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Laboratory Information Management System (LIMS)—A Case Study

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LABORATORY INFORMATION MANAGEMENT SYSTEM (LIMS) - A CASE STUDY

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SUMMARY

In the late 1970's, a refurbishment of the analytical laboratories serving the Materials Division at the NASA Lewis Research Center was undertaken. As part of the modernization efforts, a Laboratory Information Management System (LIMS) was to be included. Preliminary studies indicated a custom-designed system as the best choice in order to satisfy all of the requirements. A scaled-down version of the original design has been in operation since 1984. The LIMS, a combination of computer hardware and software, provides the chemical characterization laboratory with an information data base, a report generator, a user interface, and networking capabilities. This paper is an account of the processes involved in designing and implementing that LIMS.

INTRODUCTION

A customized Laboratory Information Management System (LIMS) has been in place since October, 1984 in the Analytical Science Branch of the NASA Lewis Research Center. Two laboratories located in adjacent buildings make up the branch, one laboratory specializing in chemical analysis, the other in microstructural analysis. These laboratories provide analyses to a materials research division active in the areas of ceramics, metallic alloys, metal matrix composites, polymers, and coatings. The annual workload averages about 10 000 samples, most of a nonroutine nature. In the late 1970's, a major refurbishment of the laboratory facilities was undertaken. As part of that refurbishment, the lab management began investigating the possibility of computerizing the sample submission and reporting process. With the relatively small sample load, sample tracking had not been a problem under the previous manual system. In fact, many of the benefits that large analytical labs obtain by computerization simply did not apply to a small lab serving a research community. The major advantages that were desired in a new system were a convenient, one-stop sample submittal procedure for researchers, easier access to past analysis results, the capability of retrieving consolidated data on research projects lasting several years, and the availability of a wide variety of management statistics that would indicate, for example, which research projects used the bulk of the analytical services.

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WHY A LIMS?

In the mid-1970's, local area networks and laboratory information management systems were rapidly becoming "state-of-the-art" for data transmission and data handling in many large analytical laboratories. This technology offered the Analytical Science Branch a way to "connect" its two laboratories and provide consolidation of management reports.

A feasibility study done by Lawrence Livermore Laboratories of Livermore, California weighing benefits versus costs of a LIMS proved encouraging. A second contractor, Purvis Systems Inc., of Syosset, New York was hired to determine the functional requirements and the design specifications of a LIMS. A characterization of the flow of information through the laboratory was done as part of the initial studies. The results of this characterization were used to determine the critical areas in the LIMS implementation design. The study indicated that the manual system used by the staff in both analytical laboratories for sample submission and analysis reporting was quite efficient. The computerized version of these procedures was to mimic that format as much as possible.

Potential improvements that a LIMS could provide included a computerized instrument maintenance schedule and repair log; an instrument usage report; a systematic quality control program; an inventory of supplies used in the laboratories; a computerized scheduling log for microscopes used directly by the researchers; easier consolidation and accumulation of management report data; and analytical results obtained in machine-readable format which could be utilized in data reduction and analysis programs resident on other computers.

As part of the design phase, each of the laboratories was divided into a number of "workstations". A workstation was defined to consist of one or more instruments or analytical techniques assigned to an analyst. The LIMS would connect each of the workstations to the LIMS computer via the Lewis Information Network (LINK, see appendix A), a local area cable network installed throughout NASA Lewis. As a long range goal, each of the instrument's computers could be added to the Lewis network for transferring of analytical results directly to the LIMS computer.

HARDWARE AND SOFTWARE

The hardware recommended by Purvis and subsequently procured included two Digital Equipment Corporation's PDP 11/24 computers - one to serve as the LIMS processor and the other to be used during the development phase and also to be a backup for the LIMS computer and provide additional computer resources to the materials research division. The PDP 11/24s were equipped with three 10 megabyte disk drives - a system disk, a data disk, and a journaling or backup disk. In the proposed LIMS, the system disk would contain the operating system and database programs; the data disk would contain the database records including the dictionaries; and the journaling disk would keep a log of system changes and error messages and be used for making backups of both the system and data disks. Each computer was configured with 1.25 megabytes of main memory.

