twice as fast. Thus, the laboratory can respond more favorably to peak-load work.

Rapid quality assurance can also be realized with the proposed automation systems. Presently, Region II sample workload includes approximately 50-80% quality controls such as repeat standards and duplicate and spiked unknowns.

The costs and benefits and the calculated feasibility criteria for the three optional automation systems is summarized in Table 5.

Table 5. Summary of costs, benefits, and calculated feasibility criteria.

Item	Option 1: data general lab., automation only	Option 2: data general lab., automation + communication with SFC	Option 3: digital equipment lab., automation + communication with SFC
One-time system costs	\$204,166	\$270,506	\$499,015
Gross annual savings	153,200	244,400	244,400
Added annual operating costs	30,000	74,400	81,700
Net annual benefit	123,200	170,000	162,700
Accumulated balance at 5 y	\$262,859	\$373,928	\$117,746
Payout time, y	1.90	1.82	3.84

REFERENCES

1. Development of Laboratory Computer Automation Systems, EPA-IAG-D6-0321, Interagency Agreement between Energy Research and Development Administration and Environmental Protection Agency, Washington, D.C. (1976).
2. United States Government, Bureau of Budget Circular A54, Washington, D.C. (1977).
3. F. J. Stermole, *Economic Evaluation and Investment Decision Methods* (Investment Evaluations Corporation, Golden, CO 1974).

APPENDIX A. DESCRIPTION OF THE PROPOSED OPTIONAL AUTOMATION SYSTEMS

Three optional systems for automation of the Region II laboratory are described in this Appendix. The selection of the exact equipment to be used should be deferred until the implementation design phase. Other computers and peripherals that become available may be more cost effective than the ones we have chosen for these options.

Option 1: Standard EPA Laboratory Automation System— Data General Computer

The standard EPA laboratory automation system proposed as option 1 incorporates a general-purpose Data-General computer and peripherals, laboratory instrument interfaces, and software designed and developed for the Data General NOVA 840 computer with the MRDOS operating system. Although developed for the NOVA 840, the interfaces and software are largely compatible with any Data-General system that also uses MRDOS.

In this section, we describe the standard EPA laboratory automation system currently in use. Included are details of the computer and peripherals and available hardware interfaces and software currently recommended.

Computer and Peripherals

Computer

The computer used in this cost analysis is the Data-General ECLIPSE S/230, general-purpose computer. Other computers possible for this purpose are the S/130, the NOVA 3/D, and the NOVA 840. All will handle a range of software including Basic, Fortran IV, Fortran V, and Algol. These systems also have the capability to communicate with other computers by means of HASP and 2780 emulators. All qualify as general-purpose computers that are largely compatible with the standard EPA software and interface hardware while providing the capability for future growth. If another computer is chosen, it must satisfy these same requirements. In the proposed system for option 1, 96K words of core memory are recommended for laboratory instrument automation.

Disk Storage

The proposed version of the standard EPA system incorporates the Data General model 6060 moving-head disk, as on the Region-III system now being assembled. This proposed disk has several features that make it better than disk configurations used in previously installed EPA systems. The model 6060 has storage capacity of 96 Mbytes, transfers data at three times the rate and is expected to be more reliable than earlier configurations. Although the storage capacity of the disk is far more than required to implement laboratory automation, a large capacity is recommended because smaller-capacity units do not have sufficient speed, and combined fixed-head and moving-head units are nearly equivalent in cost.

Magnetic Tape

The magnetic tape system is used for permanent storage of software programs and as a backup storage medium (i.e., backup relative to core memory and disk) for the storage of data and information that are being accumulated over extended periods of time. The proposed version of the standard EPA system includes a magnetic tape unit that drives the tape at 75 in./s. Experience with the currently installed EPA systems having slower tape drives indicates that a faster drive would be better, especially if data backup operations are to take place daily or more frequently.

Line Printer

The line printer in the current EPA systems is used to produce, for example, hard copy listings of programs, preliminary and final summary data reports, and multi-position sampler patterns. In a multi-user automation system, a fast unit is desirable; a 300 line/min unit is proposed for the Region-II system.

Paper-Tape Reader

A paper tape reader is a recommended component of the standard EPA system. It is used for system start-up and for the diagnosis of hardware problems when disk or magnetic tape are not available.

Analog/Digital Converter

A multi-channel analog to digital converter with full scale resolution capability of one part in 16,384 is proposed. The converter is essential for digitizing the various analog signals from laboratory instruments interfaced to the computer system. The number of channels required is equivalent to the number of analog signals that have to be processed. For Region II, a total of 14 channels is anticipated initially; therefore, a 16-channel converter is recommended (minimum 8-channel modules are provided). This provides two channels for spares and future expansion, which should be adequate. EPA will probably limit its future purchases to instruments that incorporate a data-processing capability and are designed to be interfaced directly to computers. They contain their own analog-to-digital conversion and will not use the system's converter.

Terminals

Keyboard terminals, through which information is entered and received, are used at the computer, at the interfaced laboratory instruments, and at other potential locations such as sample-receiving and management offices. The proposed system does not include a specific terminal type because the implementation design of the system has not been made. However, two general terminal types are used in the standard EPA system: hard copy teletype devices such as the Texas Instruments Silent 700 and the cathode ray tube (CRT) display devices. The latter may include the "roll-back" feature, allowing for rolling back lines of information or data that have disappeared from the limited-line display screen. Special terminals equipped with a keyboard, CRT display, hard copy unit, and telecommunications accessories are recommended for those options that include communication with a SFC.

