ARIZONA DEPARTMENT OF TRANSPORTATION

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CONSTRUCTION MATERIALS TESTING AND QUALITY ASSURANCE INFRASTRUCTURE

Concept Report

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16. Abstract

The Arizona Department of Transportation monitors the construction of Transportation related facilities throughout Arizona. As part of that process, materials are sampled and tested to insure compliance with specifications. Presently the information is stored in hard copy and summary information transmitted in hard copy form. This system is time consuming, cumbersome, redundant and can lead to errors. The main disadvantage is that the information collected is not easily available to affected users.

The report presents a concept for automating this process. The concept consists of a LIMS operating on a central processor, workstations collecting information at the construction sites and a communication system to tie the system together.

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I. MANAGEMENT SUMMARY

The Research Section of the Arizona Department of Transportation (ADOT) has requested assistance in the development of a conceptual solution and specifications for hardware and software to support ADOT's construction materials testing and quality assurance functions. Throughout the report, we refer to the future application system as the Construction Materials System, or just the system.

The objectives of this project are to:

- Develop a technical concept that will support materials management
- Develop specifications for the concept that will allow ADOT to obtain implementation services.

The technical concept consists of a hardware and software configuration that could support materials management. Once the concept is agreed upon, the specifications for that concept will be documented so that hardware and software implementation services can be obtained based on the specifications.

After this project is completed, the next steps to be performed include:

- Prepare a Request for Proposal (RFP) for a turnkey operation, which includes hardware, software, and implementation services
- Select the vendor
- Perform a system design
- Install the hardware, system software, and package application software
- Develop additional software and customize purchased software as necessary.

I.1 APPROACH TO THE WORK

The study is structured around four tasks. These four tasks include:

- Task I - Review Current Procedures
- Task II - Develop Project Concept
- Task III - Develop Specifications
- Task IV - Project Management

Task I, Review Current Procedures, was completed throughout the first three weeks of the study. During the task, personnel from the Districts and from central office were contacted and interviewed by project team members. Project team members also conducted field visits to project, area, and district laboratories and a portable bituminous concrete plant and aggregate pit. The personnel contacted and interviewed are listed on Exhibit I-1.

Task II, Develop Project Concept, has resulted in the completion of this report, which details the suggested concept that the project team feels will best meet the objectives of the Highways Division, and specifically construction materials management.

I.2 SUMMARY OF BUSINESS PROBLEMS

In 1987, ADOT and IBM representatives participated in a study to determine what ADOT should do to improve the consistency and timeliness of construction materials reporting and quality assurance on construction projects. The study, called the Testing and Quality Assurance Study, identified and documented business problems related to materials management that could be improved upon or eliminated through the proper use of technology and associated procedures. The problems identified in the study are summarized here.

- Decisions are based on incomplete information.
- The quality of information is inconsistent.
- There is often duplication of effort because information is not available, e.g., the same data is manually written and massaged several times by several people.

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EXHIBIT I-1 PERSONNEL INTERVIEWED

Highways Division

Tom Bryant
Dave Schmitt

Research Center

Frank McCullagh
Larry Scofield

Materials Section

Gary Cooper
Doug Forstie
Don Corum
Jim Stroud
Hipolito Barriga
Ed Suserud
George Way
John Lawson
Don Rushton
John Eisenberg
Al Gastelum
Leroy Heyduke

Administrative Services Division Information Systems Group

Roy Walker
John Amidon

Non-ADOT Interviewees

Don Green - Tanner Companies
Rick Cheever - Ernst & Whinney

Construction Section

Herb Hazelwood
Lloyd Taylor
Dave Elack
Gordon Bergman
Jamal Sarsam

District I

Bill Hoffman
Kenny Speer
Dan Powell
Dan Lance
Tom Warne
Ron Williams
Diane Shotka
Perry Powell
Gary Post
Bob Laux
Dick Westin

District III

Jim Judd
Jim Dorre
Jim Glasgow
Don Smith
Mark Anthony

District II

Tom Schmitt
Norm Bloom
Larry Oliver
Bill Beck
Bob Block
Ron O'Daniel
Lloyd Thomas