The terminals selected for use with the LIMS were DEC VT100s, VT125s, and a Decwriter III to be used as the system console. The printers selected were a

DEC LA 100 letter quality printer for reports and Integral Data Systems Prism dot matrix printers for interim reports, customer receipts, and sample labels. A Racal Vadic auto-answer modem was purchased for off-site access to the LIMS. This modem was and continues to be used for software development. The work-station terminals were to be connected to a bus interface unit (BIU, see appendix A) which would provide the protocol for transmitting LIMS communications over the NASA Lewis cable network.

Two operating systems were procured, Digital Standard MUMPS (DSM -11) and RSX-11M. RSX-11M was used for developing the network code needed by the BIUs and DSM-11 was chosen for the LIMS software development. MUMPS (Massachusetts General Hospital Utility Multi-Programming System) is a high-level, interpreted programming language which was developed at the Massachusetts General Hospital Laboratory of Computer Science. It provides dynamic memory allocation and a tree data structure. This type of data structure allows for easy database modification, growth and fast data retrieval.

LIMS SOFTWARE DESIGN SPECIFICATIONS

Certain guidelines were established by the project team in creating the functional design of the LIMS. Of primary importance was that the system be easy to use and menu driven. The number of key strokes necessary to access the various functions were to be kept at a minimum. In order to protect the integrity of the system and yet include a wide range of functions, it was suggested that a password system be used along with different classes of users. Four classes of users were chosen: manager, analyst, customer and guest. As a user logged on to the system, the class would be checked, and he or she would only be given access to the appropriate functions.

The main design specifications fell into the following categories, each of which will be discussed separately:

Dictionaries and Menus
Sample Management Functions
Laboratory Database Functions
Management Reporting Functions
Interface to Local Area Network
Ancillary Functions

Dictionaries and Menus

A series of data dictionaries was proposed to store information that remained relatively fixed over time, but required periodic updating. Separate dictionaries were created to store data about users, workstations, instruments, test codes, and accounting charges. Besides the obvious benefit of allowing the LIMS to be recustomized to any changes in lab capabilities or organization, the dictionaries would help minimize keystrokes in entering analysis requests. In particular, the user information dictionary, which was keyed to the initials of the users, would allow both lab personnel and researchers to identify themselves to the LIMS simply by entering their initials, rather than having to type in their name and identifying information each time they used the system. These dictionaries were to be maintained by the LIMS manger. Figure 1 shows an example of the data entry screens used to enter or edit data in the dictionaries, in this case, the user information dictionary.

For each class of user, access to the LIMS routines was to be controlled by a different set of nested menus. When a user logged on to the LIMS using his or her initials and password, the log-on routine would check the class of the user and present the appropriate top-level menu for that class. The menus were structured so that managers could access all LIMS functions or routines; analysts could use only those routines involving analysis data and results, time and record keeping, and word processing; and the customer or guest could access only his or her analysis requests and sample status. (The distinction between customer and guest was that a customer had to have a password and be "known" to the LIMS. A guest was to be permitted to log on using his or her initials as password strictly for the purpose of submitting samples. Guests would either have to wait for hard copies of analysis results to be mailed to them or change their status to customers in order to query the LIMS directly about their analyses.) Figures 2 through 4 illustrate the top-level menu for the different classes of users.

Sample Management Functions

The sample management functions included requests for analysis, the capability of checking on the status of samples submitted for analysis, entering analysis results, generating analysis reports, displaying queue lists for each workstation, and storing exception log entries - changes made to the database by the analysts or manager (i.e., addition or deletion of test requests, editing of sample data, or analysis results, and so forth).