Laboratory-Instrument Interfaces

The laboratory-instrument interfaces are the electronic devices that link the analytical instruments to the computer. In the standard EPA system, the instrument signal output terminal is the principal location where interfacing has been installed. The candidate instruments for automation in the Region II laboratory can use the existing interface designs. Table A-1 lists the currently available interface designs and their applications.

Table A-1. Currently available interface designs.

Interface	Application
General computer interface	Timing and control signals
Technicon AutoAnalyzer I	Data signal acquisition
Technicon AutoAnalyzer II	Data signal acquisition
Perkin-Elmer AA spectrophotometer	Data signal acquisition
Varian Techtron AA spectrophotometer	Data signal acquisition
Instrumentation Lab AA spectrophotometer	Data signal acquisition
Sample wheel for AA spectrophotometer	Random and sequential sampler control
Total organic-carbon analyzer	Data signal acquisition
Jarrell ash emission spectrometer (sequential readout)	Data signal acquisition and monitor channel position
Ultraviolet-visible spectrophotometer	Data signal acquisition
Graphite furnace for atomic absorption	Detection of furnace cycles for control of signal acquisition
Mettler electronic balance	Data signal acquisition

Software

While developing automation systems for EPA water-quality laboratories, extensive software has been developed for use in a variety of laboratory instrument applications. The software includes assembly language coding and high-level Basic language programming. Table A-2 summarizes the programs developed to date that are considered part of the EPA standard system.

Table A-2. Standard EPA laboratory automation system — summary of applications programs for laboratory instruments.

Instrument	Functions ^a							
	1	2	3	4	5	6	7	8
Technicon AutoAnalyzer								
AutoAnalyzer I	1	2	—	4	5	6 ^b	7	8
AutoAnalyzer II	1	2	—	4	5	6	7	8
Atomic absorption spectrophotometers								
Perkin-Elmer model 303	1	2	3	—	5	6	7	8
Perkin-Elmer model 306	1	2	3	—	5	6	7	8
Perkin-Elmer model 503	1	2	3	—	5	6	7	8
Varian Techtron AAS	1	2	3	—	5	6	7	8
Instrumentation Laboratory 453	1	2	3	—	5	6	7	8
Carbon analyzer								
Beckman TOC, 915	—	2	—	—	5	6	7	8
Electronic balance								
Mettler, HE20	—	2	—	—	5	6	7	8
Emission spectrometer								
Jarrell Ash, Mark IV, spark excit.	—	2	—	—	5	6	7	8
Spectrophotometer								
Perkin-Elmer (Coleman) 124	—	2	—	—	5	6	7	8

^aThe following is a list of functions and data reduction processes provided by the software:

1. Interactive input routine for setting up a schedule of samples, standards, and controls to be run on a sample changer.
2. Method and instrument operation prompts.
3. Sample-changer control and monitor.
4. Sample-changer monitor only.
5. Data acquisition.
6. Data reduction, standards, quality-control samples.
7. On-line results displayed or typed.
8. Report generation (report is exclusive for each instrument).

^bData reduction processes are:

- Creation of standard curves using first, second and third degree polynomial fits.
- Calculation of unknown concentrations by interpolation between the two nearest standards.
- Calculations of spike recoveries, check standards compliances, and differences between duplicates.
- Calculation of statistical error bands using Shewhart and Cusum Methods.

Option 2: Standard EPA Laboratory Automation System—Data General Computer With Communications to a PDP-11 Computer for SFC

Option 2 is an outgrowth of the EPA decision to adopt the Digital Equipment Corporation PDP-11 system for decentralized processing. It is composed of the standard EPA laboratory automation system with the Data General computer as described in option 1, including hardware and software to communicate with the PDP-11 computer for SFC functions.

Hardware is required on both ends of the communication link. At the laboratory, a synchronous line adaptor will be needed, while at the SFC computer, an additional disk drive and interface will be required. Two console terminals equipped with a keyboard, cathode ray tube display, and printer will be needed at the laboratory end to facilitate communications with the PDP-11.

The ECLIPSE S/230 computer used for cost estimation contains the Data-General version of the HASP (Houston Automatic Spooling Process) emulator for communications to the PDP-11. Appropriate software using HASP is being developed to send data to the PDP-11 through the synchronous line adaptor.

Option 3: Laboratory Automation Using a PDP-11 With Communications to a PDP-11 for SFC

As for option 2, option 3 is based on the EPA commitment to PDP-11 computer systems. The option proposes that the standard EPA laboratory system be modified in hardware and software to run on a PDP-11 system. The option includes communications to the PDP-11 for SFC functions. The modifications required include redesign of the general computer interface to the instrument automation system and extensive rewriting and debugging of the automation software. More details are presented in Appendix B.

APPENDIX B. DETAILED BREAKDOWN OF THE ONE-TIME COSTS FOR THE THREE SYSTEMS

Computer and Peripherals

The costs for the computer and peripherals for the three proposed optional automation systems are listed in Table B-1.

Terminals

For option 1, eleven terminals are recommended: one terminal at the computer console (that can be switched between foreground and background), one at each of six instrument installations, and four terminals for eight channels of AutoAnalyzer II instrumentation. The estimated cost of terminals for option 1 is \$2,000 per terminal, a total cost of \$22,000.