District IV

Rick Genteman
Ervin Boren
Diedre Beekman
Scott Brown
Frank Anaya

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EXHIBIT I-2 LIMS PACKAGES

PACKAGE	VENDOR	HARDWARE	DATA STRUCTURE	NUMBER OF INSTALLATIONS	LANGUAGE WRITTEN IN	PHONE NUMBER
LIMS 2000VX	Perkin Elmer	DEC VAX	Relational (Oracle)	4	Fortran	301-984-4759
LIMS 2000CX	Perkin Elmer	Concurrent	Binary Tree (DMS32)	330	Fortran	301-984-4759
Access LIMS	Perkin Elmer (Formerly Nelson Analytical)	DEC VAX	Relational (Oracle)	10	Forms (Oracle Application Generator)	408-725-1107
CALS	Beckman Instruments	DEC VAX HP A Series IBM 9370 (MVS only)	Indexed Files	250	Fortran	201-444-8900
Encompass	Chesapeake Software	DEC VAX	Indexed Files (DEC DBMS)	400	Smartstar (4GL), Fortran	302-475-5229
LabTrac	Laboratory Microsystems	IBM PC XT, AT, Compatibles	Relational (Informix)	15	Informix (4GL)	518-274-1990
LIMS/SM	Digital	DEC VAX	Indexed Files	30	Fortran	215-6400-2513
VM LIMS	Axiom Systems	IBM 9370 (VM Only)	Relational (SQL/DS)	15	PL1	415-967-2910
Labforce	Labforce, Inc.	Prime	Relational	50	Infobasic	214-349-4025

* * * * *

All packages listed include ad-hoc query and reporting capability, some statistical analytical capability, and instrument connectivity support using RS232 interfaces.

- Needed support from information is unavailable or difficult to obtain, e.g., to address claims in courts.
- Clear audit trails are not present. It is difficult to track information from its source through its flow to any destination.
- It is difficult to analyze data. There is currently no capability to extract relevant information and produce exception reports. Forecasting and trend analysis are difficult if not impossible.
- Test results, both current and historical, are not easily accessible.
- It is difficult to communicate test results among central, district, and project offices. The only forms of communication are radio, inter-office mail, and telephone.
- There is a question of credibility of data since most of it is manually maintained, calculated, and verified.
- It is difficult to control consultant laboratories since procedures are completely manual.

I.3 CONCEPTUAL OVERVIEW

The Testing and Quality Assurance Study performed by Department personnel and IBM provided a thorough analysis of the business problems to be solved by the proposed automated application system and presented an alternative for the technical architecture to support the system. Using the results of the Testing and Quality Assurance Study, our experience with other clients, technical expertise, analysis of ADOT's materials management functions, and in-depth discussion with ADOT personnel, the project team has developed a conceptual solution for the construction materials testing and quality assurance infrastructure.

Peat Marwick recommends the solution consist of a central processor communicating with a network of intelligent workstations with package software to support the application. This concept is explained in detail and graphically illustrated in Section IV. This solution provides:

- Dedicated support of the materials testing functions
- Control of software and data from a central processor and user support group
- The ability to download data from the central processor to workstations for use in existing software programs written for microcomputers
- Timely availability of all data collected by the system
- A state wide communication network that will allow access to the system from all nodes on the network
- Package software that will reduce development time and expense and provide a framework around which the system can be built
- The ability to interface with the existing computers used by the Department
- Use of proven technology that is available today and less risky than a solution that uses technology that is promised but not yet in use
- Use of intelligent workstations which will provide backup capabilities so that remote laboratories can operate if the communication line or host system is unavailable.

We believe that this solution can be successfully implemented in a reasonable timeframe, with minimal risk. It provides an open ended architecture that will allow migration and growth as technology advances. It is flexible because it will meet the needs of the users immediately with current technology, and will allow enhancements and additional functionality as the Department increases automation in other areas.

Each major component of the recommended conceptual solution is explained following.

Central Processor

The recommended solution includes a central processor that will support the major laboratory information management system functions. Use of a central processor will allow central control by one support group over the software that is being used to manage laboratory testing at all locations. There will be one version of the software running on one machine. All users will be using the same validation files, specifi- cations, calculations, and on-line screens to perform the laboratory testing. Users will not be required to control their own data, e.g., back it up and upload it to a central repository. The central processor will act as the repository for all data in an immediate, near real time mode. A change in the laboratory information management system software will be made to only one version of the software and will be available immediately to all users of the system.

A central processor will allow protection of the data against unintentional destruction without the user having to worry about data protection or security. As soon as data entered into the processor is approved by the authorized user, it will be available to all other users of the system. With available hardware and software, this kind of central control is difficult to implement in a distributed environment where users are executing programs that run on their own workstations rather than a central machine. The central processor does provide the capability to collect data from special testing instruments or microcomputers. It also allows data to be extracted from its central repository and downloaded to a selected microcomputer or other processor for use in a user developed Lotus or DBase program, so the flexibility of microcomputer capabilities is not lost.