Samples were to be identified in the database by a computer-generated seven-digit number. The first digit would represent the last digit of the fiscal year, the next four digits were to contain the batch number ranging from 0001 to 9999, and the last two digits to indicate the sample number within the batch from 01 to 99. As an example of this scheme, 7012304 is the fourth sample of the 123rd batch submitted in fiscal 1987. (Note that this numbering scheme, designed in 1980, will provide unique sample numbers for only 10 years. We are currently anticipating some problems as the year digit "rolls over" in 1990. Designers of future systems would do well to anticipate the century roll over in the year 2000.)

Submitting a sample for analysis would require the researcher to enter a task number for accounting purposes as well as various identifying information such as phone number, mail stop, and so forth as shown in figure 5. Normally, much of this information would be automatically retrieved from the user information dictionary and the form completed with the researcher being allowed to edit the information if needed. A project link number could be added for identifying batches common to a specific, long-range project. A short textual description of the batch of samples could also be added.

Once this form was completed the batch number was assigned. The next form requested that a unique sample identifier be entered, an optional sample description and the analytical tests to be performed. When each sample had been entered, the submitter would review a summary of the samples submitted and the tests requested and could choose to edit the information, print receipts and sample labels. Researchers could also check on the status of all samples submitted within a three year period. (Each data disk would contain only 3 years of data in order to permit faster data retrieval.)

The analysts were to be responsible for assigning samples to the appropriate workstation, entering analysis results and generating analysis reports. On demand, LIMS would provide the analysts with a queue list of all samples awaiting analysis for a particular workstation. These queue lists could either be displayed on a CRT or be printed. The queue list would display sample numbers and descriptions along with information such as date submitted, name of submitter, tests requested, and the current status. Once the batch was analyzed and the results entered in the system and verified by the analyst, it would be removed from the queue lists.

The analyst's menu was designed to be a multi-level menu. Submenus would offer editing of test requests and analytical results, options for comments to the submitter, notes to other analysts, word processing, mailing labels, and so forth.

Laboratory Database Functions

The LIMS was to provide improved bookkeeping features for the laboratories. Listings of analytical instruments, workstations, and outside contract laboratories stored in dictionaries would allow easy updating of the laboratory capabilities report. An inventory of supplies was desired so that the LIMS manager would be alerted when items should be reordered. Scheduling of microscopes used directly by the research staff and an instrument log of maintenance and downtime were two other features LIMS would provide.

Standard Management Reports

One of the most desired features of the LIMS was its ability to easily generate management reports. The analysts were routinely required to compile lists of all samples submitted from the various research groups and compute the relative amounts of time spent on the analyses. Funding for the labs was apportioned from the research group project accounts in proportion to the amount of analytical services requested and used to compensate for instrument maintenance and replacement. A LIMS could generate these reports in a fraction of the time required of the analysts to do it manually.

Interface to Local Area Network

The LIMS design included use of the LINK broadband cable network as the means of connecting remote terminals and instrument computers to the LIMS computer. This feature offered researchers throughout Lewis the possibility of being able to access the LIMS from any terminal connected to the cable network. It also allowed for the possibility of creating a communications link from the LIMS computer to the NASA Lewis mainframe computers. The analysts would be able to use application packages resident on those computers for further data reduction or statistical analysis.

Ancillary Functions

Other functions that were included in the LIMS design were on-line help, a quality control subsystem, and word processing. The on-line help was to be available at each request for user input. It would range from one or two lines of text to more detailed explanations when necessary. Each menu was to include a help text to explain the menu selections.

A systematic way of performing quality control on analytical techniques would be developed which would mark and identify samples to the LIMS as quality control samples. The results would be accumulated and stored in the database to provide a history for the instruments and a check of the quality of the analytical technique.

IMAGE, a word processing package which runs under DSM-11 was selected to provide text storage capabilities for the analysts. MUMPS was not designed for easy storage of large amounts of text within a database structure. Special programs must be written to handle the storage and retrieval of each 255 character string in text format. The use of IMAGE by the analysts would give them the capability to compose and store such items as descriptions of analytical techniques, detailed explanations of unexpected analytical results, and memos.