For options 2 and 3, thirteen terminals are recommended; in addition to the eleven described for option 1, these include two special terminals, one each for OSCAR and QC-administrative purposes for communications with the SFC computer. Both SFC terminals will be equipped with a keyboard, CRT display, hardcopy unit, and telecommunications accessories. The estimated cost of terminals for options 2 and 3 is \$22,000 for one console and ten instrument terminals, and \$4,900 each for the two SFC terminals. Therefore, the total cost of terminals for options 2 and 3 is approximately \$31,800.

Table B-1. Costs of computer hardware and peripherals.

Item	Option 1: data general	Option 2: data general + link to SFC	Option 3: (PDP-11/70) + link to SFC
Computer with 96K words core memory, floating point processor, memory map, and real-time clock	\$27,635	\$27,635	\$51,660
Moving-head disk, 96 Mbytes	29,000	29,000	36,750 (88 MB)
Magnetic tape	14,110	14,110	26,500
Line printer	11,390	11,390	11,800
Paper tape reader	1,700	1,700	5,060
System cabinet	2,990	2,990	—
Analog/Digital converter, 16 channels	6,145	6,145	6,145
Multiplexer asynchronous line	3,600	3,600	3,600
Computer system software	1,000	1,000	3,660
Communications hardware synchronous line adaptor (laboratory end)	—	1,100	1,300
Communications hardware full/half duplex synchronous interface (PDP-11 end)	—	3,100	3,100
Additional disk drive, 88 Mbyte (PDP-11 end)	—	32,340	32,340
Total costs	\$97,570	\$134,110	\$181,915

Site Preparation

Site-preparation costs are estimated to be approximately \$15,000.* They will be incurred in preparing the existing chemical conference room of approximately 330 ft² where the computer can be located. The room must be equipped with appropriate electrical and service outlets and air conditioning. The estimated costs include the installation of cables that link the laboratory instruments with the computer.

Spare Parts and Test Equipment

To maintain the system, a minimum complement of spare parts and test equipment must be acquired. Spare parts should include items such as control logic cards, power supplies, operational amplifiers, relays, and connectors. The cost for a recommended quantity of these items is approximately \$3,000. The major test-equipment item—an oscilloscope—will cost approximately \$7,000. Thus, approximately \$10,000 is estimated for both spare parts and test equipment.

System Installation

Based on previous installations, system-installation costs are estimated to be \$37,000. Costs include shipment of the system, installation at the Edison laboratory, hardware and software check-out, operational testing of the complete system, and training of personnel who will use the system.

Instrument Interfaces

For options 1 and 2, the existing interface designs from previous EPA installations are applicable to Region II candidate instruments. For option 3, however, it will be necessary to redesign the general computer interface (digital bay, etc.). We anticipate that the laboratory instrument interface designs for the existing system will be applicable with the option 3 PDP-11 system.

Fabrication costs will be incurred equally for all three options. A summary of interface design and fabrication costs is given in Table B-2.

Table B-2. Summary of interface design and fabrication costs.

Type of interface	Options 1 & 2	Option 3
General interface design	—	\$5,741
General interface fabrication	\$9,300	9,300
Beckman 915 fabrication	1,300	1,300
Oceanographic international fabrication	3,000	3,000
AutoAnalyzer II (4 units) fabrication	16,200	16,200
Atomic absorption PE 460 fabrication	1,300	1,300
Atomic absorption PE 403 fabrication (2 units)	3,600	2,600
Mettler balance fabrication	600	600
Total cost	\$34,300	\$40,041

*Includes shared cost of a 36,000-BTU air conditioner required to supply conditioned air to several rooms, one of which is the proposed 330-ft² computer room.

Software

For options 1 and 2, existing laboratory instrument's applications programs developed for currently installed EPA automation systems are applicable to the Region II candidate instruments and quality control operations. However, for option 3, extensive modifications and debugging will have to be made to adapt the automation software to a PDP-11 system.

We estimate that rewriting the Assembly-language code for the operating system and the instrument programs (assembly language calls) will require approximately 50% of the effort to initially develop the coding. We estimate that rewriting of the Basic-language applications programs will require approximately 35% of the initial effort to develop the programs. Table B-3 lists a breakdown of the software costs.

Table B-3. Cost of rewriting EPA software to operate on a digital equipment PDP-11 system.

Rewrite task	Assembly-language code	Basic-language code
Computer system programs	\$41,000	—
Technicon AutoAnalyzer program	12,000	\$30,000
Atomic absorption program	7,000	21,000
Mettler balance program	3,500	6,500
Beckman 915 program	3,500	15,000
Oceanographic international program	7,000	15,000
Subtotals	\$74,000	\$87,500
Total		\$161,500

For options 2 and 3, additional software costs will be incurred to implement communications with the SFC system. For Region II, this is estimated to be approximately \$20,000, which represents only a small fraction of the total costs required to develop the entire laboratory management system. It is assumed that each EPA laboratory interested in developing a SFC system will budget a minimum of \$20,000 toward its development. The Office of Research and Development and the Management Information and Data Systems Division of the Office of Planning and Management are committed to fund a portion of the SFC development costs.

Table B-4 summarizes the software costs for the three proposed optional automation systems.

Table B-4. Summary of software costs for the three optional automation systems.