Intelligent Universal Workstations

The recommended solution includes the use of intelligent universal workstations. Universal workstations are microcomputers which can act as communication devices to the central processor and other host computers, or as standalone microcomputers. The use of universal workstations will allow one device to provide access to the Construction Materials System, as well as to other ADOT system running on other computers. This will prevent users having multiple terminals for the various computer systems that they need access to. The workstations can be used to receive downloaded data from the central processor or the existing Amdahl mainframe so that microcomputer processing can be performed, thereby saving use of expensive resources. The universal workstation can be networked on a local area network to other microcomputer workstations so that microcomputer peripherals, software and data can be shared without intervention of associated host processors. The universal workstation is more expensive than the non-intelligent terminal; however, its ability to function in several different technical environments makes it a practical and flexible long term investment. The universal workstation will also be used as a backup processor for critical functions of the system in the event that the central processor is unavailable.

Communication Capability

The conceptual solution requires a data network to provide interactive communication from district, area, and project offices to the central processor. Remote offices can use dial-in capabilities to access the central processor; however, the sites that are more permanent, e.g., area and project laboratories that are in the same location for a year or more, should be added to the network by installing a leased line or a drop off a multi-drop leased line. A leased line provides a higher quality communication capability than a standard phone line and will be more economical over the long term for laboratories that will be accessing the central processor on a daily basis. A multi-drop line provides a means of connecting several offices in close proximity to the central processor over one leased line, thereby maximizing the use on the line and eliminating the need for several individual lines. Implementation of the appropriate dedicated network will ensure that reliable communication can take place among the central, district, area, and project laboratories in a timely and dependable manner.

Package Laboratory Information Management System

In formulating the conceptual solution, Peat Marwick assessed the practicality of a package Laboratory Information Management System (LIMS). A package LIMS is a commercially available, off the shelf software package developed to provide laboratory automation support. We analyzed several LIMS packages commercially available to determine if such a package is practical for ADOT. We analyzed the packages by reviewing documentation, holding discussions with vendors and with users, and attending demonstrations of the operating packages. The packages analyzed include:

- DEC LIMS/SM and LIMS/IM for DEC minicomputers
- AXIOM Systems' VM LIMS for IBM VM environments
- Beckman Instruments' CALS for DEC minicomputers
- Chesapeake Information Systems ENCOMPASS for DEC minicomputers
- LABFORCE, Inc. LABFORCE for PRIME minicomputers
- Laboratory Microsystems PC/LIMS microcomputer based system
- Nelson Analytical's relational data based system for DEC minicomputers
- Perkin Elmer's systems for DEC and concurrent minicomputers.

Exhibit I-2 provides a summary of key features of the packages.

The packages provide menu driven systems that include standard laboratory functions such as sample tracking, results entry, instrument interfacing, comparison to specifications, ad hoc querying and reporting, standard reporting, and data base management. Most packages also support statistical analysis either through an interface to a statistical software package such as SAS or within the LIMS itself. From our analysis, we concluded that a LIMS package will provide some of the functions required by ADOT's materials testing laboratories; however, any package selected will require fairly extensive customization of screens, reports, test procedures, calculations, etc. Some functions of ADOT may require complete custom development because the function is not included in the selected package. Starting with a package despite functional limitations is still advantageous to complete custom development, provided the package is carefully selected and appropriate resources are committed to its installation. Each package has different capabilities and they vary widely in price, e.g., the Beckman Instruments CALS package provides instrument interfacing while other packages do not. The ultimate package selected will be dependent on the hardware selected. Most of the packages have been developed for a particular vendor's hardware. There are few packages available for mainframes since mainframes are less suitable then dedicated minicomputers for the requirements of a laboratory. The advantages of using a package versus completely custom developing a system are:

- The expertise of the vendor and other users is available
- The package provides a structure around which to build a system
- The system will be available sooner because customization of the package takes less time than complete custom development

- Experience of other users of the package can provide valuable insight to avoiding potential problems
- Purchasing a package should be less expensive than custom developing the entire system
- Maintenance of package software should be easier and most vendors provide maintenance support of their packages.

Strengths of Conceptual Solution

The conceptual solution includes use of a central processor and a package Laboratory Information Management System (LIMS). The availability of package application software is a favorable factor in the recommendation of a central processor.

As explained previously, a software package can significantly decrease development time and expense, provided the package is flexible and can be customized to fit the needs of the ADOT laboratories. We believe that several of the available LIMS packages offer such flexibility to ADOT. Few LIMS packages are available for technical platforms other than central processors; most have been developed for minicomputers.

More important than the availability of software is the central control allowed by the conceptual solution. The ability for one support group to maintain the system and its technical operations prevents the users from being burdened with operational tasks such as version control of software, data backup, upload/download tasks, etc. A central processor allows one version of the software to be maintained on one machine, with all users having access to that software. Likewise, all data necessary for the operation of the system is maintained on the central processor, without the need to download and upload data continually for day to day operation. Finally, all data entered into the system and produced by system calculations is stored immediately in one central location and available to all users of the system as soon as the originator of the data authorizes it, without the need for users to back up and transfer data to a central repository.