The LIMS was to provide access to DSM-11 system operations for managing and maintaining the database. Access to this part of the LIMS was to be available only to the manager class of users. The most useful of the DSM-11 utilities include routines for quick searching and editing of the database, for maintaining terminals and printers, and for performing system backups.

LIMS SOFTWARE CONTRACT

The LIMS design was formidable and the preliminary studies determined that no existing commercially available LIMS could provide all the functionality requested, particularly the networking capabilities. A contract was drawn up to have the software custom written and a vendor was selected. During negotiations, some of the LIMS features were designated as optional, to be implemented if time and funding permitted. These included the quality control subsystem and the on-line help. The vendor proposed a schedule for software development, system testing, and analyst training. After approximately eight months, the system was delivered for initial testing. It was quickly apparent that there were serious problems with the software package. Errors in data entry often caused routines to crash and leave the user at the DSM-11 system prompt instead of displaying an error message and prompting the user to enter another response. The vendor requested both time and funding extensions to correct the software. A time extension was granted; however, during the second attempt at on-site testing, it was quite evident that the LIMS would be unusable without major revisions and that the vendor was not in a position to provide the revisions satisfactorily.

LIMS REVISION

At this point, three options were available: abandon the project, request additional funds for another vendor to finish the project, or finish it in-house. Trying to secure additional funds to continue with another vendor was not a possibility since the project was beyond its completion date and was well over budget.

The idea to abandon the project was gaining favor with management for several reasons. The in-house development of the interface to the local area network was not going smoothly. The frequency on the broadband cable that had been allocated for the project had been changed after most of the programming of the interface units had been done. This had required major hardware modifications at significant cost in order for the units to operate at the new frequency. The communications between the LIMS computer and the BIUs had intermittent problems, the most serious of which caused single terminals to randomly lock up. The only apparent means for reestablishing communications to the affected terminal was to reset a board on the LIMS computer which would adversely affect other users accessing the LIMS over the network. This problem remained unsolved despite many months of effort and cast serious doubt on the prospect of using the network for all terminal connections to the LIMS.

Resistance to the LIMS was still being voiced by the analysts in the microstructural laboratory. They had not been convinced that the LIMS would provide them with any real benefits and they were concerned that too much time and effort would be required to input their analysis results in a LIMS-compatible format.

An in-house project team was consulted as to the feasibility of finishing the project at Lewis. Reviewing the state of the project and assessing the various stages of its completion the team concluded that by radically modifying the original design, a scaled-down version of the LIMS could be implemented for use in the chemical characterization laboratory only.

The modifications included:

- eliminating the microstructural laboratory from the design
- designing the video output specifically for VT100 terminals
- debugging the manager class of programs and rewriting the analysts and customers programs
- including on-line help
- postponing the inventory and instrument repair logs

LIMS IMPLEMENTATION AND TRAINING

The in-house team spent seven months rewriting the software while work continued on solving the BIU communications problem. The system was tested for major flaws and revised accordingly. Training began in August, 1984 for the analysts with a two-day seminar on the LIMS, including hands-on demonstrations. During the next two months, the analysts provided the fine tuning of the system, finding subtle errors in the programs and requesting improvements in the display and reporting features. The manual paper system was maintained for 1 year while the LIMS database proved its reliability and the analysts handled all of the data input to the LIMS.

During that year, minor modifications and improvements were added to the system. The LIMS computer was moved into the laboratory where terminals were positioned for easy access by both analysts and researchers. Because the BIU communications problems had not been satisfactorily resolved to allow for reliable network communications, all user terminals were connected directly to the LIMS computer. In January, 1986 the researchers became LIMS users and were required to enter their own sample analysis requests to the LIMS.

Training for the researchers was done on an individual, as-needed basis with the analysts and LIMS manager serving as tutors. The help screens were compiled into a manual and information sheets for accessing the system were readily available at the researchers' terminals. A remote terminal was still maintained for the analysts and it is currently using a different type of modem. This type provides the connection to and from the LINK for most of the terminals and personal computers in use at NASA Lewis.