Software	Option 1	Option 2	Option 3
Instrument applications programs	No cost	No cost	\$161,500
Communications with SFC	Not appl.	\$20,000	20,000
Totals	—	\$20,000	\$181,500

APPENDIX C. DETAILED ASSESSMENT OF AUTOMATION BENEFITS

To assess the benefits that will accrue to Region II as a result of automation, we compared the manual effort (no automation) that will be required to meet the expected workload (in the candidate instrumental analysis and sample coordination and management areas) to the effort we project will be required if automation is implemented. Effort here is defined as the time required for an employee to perform a task and is expressed as multiple or fractional full time employee (FTE), or both. We examined the detailed procedural tasks associated with the instrumental methods and sample management processes that are candidates for automation. For each candidate, only those tasks that can be fully or partially automated will be more effort-efficient.

Instrumental Methods

We have adopted a model to calculate the effective time required of a chemist to make a determination using any of the candidate instruments. The model takes into consideration the multiple tasks that he must make which includes factors for quality control samples, reruns, and samples that are diluted. With the effective time, and the number of determinations per year, one can calculate the total chemist time in effort (FTE) to handle the workload.

The model is used to calculate the effort required for a single determination using manual techniques vs automated techniques.

The following two equations are used in the model:

$$t_s = p + (1 + f)(w + i + c) + fd,$$

where

t_s = total chemist time needed for each determination,

p = time for preparation of sample and log book per determination,

w = time needed to write log and introduce sample per determination,

i = chemist time spent in operating the instrument per determination,

c = time needed to calculate and transcribe results per determination,

d = time taken for a single dilution,

and

f = fraction of off-scale samples requiring dilution;

and

$$e = t_s \cdot q \cdot r \cdot \frac{H}{H - T_b}$$

where

e = the effective chemist time taken per determination,

q = quality assurance factor,

r = retest factor (fraction of samples retested for reasons other than being off-scale),

H = time of a work session (this is the total average operator time spent for a work session),

and

T_b = time to set up instrument at the beginning of each work session, shut it down at the end, and run standards.

With the model, calculations of the benefits to be realized by automation of the candidate instrumental methods, quality-control procedures, and management tasks are given in the following sections.

Technicon AutoAnalyzer

It is projected that in two years, approximately 6000 determinations/y will be performed by the Technicon AutoAnalyzer. In Table C-1 we give a breakdown of the tasks involved in the method and a comparison of the effort that will be required for the present methods vs automated methods.

Table C-1. Technicon AutoAnalyzer.

Description of the task-times and time factors	Symbol	At present	With automation
Preparation of the sample	p	6.0 min	6.0 min
Write log, introduce sample	w	1.4 min	1.5 min
Operation of instrument by chemist	i	2.2 min	2.2 min
Calculation and transcription of results	c	4.4 min	1 min
Dilution of one off-scale sample	d	5.0 min	5.0 min
Factor for samples diluted	f	0.15	0.07
Calculated chemist time/determination	t_s	19.4 min	10.3 min
Retest factor	r	1.05	1.01
Quality-control factor	q	1.5	1.5
Setup and shutdown hours per work session	T_b	1.75	1.75
Hours per work session	H	6.5	6.5
Calculated effective chemist time per determination	e	41.8 min	21.4 min
Benefit calculations			
Number of determinations/chemist-day		11.5	22.4
Determinations/y (projected)		6000	6000
Chemist-days/y to meet load		522	268
Chemist-days/y (av)		225	225
Chemist-years (FTE) to meet load		2.32	1.19
Effort efficiency = $2.32/1.19=1.13$ FTE			

Atomic Absorption Spectrophotometers

It is projected that approximately 7000 determinations/y will be made using the atomic absorption spectrophotometric method. Table C-2 gives a breakdown of the tasks involved in the method and a comparison of the effort that will be required for the present methods vs automated methods.

Total Organic Carbon

It is projected that approximately 1000 determinations/y will be performed by the Beckman 915 Total Carbon method. Table C-3 lists the tasks involved in the method and a comparison of the effort that will be required for the present methods vs automated methods.

Total Organic Carbon

It is projected that approximately 1000 determinations/y will be performed by the Oceanographic International total carbon methods. Table C-4 gives a breakdown of the tasks involved in the method and a comparison of the effort that will be required for the present methods vs automated methods.

Electronic Balance

It is projected that approximately 2000 determinations/y (approximately 6000 weighings) will be made on the electronic balance. Table C-5 gives a breakdown of the tasks involved in the method and a comparison of the effort that will be required for present methods vs automated methods.

Quality Control

During 1976, approximately 1.25 FTE of the operations and review (O&R) personnel was devoted to control compliance. In Table C-6 we show a breakdown of the tasks and compare the present effort to that projected after automation.

Table C-2. Atomic Absorption.

Description of the task-times and time factors	Symbol	At present	With automation
Preparation of the sample	p	3.9 min	3.9 min
Write log, introduce sample	w	1.0 min	0.5 min
Operation of instrument by chemist	i	2.0 min	2.0 min
Calculation and transcription of results	c	2.0 min	0 min
Dilution of one off-scale sample	d	5.0 min	5.0 min
Factor for samples diluted	f	0.1 min	0.1 min
Calculated chemist time/determination	t_j	9.9 min	7.2 min
Retest factor	r	1.02	1.02
Quality-control factor	q	1.8	1.8
Setup and shutdown hours per work session	T_D	0.5	0.5
Hours per work session	H	6.5	6.5
Calculated effective chemist time per determination	e	19.7 min	14.3 min
Benefit calculations			
Number of determinations/chemist-day		24.4	33.6
Determinations/y (projected)		7000	7000
Chemist-days/y to meet load		287	208
Chemist-days/y (av)		225	225
Chemist-years (FTE) to meet load		1.28	0.92
Effort efficiency = $1.28/0.92=0.36$ FTE			

Table C-3. Beckman 915.