The alternative to the centrally based system is a distributed system in which software and data are stored in multiple computers in various locations. Distribution of software and needed data to distributed computers is an on-going maintenance task which is not easily accomplished. Users are burdened with the tasks of ensuring that they have the most current versions of software and data. The users are responsible for daily backup of their data, which is not easily controlled or enforceable. Users are also responsible for establishing communication to the central data repository and performing daily uploading of their data to that repository. This requires coordination with central support staff and adds another data maintenance task to the users' responsibilities. With available technology, the ability to control data and software in a fully distributed environment, i.e., one in which each workstation runs its own software and stores its own data, is difficult and requires significant end user involvement <u>and</u> central technical support. The criticality of these issues must be emphasized, although they are difficult to understand until experienced.

Any solution will require management support in the form of a commitment to staff for maintenance and support of the selected hardware and software. The recommended solution requires at least two additional full time staff support people.

System backup is a concern in a laboratory environment, especially at ADOT with its many remote locations. With the recommended solution, users will be dependent on the central processor and the communication network for the fully functioning system; however, major tests will be supported on the intelligent workstations as a backup should the central processor be unavailable.

The detailed description of the conceptual solution in Section IV includes a minicomputer composed of two processors packaged as one computer. The two processor computer provides higher volume throughput, allows more users to access the system, and provides automatic backup by the second processor if one of the processors goes down. To provide backup for communications, a second communication controller can be purchased for a relatively insignificant cost, provided the need for such backup becomes apparent after the system is in production. Since the reliability of the communications network is a concern, it may be necessary to provide backup dial-in communication lines for selected sites that use leased lines. The modems used with the leased lines can be equipped with automate dial-in capability so that the dial-in line is automatically invoked if the leased line fails. Hardware and software reliability is constantly being improved upon, especially in the central processor environment which has become relatively well established by now. With the proper technical support and physical component backup, downtime can be all but eradicated.

As part of our study, we surveyed other state Departments of Transportation to assess their strategic plans for automated materials management support. The majority of states are interested in developing a computer system to support materials management. States have implemented varying levels of computer support through microcomputers, minicomputers, and mainframes. Very few states have successfully interfaced testing equipment for automatic results retrieval; most are at the early stages of development and are doing little more than keying final results into an existing mainframe for district access. Details of each state's efforts in automated materials management support are presented in Appendix A at the end of the report.

I.4 MANAGEMENT ISSUES

During the project, issues have surfaced which require management attention. The issues are listed below.

Management Commitment/User Involvement

The successful implementation of the Construction Materials System depends on full management commitment and user involvement throughout the design and implementation of the system. Management must make a commitment to the system to provide direction and enforce procedural changes that may result from the implementation of the system. A full time project manager from the user community must be assigned to the project as soon as possible to provide unity and consistency and maintain momentum during the transition between the current project and the implementation project. In addition, a full time project participant from the user community should be assigned to act as the user liaison between the project implementation team and the user community. This user liaison will help to ensure that user needs are met, and will determine when additional user involvement is necessary. The liaison will provide functional expertise during design, assist in the development of test data and plans, coordinate training, and review documentation and other deliverables.

Additional Staffing Support

Regardless of the solution selected, the automated system will require full time support of a person dedicated to the technical environment, e.g., hardware and communications, and a person dedicated to the support of the application software, i.e., the LIMS. Staffing is further discussed in Section IV.

Hardware and LIMS Selection

The Request for Proposal (RFP) should include specifications for hardware and a package Laboratory Information Management System (LIMS). The two components cannot be selected independently since not all types of computers have package LIMS available. A LIMS that is not currently being used in a production environment should not be considered, nor should a LIMS that has been custom developed for a particular environment and packaged as a generic solution. The requirement of an available LIMS for the selected hardware will limit the number of vendors that can meet ADOT's needs; for example, most of the leading minicomputer vendors have their own LIMS packages available or packages that have been developed by third parties for the specific hardware, while there are far fewer LIMS packages available for mainframes and microcomputers. Consideration of hardware and LIMS cannot be made independently. Ideally, the advantages and disadvantages of LIMS packages should be weighed against the flexibility of the hardware, and a combination should be selected that provides functionality and reliability. The Construction Materials System has special needs of both hardware and software that must be jointly met.

Hand Held Data Collection

Some acceptance testing is performed by inspectors on the construction project or witnessed at the plant site. Results of the tests are recorded on forms. This data is needed by the Construction Materials System and will be entered into the system at the workstations. Ideally, hand held data collectors would be used to record the data at the construction site or plant. These data collectors would then be taken to the district or project office where the data would be automatically loaded into the system. The appropriate forms would then be printed and signed and kept as the source document. Data collection devices have become common in both government agencies and private industry and are designed for operation in harsh conditions. The use of hand held data collection devices will be an effective productivity tool for ADOT and should be included in the design of the system; however, we recommend that they be viewed as a feature to be added at a later date after the base system has been fully implemented. Currently, a drawback to the hand held data collection devices is the cost. Costs for data collection devices begin at $300; however, programmable devices that are much more flexible and could handle the various types of data that would be collected for the system cost $1,000 or more. The price of data collection devices will continue to decrease and ADOT should view data collection devices as a future productivity tool to assist in the collection of the acceptance data.