FUTURE LIMS PROJECTS

The idea of direct data transfer from the analytical instruments to the LIMS is still being pursued. The ICP emission spectrometer computer, a PDP 11/23, will be connected via the LINK within the next year. This will allow for the direct transfer of ICP analysis results to the LIMS computer and also provide the ICP terminal with the LIMS terminal capabilities.

There is some discussion about implementing a small LIMS in the microstructural laboratory to handle bookkeeping functions, scheduling of user instruments, and maintaining an inventory of supplies. The LIMS has demonstrated tangible benefits that could apply equally well to the microstructural laboratory.

MAINTENANCE

The LIMS has required very little maintenance, both in hardware and software. Periodic maintenance is performed annually on the hardware to ensure optimum performance and locate potential hardware problems. Disk backups are currently performed twice a week on the data and any time a change is made to the system software. Archiving of analytical data is done so that only three years of data is stored on a data disk.

The LIMS manager is required to have experience with MUMPS programming and have an understanding of the database structure. He or she is responsible for maintaining the software and for scheduling maintenance of the hardware. On-site contractors provide the hardware maintenance support. Both maintenance capabilites have provided quick response times for LIMS-related problems and have allowed implementation of user suggestions to the software.

ENHANCEMENTS

Enhancements have been made to the system including an electronic time card function with which the analysts can record the amount of time they spend on different projects. A partial report option was added so that the researchers could receive the analytical results from those workstations finished with their part of the analysis. In the original design, researchers had to wait for all tests requested at all workstations to be completed before receiving an analysis report on a batch of samples.

BENEFITS

The LIMS has provided a number of benefits to the analytical laboratory: the central storage of analysis results, the ease of data retrieval, and a variety of management reports to name a few. A side benefit is that the analysts have become more computer literate due to the in-house development effort and are less reluctant to try new computerized equipment.

Personal computers have also found their place within the research organization and are used in various capacities, from word processing, spreadsheets, graphics and databases to data acquisition and instrument control. The growth of this industry and increase in storage capacities of the new PC, indicate that a personal computer may be a good choice for the main computer of a small LIMS.

CONCLUSIONS

When this LIMS was being designed, in the late 1970s, there was very little in the literature to assist with choosing a LIMS or to warn prospective LIMS designers of the pitfalls in a custom-designed system. Technology was changing rapidly in the computer industry and standards were still being decided upon in the area of local area networks. The cost of commercially available LIMS software was in the $60 000 or more range with custom software ranging upwards of $150 000.

Today, much has been written on the subject of LIMS dealing with methods for determining if your laboratory can benefit from a LIMS, what LIMS features are necessary to meet your needs, choosing the right hardware and software, and what the staffing requirements are for maintaining a LIMS. Prices for commercially available minicomputer-based LIMS systems depend on the number of features included and the type of hardware desired. In 1985, prices for both hardware and software costs ranged from $15 000 to $600 000. Custom designed software was and is still priced well over $100 000. PC-based LIMS systems have been developed and PCs in the laboratory can be networked to fully utilize this type of LIMS.

Joseph Goulden of Laboratory Management Systems Inc., a New York consulting firm (ref. 1), advises that LIMS may not be suitable to all laboratories. He proposes that in a small laboratory, "the labor savings may not justify a system purchase. Maybe just a change in procedure, in logging in or routing, can clear up a problem." A database management program running on a PC may be all that is required for data handling.

One of the major reasons a LIMS is not accepted in a laboratory is that the users are not consulted about their needs or those needs are ignored by the designers. When the idea is still in the design stage, users should be asked for their input. Henry Ledgard (ref. 2), a private consultant specializing in software engineering and education, states that if "human factors are important, they should be a concern from the beginning to the end of the software life cycle... Human engineering is not something that can be grafted on to an existing system. It is the fiber of technical development." How menus are organized, if special function keys might be helpful, what notations are to be used for data entry, etc. are the types of questions good technical designers should consider. When users are given a chance to have input and make recommendations, they tend to feel more comfortable with the final product.