Description of the task-times and time factors	Symbol	At present	With automation
Preparation of the sample	p	5.0 min	5.0 min
Write log, introduce sample	w	6.0 min	2.0 min
Operation of instrument by chemist	i	12.0 min	12.0 min
Calculation and transcription of results	c	6.0 min	0 min
Dilution of one off-scale sample	d	5.0 min	5.0 min
Factor for samples diluted	f	0.1	0.1
Calculated chemist time/determination	t_j	27.5 min	20.9 min
Retest factor	r	1.01	1.01
Quality-control factor	q	1.8	1.8
Setup and shutdown hours per work session	T_D	0.6	0.6
Hours per work session	H	3.1	3.1
Calculated effective chemist time per determination	e	62 min	47 min
Benefit calculations			
Number of determinations/chemist-day		7.7	10.2
Determinations/y (projected)		1000	1000
Chemist-days/y to meet load		130	98
Chemist-days/y (av)		225	225
Chemist-years (FTE) to meet load		0.58	0.44
Effort efficiency = $0.58/0.44=0.14$ FTE			

Table C-4. Oceanographic International.

Description of the task-times and time factors	Symbol	At present	With automation
Preparation of the sample	p	12.0 min	12.0 min
Write log, introduce sample	w	6.0 min	2.0 min
Operation of instrument by chemist	i	12.0 min	12.0 min
Calculation and transcription of results	c	6.0 min	0 min
Dilution of one off-scale sample	d	5.0 min	5.0 min
Factor for samples diluted	f	0.1 min	0.1 min
Calculated chemist time/determination	t_s	34.5 min	28.0 min
Retest factor	r	1.01	1.01
Quality-control factor	q	1.8	1.8
Setup and shutdown hours per work session	T_b	0.6	0.6
Hours per work session	H	4.6	4.6
Calculated effective chemist time per determination	e	72 min	59 min
Benefit calculations			
Number of determinations/chemist-day		6.7	8.1
Determinations/y (projected)		1000	1000
Chemist-days/y to meet load		149	123
Chemist-days/y (av)		225	225
Chemist-years (FTE) to meet load		0.66	0.55
Effort efficiency = $0.66-0.55=0.11$ FTE			

Table C-5. Electronic balance.

Description of the task-times and time factors	Symbol	At present	With automation
Preparation of the sample	p	10.0 min	10.0 min
Write log, introduce sample	w	2.0 min	1.0 min
Operation of instrument by chemist	i	1.1 min	1.1 min
Calculation and transcription of results	c	3.3 min	0 min
Dilution of one off-scale sample	d	—	—
Factor for samples diluted	f	—	—
Calculated chemist time/determination	t_s	16.4 min	12.1 min
Retest factor	r	1.02	1.02
Quality-control factor	q	1.2	1.2
Setup and shutdown hours per work session	T_b	0.2	0.2
Hours per work session	H	7.5	7.5
Calculated effective chemist time per determination	e	21.5 min	15.9 min
Benefit calculations			
Number of determinations/chemist-day		22.3	30.2
Determinations/y (projected)		2000	2000
Chemist-days/y to meet load		89.7	66.2
Chemist-days/y (av)		225	225
Chemist-years (FTE) to meet load		0.40	0.29
Effort efficiency = $0.40-0.29=0.11$ FTE			

Table C-6. Quality control.

Tasks	Quality control at present, FTE	Quality control with automation, FTE
Statistical selection and calculation of Shewhart criteria	0.85	0.20
Review of sample results for compliance to Shewhart limits	0.40	0.10
Totals	1.25	0.30
Effort efficiency = $1.25 - 0.3 = 0.95$ FTE		

Sample Management Tasks

Administration and supervisory duties, coordination of studies, data collation, and summary analyses reports are considered management tasks. In this study, we are concerned with those tasks that relate directly to operations of the analytical laboratory and the report of analyses. Our purpose in this study is to determine what part of the general management effort is related to analyses reports, which tasks can be automated, and the benefits to be accrued.

During 1976, the management effort of the Technical Support branch was determined to be 2.6 FTE; this included 10% of the branch supervisor and 50% of a secretary, 50% and 20% of the time of two section supervisors, 80% of a sample-receiving and log-in (OSCAR) employees, and 5% of the time from ten laboratory analysts.

Table C-7 shows a breakdown of the management tasks and a comparison of the present effort expended relative to the effort projected after automation.

Table C-7. Management tasks.

Tasks	Present effort, FTE	Effort with automation, FTE
Setting up new studies	0.10	0.05
Determining the status of studies	0.20	0.04
Collating data on samples (OSCAR)	0.60	0.10
Coordinating priorities relative to concurrent studies, workload, etc. (OSCAR)	0.10	0.05
Handling requests and implementing changes in study plans (OSCAR)	0.10	0.01
Checking summary analyses ^a	0.80	0.15
Managing branch activities, personnel, finances, etc.	0.20	0.20
Typing relative to analysis data	0.50	-
Total	2.60	0.60
Effort efficiency = $2.6 - 0.6 = 2.0$ FTE		

^aPart of the FTE effort in this category is related to quality-control data.