Bar Code Generation

To speed data collection, bar coded labels would be generated at the project or district office and then attached to the identification cards and the actual samples. The generated labels would contain the project number, contractor, material type, and any other standard information that is known ahead of time. This would allow more efficient setup of the samples once the samples were received at the laboratory. The bar coded labels could be generated in volume at the beginning of the project and then used on all samples lifted during the course of the project. As with the hand held data collection devices, we recommend that bar code generators be included in the design of the system and phased in after the system has been fully implemented.

Timing of Instrument Interfacing

The project team recommends that automated instrument interfacing be included in the design of the system and phased in after the Construction Materials System has been developed and implemented in a production environment. Instrument interfacing is a complex and error prone endeavor, and could consume resources that we believe should be devoted to developing the basic and more critical functions of the system. Instrument interfaces can be established at any time after the system is implemented without having an adverse impact on the effectiveness of the system.

The use of bar code readers, hand held data collection devices, and instrument interfacing should be included in the vendor's cost estimates in the respones to the eventual RFP and should be part of the system design. We are not recommending that these productivity aids be disregarded. We are suggesting that the base system be developed first so that resources are devoted to getting a working system up and running before time is spent on the additional technology. As soon as the system is functional, these features must be added to obtain the full benefits of laboratory automation.

Standardization of Equipment

Interfacing testing equipment to computers to allow automated data collection requires some custom development of computer software. For this reason, testing equipment should be standardized so that once an interface is established, the same interface software can be used for all equipment of that type.

Leased Lines on Network

Using the recommended alternative, several workstations on the network may warrant leased communication lines as opposed to a dial-in line. Based on our current analysis, we estimate that at a minimum, each district office will warrant a leased line because of the volume of data that will be sent over the line. We have provided estimates of the cost of a leased line versus a dial-in line in Section III. As workstations use the network, a determination can be made regarding the economic benefit of installing a leased line based on an analysis of the actual volume of use and the benefits of a leased line in terms of reliability and quality.

Sample Setup

Before samples are tested, they must be set up in the laboratory information system so that the system can begin accepting data for the tests to be performed. A sample setup will involve entering a sample identification number, project number, material type, material source, and other identifying information. The system will validate this information against pre-established tables to ensure the highest level of accuracy possible. Ideally, the setup should be performed at the workstation closest to the source of the sample, e.g., at the project rather than at the laboratory where the sample will be tested, since the project office staff will be most knowledgeable of the setup information. The system will be designed to allow the setup to take place at any workstation on the network; however, management should make a decision as to where the setup will take place and should enforce procedural changes if necessary.

II. BUSINESS FUNCTIONS AND CURRENT ENVIRONMENT

This section of the conceptual solution report contains a summary of the business functions to be addressed by the Construction Materials System and an analysis of the current environment. This summary resulted from our analysis of the Testing and Quality Assurance Study report and our interviews and observations performed during the first part of the current study. Exhibit II-1 provides a high level summary of business functions currently performed in materials management. Exhibit II-2 provides a more detailed depiction of the current flow of data as relates to materials management business functions. Using these current business functions as a basis, we have identified the functions to be included in the future application system to be developed. Subsection II.1 provides a discussion of the major functions that should be designed into the application system.

II.1 MAJOR BUSINESS FUNCTIONS OF SYSTEM

The major business functions to be addressed by the new system have been grouped into seven areas:

Laboratory Testing

Field Office Functions

Materials Management - Central

Quality Assurance

Administration

System Interfacing

Management/User Reporting

Each of these areas address a work process that today is accomplished through manual procedures, microcomputer applications, mainframe applications, or some combination. The seven areas are listed below with the functions performed in

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Arizona Department of Transportation
Materials Management
Current Function Summary

Lab Testing

Inputs:
- Area/Project Laboratories
- District Laboratories
- Central Laboratory

Functions:
- Perform Project Acceptance Tests
- Perform Correlation Tests
- Perform Independent Assurance Tests
- Maintain Material Sample/Test Logs
- Analyze Test Results
- Certify Materials