This is one area where our LIMS design failed. The microstructural laboratory has a very efficient manual system for handling analysis requests and reporting sample results. The feasibility study failed to impress on our management the potential problems associated with trying to replace this system with a computerized one. The analysis reports generated by SEM, TEM, and X-ray Diffraction analysis are not numeric in nature but rather photographs and text which cannot readily be put into the required computer format. The feasibility study did not present enough advantages in this area to warrant the full LIMS capability for the microstructural lab. Prototyping, had it been done, would have revealed some of the weaknesses associated with the original LIMS design. A modified version which included scheduling for the user instruments, an instrument log for maintenance and supplies, a sample submission form and an analysis completion record could have provided enough data for management reports, sample status and instrument usage in the microstructural laboratory.

Ira Cotton from Booz-Allen and Hamilton Consultants, has a selection criteria for choosing a local area network which can also be applied when selecting a LIMS.

Functionality	-	capabilities provided
Performance	-	speed of retrieval, error handling
Maintainability	-	reliability
Extensibility	-	growth potential
Vendor stability	-	experience, reputible
Price	-	within budget (ref. 3)

Functionality and performance requirements should be determined by examining what your lab does, how data-flow is handled, and what steps are required by both the submitter and the analyst. This structured analysis should be incorporated in the initial design. Once the design is completed, those responsible for managing the laboratory should decide whether this structured environment, which LIMS may impose, is desired in the laboratory. John Domanico (ref. 4), senior quality engineer for Warner-Lambert, recalls that "we did not identify all our needs in depth before going out and buying things; as a result we had to do more work to fix the software." Taking the time to do a thorough analysis prior to deciding on a LIMS may save time, money and much frustration later.

Maintainibility and extensibility are the next critical features of a LIMS. As we have learned, if a system is unreliable due to either hardware or software failures, new users will be uncomfortable with and therefore reluctant to use the system. A few considerations when implementing a LIMS according to Raymond Dessy, professor of chemistry at Virginia Polytechnic Institute, are:

(1) No more than a day should be required to learn to use the system.
(2) No more than a month should be required to become a skilled programmer.
(3) The ability to implement change quickly and frequently is a necessity (ref. 5).

Vendor stability and price should be considered in order to determine how much in-house support will be required. By utilizing the idea of prototyping, the vendor's understanding of the requirements will be evident. This can also reveal the need for modifications in the design. In our case, if a prototype had been developed which dealt with the specific needs of each laboratory, the project team could then have tested it for weaknesses and suggested possible changes to the design. Prototyping would have generated a baseline system with all the critical features. Once the baseline was operational, adding the options could have been the responsibility of the project team. Had this possibility existed, the LIMS project might have had a better chance of being implemented in both laboratories.

The electronics industry has been rapidly improving capabilities in disk storage, processor speed, compatibility, and networking. Many industry standards have been developed within the past 5 years to make choices on types of hardware and software easier for the consumer. Our LIMS was designed during this period of rapid growth and as a result was obsolete by the time it became operational. Networking today is more readily accomplished through industry-accepted standards which utilize commercially available local area networks (for example, Ethernet or Decnet). It is evident that once standards have been established, individuals or industry as a whole can better utilize technology in developing applications and improving data management and communications. Laboratory information management systems will continue to be viewed as state-of-the-art for data management and communications in many laboratories for years to come.

FOOTNOTES

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2. Ledgard, Henry F., "Three Misconceptions", PC Tech Journal, 190, (February, 1987).