Table C-8. Summary of automation benefits.

Candidate area for automation	Effort efficiency from automation, FTE
Automation of instruments	
Technicon AutoAnalyzers	1.13
Atomic absorption spectrophotometry	0.92
Electronic balance	0.11
Total carbon analyzers	0.25
Subtotal	2.41
Automation of quality control	0.95
Automation of sample management	2.00
Total	5.36

APPENDIX D. BREAKDOWN OF ADDED OPERATING COSTS FROM AUTOMATION

The three proposed optional automation systems each will add new costs to the annual operating costs of the laboratory. Included will be maintenance of the computer hardware and peripherals, the laboratory instrument hardware interfaces, and the software associated with the automated instruments. Also, for those options that include communications with a SFC system, there will be additional costs for maintenance of the added computer hardware, software, and telephone communications.

New skills and capabilities will clearly be required by Region II to implement and maintain an efficient automation system. The Environmental Research Center (ERC) in Cincinnati, through its experience with laboratory automation, has summarized these requirements (see Appendix E).

The annual operating costs that reflect the above requirements for the three options are listed in Table D-1.

Table D-1. Annual operating costs for three options of the proposed laboratory automation system.

Operating cost category	Option 1 costs	Option 2 costs	Option 3 costs
Maintenance of the computer hardware and peripherals (vendor supplied) ^a	\$10,000	\$14,400	\$21,700
In-house maintenance of interface hardware and software (including communications with SFC ^c for options 2 and 3)	20,000 ^b	60,000	60,000
Total	\$30,000	\$74,400	\$81,700

^aEstimated to be equivalent to 12% of the cost of the computer and peripherals.

^bApproximately one-half of a full time employee's time (0.5 FTE) with the skills described in Appendix E is recommended.

^cA total of one full-time employee (FTE) with the skills described in Appendix E is recommended. The additional 0.5 FTE relative to options 1 and 2 is required for maintenance of communications with SFC.

APPENDIX E. NEW PERSONNEL SKILLS AND CAPABILITIES RECOMMENDED FOR THE AUTOMATED LABORATORY

Bruce P. Almich
Environmental Research Center (ERC)
Cincinnati, Ohio

Our purpose in this appendix is to describe the management of a prospective automated client laboratory: a concise description of the new skills and capabilities required to plan and implement the processes of training, manpower allocation, and (if necessary) hiring before the system is installed. This appendix is also designed to serve as an operational-policy basis for client-ERC-LLL-vendor relationships.

The new functions and responsibilities required in an automated laboratory are divided into two broad activities related to: (1) laboratory use, and (2) computer-system maintenance. The two activities require different personnel skills and capabilities. Within the laboratory, the following subdivisions exist.

1. The system is used as a means of processing analytical samples; for example, conducting a dialogue with the computer as it executes instrument-control, data-acquisition, and manipulation programs.
2. Programs are modified, as required, to tailor them to specific laboratory needs. Modifications by the laboratory scientist are limited to changes in the basic programs, such as report format output, and data-reduction procedures.

For computer maintenance, the following subdivisions exist.

1. Hardware maintenance and upgrades. This includes handling the vendor's computer service contract, as well as taking responsibility for maintaining the custom electronics hardware. Details of these skills are described below.
2. Instrument control and applications software maintenance and upgrades (if any). This includes assisting the laboratory scientist in making changes in the basic programs.

The first broad-skills area is associated with the daily use of the system by the laboratory scientist. To use an automated laboratory system, the laboratory scientist must interact with the computer. He accomplishes this at the typewriter terminal located near the instrument by entering data and control information in response to computer queries and prompts. The scientist must modify his previous analytical procedures and methods somewhat to accommodate this new man-machine dialogue. He should be aware of what corrective actions are necessary when an error occurs; for example, he types in the wrong command, injects the wrong sample, or the computer detects or causes an error. As the laboratory scientist becomes more familiar with the system during the first two months of operation, he should be able to spot and correct human, instrument, or computer malfunctions quickly and be able to report the symptoms of more involved problems to the system-maintenance person for action. These direct-system skills are acquired by the laboratory scientist in four ways.

1. Working visits can be made to ERC/Cincinnati for instruction before delivery of the system. This includes observation and use of a similar automated instrument or procedure by the prospective new client under the guidance of a scientist skilled in using the new equipment.
2. An existing laboratory system computer can be remotely accessed from a dial-up terminal for learning the basic language and instrument program dialogues before the system is delivered at the client's site.
3. The automation-installation team can tutor scientists at the client's site during system installation.
4. Self-study operation manuals for each instrument and facility can be provided with the system.

As the laboratory scientist becomes more familiar with the use of his automated instrument, he will probably want to modify and extend the capabilities of the Basic applications software as follows.

1. Streamline the instrument setup and operation dialogue once he has gained familiarity with the inputs needed for the system to carry out his analyses. (For example, shorten ENTER NUMBER OF SPIKED SAMPLES to SPIKES?)
2. Convert runtime options (provided with the delivered system) to program constants to save time in the event that the inputs would not need to be changed during a normal future run. (For example: remove variable input prompt SPIKES? and convert it to a program constant.)

3. Change the instrument data-reduction algorithm to accommodate a special data-analysis requirement or to implement a new analysis method.
4. Change the structure, content, or appearance of an output report.