Outputs:
- Test Results
- Logs
- Weekly Summary Reports

Field Office Functions

Inputs:
- Area/Project Laboratories
- District Laboratories

Functions:
- Update Sample Checklist
- Monitor Consultant Labs
- Maintain Retention Factors
- Review Contractor Test Results
- Perform On-Site Field Tests
- Maintain Mix Designs
- Maintain Project Records
- Perform Plant Inspections
- Monitor Plant Mixes
- Determine IA Sample Reuirements
- Generate Change Orders
- Track Failed Test Response
- Prepare Weekly Test Report
- Track Concrete Pours
- Compare IA/Correlation/Acceptance Tests

Outputs:
- Mix Designs
- Sample Checklist
- Test Results
- Project Records

Central Office Functions

Inputs:
- Materials Section
- Contracts and Specs
- Central Laboratory

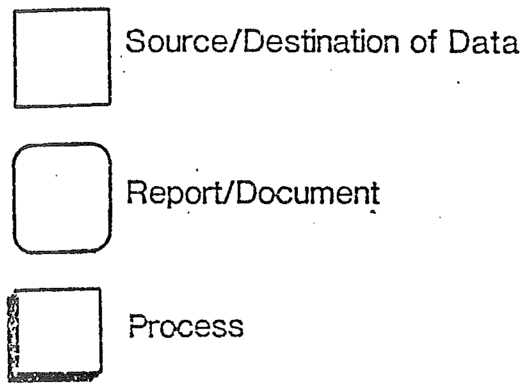
Functions:
- Maintain Contract Bid Items
- Maintain Contract Specifications/ Special Provisions
- Maintain Material Specifications
- Maintain Approved Materials List
- Verify Mix Designs
- Create Material Design Memorandum
- Generate Sample Checklist
- Inspect Laboratories
- Test Proficiency Samples
- Perform Special Item Tests

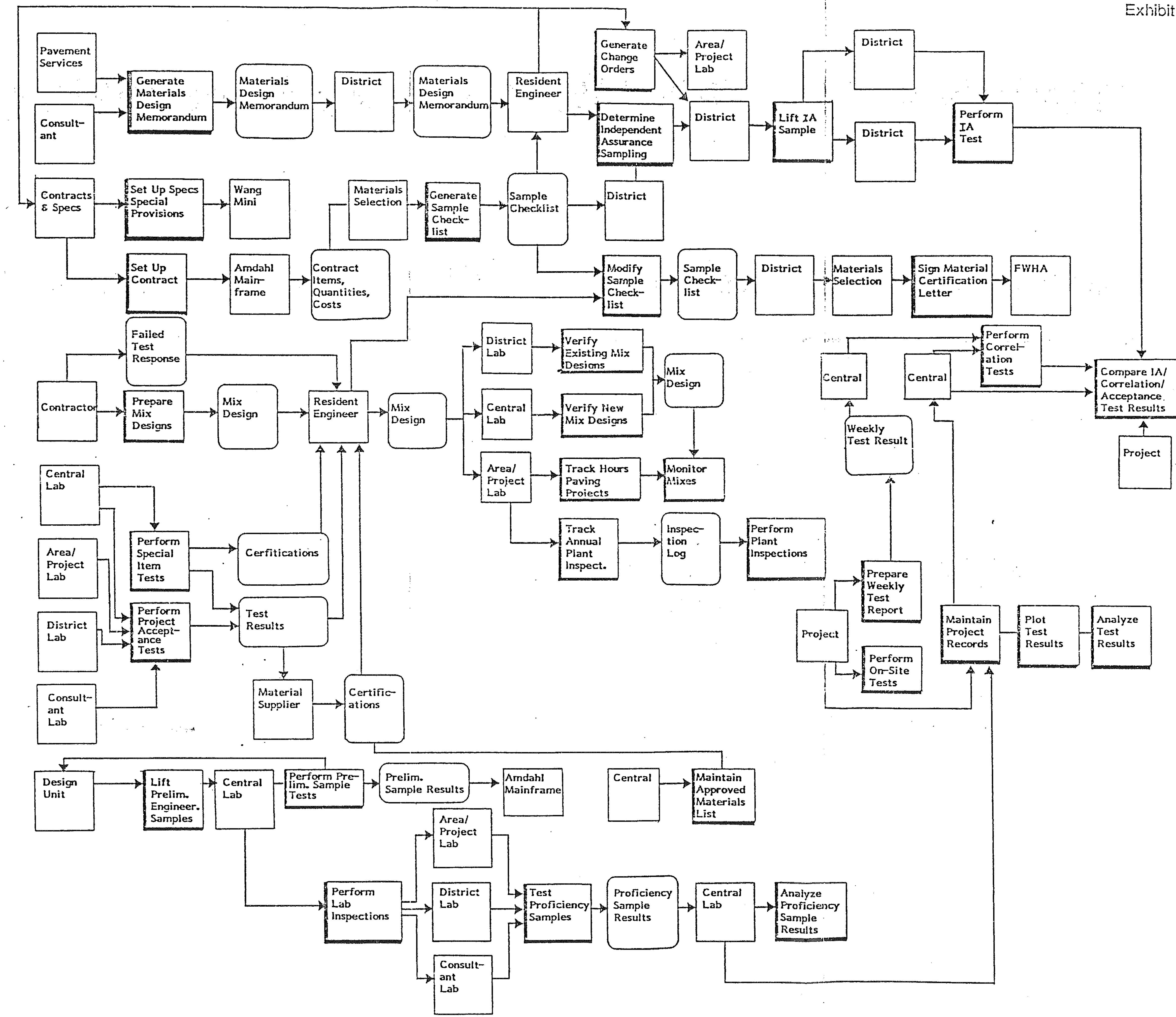
Outputs:
- Contracts
- Specifications/Special Provisions
- Material Specifications
- Approved Materials List
- Design Memorandum
- Sample Checklist