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APPENDIX A

LEWIS INFORMATION NETWORK (LINK)

The LINK, NASA Lewis' local area cable network, was designed by Mitre Corporation of Bedford, Massachussetts and is based on CATV technology. The system uses a pair of parallel broadband coaxial cables, one cable to carry the inbound signals and the other for the outbound signals. The frequency range extends from 50 to 300 MHz on each cable with the frequencies divided into 6 MHz band channels. Both data and video signals are transmitted via this cable sytem with the inbound and outbound signals being coupled at the head-end thus providing two-way communications.

BUS INTERFACE UNITS (BIUs)

These BIUs were made by Digital Communications Corporation of Bethesda, Maryland. The BIUs are Z80-based and were programmed in-house to perform the packetizing, routing and error-checking of LIMS network-bound data. The protocol running on the LINK utilizes the resource sharing concept where each resource, whether it be a computer, terminal, or printer is known to the network and declares itself available or unavailable and must specify the number of users it can handle simultaneously. When users want to access a resource they either specify the channel or make a call to a front-end processor which routes the call to the appropriate channel. Once the channel is opened, it remains open until explicitly closed by either the receiving or transmitting end. The LIMS computer was configured to handle up to 16 network channels simultaneously.

DCA-205/11 STATISTICAL MULTIPLEXER CIRCUIT BOARD

The LIMS computer contains a DCA-205/11 statistical multiplexer circuit board made by Digital Communications Associates of Norcross, Georgia. The DCA board, which plugs into the Unibus backplane on the PDP 11/24, emulates a series of DEC DZ-11 serial multiplexer boards. Because these DZ-11 boards are supported by the PDP 11/24s, the LIMS computer requires no special software to communicate with users via the DCA board. The DCA boards use DEC's Digital Data Communication Message Protocol (DDCMP) to control data transmission with the BIUs. An in-house program was written for the BIUs to provide translation between the DCA-DDCMP protocols and the LINK protocol. This handler program allows the 16 user I/O ports on the LIMS computer to access the LINK and also identifies the port number and channel required for two-way communications over the LINK network.

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```
        Laboratory Information Management System
                  Add a User to LIMS


  User Initials:                        Date:
  User Name     :
  Password      :                       Class:
  Profes. Code  :
  Org. Code     :                       Workstation Code:
  Phone         :                       Mail Stop:

  Address       :

                Street/Number

                City          State          Zip
```

Figure 1. User Dictionary Entry Form

```
Laboratory Information Management System
         Analyst Functions

      Analysis requests and assignments
      Enter analysis results and information
      Display workstation queue lists
      Reporting functions
      Time charging functions
      Miscellaneous functions
      Help
      Quit
```

Figure 2. The analyst's menu

```
Laboratory Information Management System
         Manager Functions

        Analyst Functions
        Management Reports
        Data Administration
        System Operations Function
        Miscellaneous Functions
        Read Mailbox
        Help
        Quit
```

Figure 3. The manager's menu

```
Laboratory Information Management System
        Customer Functions

        Analysis requests
        Sample status displays
        Print sample labels
        Print batch receipts
        Help
        Quit
```

Figure 4. The customer/guest's menu

```
    Laboratory Information Management System -- Sample Mark-Up
Task number:
Engineer's initials:
Submitter name:
Organization code:
Mail stop:
Phone:
Project link number:
Return sample after analysis (Y/N)?
Batch description (Optional - up to 5 lines that will appear
                   on final report)
```

Figure 5. Submitter Information Form

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
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4. Title and Subtitle

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8. Performing Organization Report No.

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10. Work Unit No.

505-63-01

9. Performing Organization Name and Address

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

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16. Abstract

In the late 1970's, a refurbishment of the analytical laboratories serving the Materials Division at the NASA Lewis Research Center was undertaken. As part of the modernization efforts, a Laboratory Information Management System (LIMS) was to be included. Preliminary studies indicated a custom-designed system as the best choice in order to satisfy all of the requirements. A scaled-down version of the original design has been in operation since 1984. The LIMS, a combination of computer hardware and software, provides the chemical characterization laboratory with an information data base, a report generator, a user interface, and networking capabilities. This paper is an account of the processes involved in designing and implementing that LIMS.

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