To accomplish this, the scientist must spend time in learning additional details of the Basic-language interpreter and the structure and operation of the currently implemented Basic program for his instrument. The depth of knowledge required in these areas is dependent on the degree of program modification desired; informal coursework and self-study are required. The analyst should also learn how to document the programming changes he makes in the Basic code. He should make every effort to keep current and accurate the documentation for the automated operation of his instrument. If the analyst substantially modifies the diskfile or the logic structure from that of the delivered system, he should assume responsibility for the local software support. The scientist also assumes responsibility for local post-delivery modifications to the sample file control interface so that one agency-wide SFC may exist in the future.

The first broad-skills area thus represents a reallocation of existing laboratory efforts and skills to use the automated system effectively. Each analyst must learn new skills to interact with the computer in making laboratory analyses. For elementary skills, no programming training or knowledge is required. To modify the delivered package of Basic-language software to meet post-delivery requirements, the scientist must acquire programming skills in Basic language. Basic is the simplest, most flexible, and general language available; it is typically taught to high school students in mathematics classes and is required study for most technical undergraduate and graduate university degree programs. Cumulative experience within EPA indicates that the dialogues between instruments are easily learned. Modification and enhancement of the delivered Basic programs by EPA Laboratory personnel is also being accomplished in-house, albeit at a fairly low level at present. Table E-1 summarizes this discussion of the estimated resource requirements that must be met for training personnel in the first broad-skills area.

Table E-1. Estimated resource requirements for training personnel in the automated laboratory.

Training steps	Time/resources required
Learning how to use the system as delivered (tutorial course given at installation time)	One-man-wk/analyst One-man-wk/instructor
Learning how to spot and correct malfunctions	First two months of use
Predelivery orientation (by dial-up terminal or visits to ERC/Cincinnati)	Three-man-days/analyst
Introductory course/study in Basic ^a	One-man-wk/analyst One-man-wk/instructor
Advanced topics in Basic ^a (required for extensive program modifications)	One-man-wk/analyst One-man-wk/instructor
Training or self study in program structure ^a (making full use of the system)	Learned during first nine months of operation by motivated users

^aOptional

The second broad-skills area is associated with the maintenance of the overall laboratory automation system as a collection of hardware and software elements including instruments, interfaces, computers, and programs. We define "in-house maintenance person" as a person who has all the skills and capabilities required in this area, although these skills may be either concentrated in one or two people or shared among several in the laboratory. The hardware and software classes are shown in Table E-2 for reference to the following discussion.

Table E-2. Hardware and software classes.

Classes of software:

System: NOVA/ECLIPSE Assembly language, vendor supplied (Data General Corp.), and LLL/EPA-developed.

Applications: standard high-level languages, Basic interpreter code for instrument automation, and data reduction.

Classes of hardware:

Computer (maintained under service contract at a cost of \$1K/mo).

Custom (LLL/EPA-designed and developed) includes terminals, cables, connectors, instrument interfaces, computer interfaces, etc.

Lab instruments (e.g. Technicon AutoAnalyzer, Perkin/Elmer AA spectrophotometer, etc.)

With these classes and the four functional-maintenance subdivisions listed at the beginning of this appendix, the maintenance activity can now be defined.

The primary responsibility of the maintenance person is to keep the hardware and software system in working order by preventive and remedial maintenance and by installing improved and extended hardware and software (upgrades) as required. Preventive maintenance is required to minimize the frequency, losses, and restoration costs of unforeseen breakage whereas remedial maintenance is required when something breaks down.

For preventive maintenance, the main responsibilities are as follows.

1. Monitor the computer hardware maintenance contract and assure that the computer receives its monthly preventive maintenance service from Data General, as provided in the contract. Keep Data General apprised of problem areas with the equipment.
2. Periodic inspection (e.g., offline testing and observing production) of the custom and lab instrument hardware to assure correct operation.
3. Periodic backups and library maintenance of all software disk files. Backups should be made in triplicate on magnetic tape, with an indexing system for locating disk-file images on the tape. A backup should be made of the affected program and data files whenever a net investment (or replacement cost) of effort in these files exceeds an average of four hours of work per laboratory analyst or computer programmer.

The in-house remedial maintenance skills required are those needed to successfully complete the following sequence of tasks whenever equipment breaks down.

1. Identify the symptoms of the problem to ascertain which instruments, users, and system functions are affected.
2. Isolate the problem to the subsystem level; for example, to one of the three types of hardware in the system.
3. If the problem is in a laboratory instrument, initiate repairs in-house, by contract, or by outside out-of-contract repairs. (It is important to keep administrative delays to a minimum when procuring service with established, reputable organizations.)
4. If the problem is in the custom EPA/LLL hardware, initiate in-house repairs. Begin by replacing electronic spare parts. The client lab should have a complete set of replaceable parts for all custom hardware on site; this is recommended to all clients who do not have ready access to a large supply of electronics and mechanical hardware. If difficulty is encountered, assistance may come from another client such as ERC/Cincinnati, or eventually from LLL through ERC. If requested, ERC will provide a list of recommended tools and troubleshooting/repair equipment.
5. If the problem is in the computer, two determinations must be made:
 - The problem must be identified in either the hardware or software.
 - The problem must be identified as a "Data-General" problem or "non-data-General" problem. Carelessness here can result in a premature commitment to expensive out-of-contract vendor service.