Exhibit II-2

Arizona Department of Transportation

Materials Management Current Data Flow





each area and a short explanation of the function. These functions should be addressed during the design of the system, although some of them may remain as manual procedures.

Laboratory Testing

- Log Samples - Each sample to be tested will have an identification card associated with it. The identification card will contain a preprinted number that will uniquely identify the sample. The preprinted number will also be bar coded for use when bar code readers are installed. When the sample arrives in the laboratory, it will be logged in the system by keying in the preprinted number. The date and time received will be automatically recorded with the sample's identifying number. This will allow tracking of samples regardless of where or when they are tested. Eventually, this number and other identifying information will be read by a bar code reader.

- Set Up Samples - Identifying information associated with the sample will be entered in the system. This information includes material type, project number, type of sample, and other information. Ideally, this information will be entered at the source, e.g., the project site, however, the system will allow the setup to occur at any node on the network.

- Inquire Preliminary Engineering Test Results - Central laboratory performs a significant number of preliminary engineering sample tests. The results of these tests will be available to the Geotechnical and Pavement Services engineers through on-line inquiry.

- Modify Sample Checklist - Change orders to contracts may cause a change in an item quantity or the addition of a new item and quantity to the original contract. Change orders will cause the system to automatically amend the checklist when the change order will affect sampling or certification requirements. Actual tests performed will be reflected in the sample checklist through automatic updating by the system at the end of each day.

- Perform Laboratory Tests - All tests performed in the laboratory have work cards associated with them. The work card information will be entered in the system on formatted screens and through automatic data retrieval on interfaced equipment. Calculations associated with each test will be performed. Results will be compared to specifications and test status, e.g., fail, pass, or borderline, will be recorded with the sample test results. Hard copies of the work cards will be available from the system on request.

- Modify Sample Status - The status of a sample will be maintained by the system and modifiable by the system users, e.g., the laboratory testing supervisor will indicate when the sample test results are approved and therefore available to users.

- Modify Calculations - As test procedures change, the system must have the flexibility to allow calculations to be adjusted by the users.

- Modify/Correct Sample Setup - The identifying information associated with each sample will be available to the laboratory testing personnel, regardless of where the sample is actually set up. This information will be modifiable so that laboratory testers or supervisors can make necessary corrections. All such identifying information will be validated upon entry against common validation tables.

- Track Samples - Users of the Construction Materials System will be able to track samples at any time from any node in the network. By entering the desired sample's unique identification number or other unique information such as project number, material type, and date, the user can view the status of the sample, e.g., received at laboratory, tested but results not yet approved, or not yet tested.

- Perform Retests - occasionally samples are tested and results indicate that there was an error in testing. In this situation, the sample may be retested. The system will have the capability to perform a retest on the sample and save the results of both the original test and the retest, and associate both sets of results to the original sample.

Field Office Functions

- Maintain Sample Checklist - The project office personnel are responsible for maintaining the sample checklist and updating it as the project progresses, or at the end of the project. The system will provide assistance in the maintenance of the sample checklist by automatically updating the checklist as samples are tested. The checklist will be available to project office personnel for on-line review and modification or in hard copy form by request. Failed test results will be associated with the sample checklist with notation capability so that explanations for materials in non-compliance can be incorporated.

- Allow Consultant Laboratory Participation - Consultant laboratories should be required by ADOT to obtain a workstation that is compatible with the Construction Materials System so that they can use the system, and more importantly so that the test results are available to ADOT's users of the system. Full use of the system by consultant laboratories will provide ADOT with more control over the consultant laboratories' procedures. For example, calculations on raw test data entered at the consultant laboratory will be performed by the system and results compared to the appropriate specifications.

- Provide Office to Office Communication - The system will provide users with the capability to send messages to other users on the network. For example, project office users will be able to send notification of concrete pours to the area or district laboratories electronically. This electronic mail capability will supplement phone messaging and decrease or eliminate it as users become comfortable with it.