Carelessness here can result in a premature commitment to expensive out-of-contract vendor service. Generally, if the problem is in the computer hardware and present when Data-General diagnostic or unmodified system software is running (with the LLL custom hardware-interface board removed), Data General may be called in for free in-contract repairs. If the problem is in the agency-wide supported version of the

operational software, a second client lab or ERC may be called for immediate consultation or assistance if necessary. If no local resources are available, all other problems must be handled individually, with the primary repair responsibility placed on the client lab and its local resources. In-house hardware repairs and modifications should not be made on Data-General hardware. Other electronic repairs should be made at the module or board-replacement level. Purchase of electronic diagnostic and replacement equipment is at the client's discretion, but ERC/Cincinnati will consult with the client if requested. A list of parts and their availability for custom electronic and mechanical hardware should be kept current. The maintenance policy for EPA lab automation is:

1. Agency-wide support—all support external to the client laboratory—is available for all hardware and software as delivered and put in operation by the installation team and for all agency-wide-supported upgrades.
2. Depending on the nature and extent of local post-installation modifications to the delivered system and adherence to agency-wide system improvements, post-delivery support from all sources external to the client laboratory will vary. Generally, if you change a system, you must support that change even if the person who changes it leaves; undocumented changes cannot be supported by anyone. The Data-General service contract with GSA is a good reference in this area.

Another maintenance person's responsibility is to assist the laboratory staff in making necessary workable changes and additions to the delivered package of applications software. At present, this is limited to the basic instrument programs and communications with the sample file-control system. During system operation the maintenance person has historically assumed the role of instructor and consultant to the laboratory scientist. He accomplishes this by completing the training steps described in Table E-1.

The remaining responsibility for maintenance personnel is installing and testing hardware and software upgrades in one of the following circumstances.

1. If the client lab determines that it has a need for additional hardware or software that is not on the agency-wide support list, the lab can take responsibility for designing, obtaining approval for, and implementing a new facility. This can be involved and complex, especially for software modification and when obtaining headquarter approvals.
2. If a proposed upgrade is to be applicable agency-wide, external support can be obtained for its implementation. Here, a system is designed, approvals are secured, and the implementation is accomplished with the assistance of ERC/Cincinnati. This is the preferred procedure for adding a new instrument to the system. An example of this is the agency-wide maintenance of the Data General systems-software subscription service, distributed by ERC/Cincinnati and installed where needed in all laboratory automation sites.

Some of the systems-level upgrades are required to be made on all machines to extend performance, fix system bugs, and assure that applications software can be transported. This is easily accomplished at the client site because the skills required are only those using the Data General operating system command language and the text editor. More complicated software upgrades may be handled by directly loading a client computer with operating software via telecommunications with the ERC/Cincinnati facilities.

How will the maintenance person be trained to provide the services to the laboratory in the second broad-skills area? The following ideas on this training requirement were gained from agency-wide experience to date.

- With the purchase of a Data General computer system, the customer is entitled to a limited number of free training credits (two man-weeks) at one of two Data General training centers in the U.S. Before the system is delivered, two to four man-weeks of training must be completed, preferably by two laboratory people. Each person should train for one week in Data-General operating system concepts and facilities and one week in either Assembly or Fortran programming, or hardware-maintenance overview. It is desirable for two people to pursue this study for each laboratory for the laboratory to realize service continuity if the trained maintenance person is absent or changes jobs.
- Each maintenance person should spend a minimum of one week at predelivery orientation training in a working laboratory elsewhere in the agency. Five to eight working days at ERC/Cincinnati would be optimum.
- Each maintenance person should participate in the installation and delivery testing phase after receiving training from 1 and 2 above and train an additional week at delivery time from the installation team members.
- Approximately six months of post-delivery operation from time will be required for the maintenance person to become proficient in his duties.

In conclusion, we have provided the prospective client laboratory with a description of the personnel skills required for the proper use of a laboratory automation system, by describing two broad areas of functions and responsibilities. The first area, associated with a reallocation of existing personnel skills within the laboratory; the second area, associated with maintenance of the automated laboratory, can be staffed in one of the following ways.

- One or two existing laboratory people can be trained and reassigned to perform the tasks with no additional personnel required. These people could be selected from chemists with some computer background, or from an existing in-house person with electronics and some high-level language programming background. This would be especially appropriate in an established small- to medium-sized laboratory with modest modification needs.
- A new chemist or electronics technician with some previous computer background could be hired. Background in electronic equipment service and repair and Basic/Fortran programming is valuable. This is the most appropriate course of action for large-production laboratories that are interested in proper system use and upgrades.
- The persons described above could be combined to form a working team of principal-automation chemist and system-maintenance person, a desirable team for a laboratory engaged in large-volume sample testing and having the capability for significant system improvements.
- Personnel described above could be combined with a computer programmer with primary emphasis on software maintenance and improvements. Hardware could be maintained with additional outside assistance.

With these alternatives, it is estimated that the first broad-skills area should require no new hiring. The second area of skills minimally requires no new hiring in a laboratory with few plans for system improvements and one containing well-motivated chemists with prior computer science backgrounds. Most likely, one new chemist or engineer-technician would be hired for minimum support of 0.5 man-years/year by the maintenance person. The maximum new personnel requirement would be 2 man-years/year, resulting in full in-house hardware, instrument/SFC software support, maintenance, and upgrades. In this cost-benefit analysis 1 man-year/year has been allocated for proper functioning of the recommended automated system.