- Provide Retention Testing - Area and project laboratories prepare retention samples for their technicians who perform asphaltic concrete testing. The technicians perform tests and are assigned retention factors which are then added to the results of the asphalt content tests performed on construction project samples. The system will provide the ability to assign retention factors that will automatically be added to the particular technician's results.

- Maintain Contractor Test Results - Contractors perform material testing as a quality control feature. Results of the contractor's tests will be optionally entered into the system so that they can be compared to the results of ADOT tests. All sample test results will be identified by type, e.g., IA sample, acceptance sample, contractor tested sample, correlation sample, so that it is clear to the user what is being analyzed.

- Maintain Field Acceptance Tests Results - Several field tests are performed at the construction site including nuclear gauge density tests, sand cone and volumeter density tests, and concrete air content and slump tests. Ideally, the data collected as a result of these tests will be entered in hand held data collection devices, calculations will be performed by the device, and then raw data and results will be automatically loaded into the system when convenient. As discussed in Section I of the report, hand held data collection devices are available; however, there is a significant cost associated with adequate devices. The system will initially include the capability to enter the data at workstations so that hand held collection devices can be purchased in a later phase of the project.

- Maintain Material Source Information - Information for material sources, including commercial plants and pits, will be maintained by the system. For each material source, the system will maintain the mix design, quantity of construction material used from the source, results of materials tests for materials taken from the source, and projects using materials from the source. This information will be available for inquiry on-line.

Materials Management - Central

- Generate Sample Checklist - The sample checklist provides a list of the materials to be used on a construction project and the sampling and testing frequency for the material. It also lists required certifications. This list will be generated by the system using the contract bid items maintained on the Amdahl mainframe. Materials Section personnel will print the checklist or view and modify it on-line.

- Create Material Design Memorandum - The Pavement Services unit of the Materials Section creates the Material Design Memorandum which contains information used by the designers. The Project Engineers usually receive a copy of the design memorandum; however, occasionally the memorandum is not received by the project engineer who is actually in charge of the project. The system will allow the document to be created using word processing, stored by project number, and viewed or printed at the project office.

- Maintain Materials Specifications - Specifications for construction materials are published by the Highways Division in the Standard Specifications for Road and Bridge Construction manual. The system will provide on-line maintenance of those specifications that are needed for materials testing, e.g., grading limits for mineral aggregates by sieve size. These specifications will then be used by the system in determining status, i.e., pass of failure of tests.

- Maintain Approved Materials List - The Materials Section maintains a list of approved materials that can be used on construction projects. The system will provide on-line maintenance of the Approved Materials list.

- Maintain Mix Designs - Mix designs are verified by both central laboratory and district laboratories. The system will provide the capability to maintain mix designs by contractor or manufacturer. The mix design can be reviewed or printed at any node on the network.

Quality Assurance

- Track Laboratory Inspections - As part of the Quality Assurance program, consultant, area, district, and project laboratories are inspected by Materials Section personnel. The system will maintain a log of the inspections including scheduled and actual inspections. Answers to standard questions, should a standard inspection form be used, would be maintained as part of the inspection log.

- Compare Test Results - Correlation and independent assurance samples are tested in laboratories other than the project laboratory doing acceptance testing. The results of the correlation and independent assurance sample tests are compared to the acceptance tests. The system will automatically compare the results of independent assurance and correlation tests to the acceptance tests and print exception reports if the results are significantly different.

- Maintain Proficiency Test Results - Central laboratory prepares samples and sends them to area and district laboratories to be tested as a quality control measure. The system will include the ability to maintain and analyze proficiency sample test results.

Administration

- Print Final Sample Checklist - On request, the sample checklist can be printed along with the failed test reports and notifications.

- Maintain Sample Frequency Specifications - The ability to automatically generate the initial sample checklist requires the maintenance in the system of sampling frequencies for acceptance and independent assurance samples by contract bid item and quantity. The system will provide on-line maintenance of the sampling frequencies, e.g., for concrete base, bid item number 305, slump tests should be performed for every truck load of concrete.

- Provide FHWA Reports - The availability of the materials data will allow reports to be developed as necessary for FHWA.

- Track Materials Certification - Final materials certification is required for all projects, whether federally funded or not. The system will keep track of the status of the materials certification, e.g., district materials engineer has certified materials used on a particular project, but assistant state engineer for materials has not.

- Develop Specifications - Analytical capabilities of the system should assist in the development and modification of materials specifications. Specifications can be based on statistical methods since all test results will be available for statistical analysis.

- Track Plant Inspection - Commercial plants require periodic inspections. The system will track plant inspections and provide tickler reports when inspections are due.

- Maintain Special Provision Specifications - Projects often have special provisions that are incorporated into the contract and result in a change in the material specification. The system will provide the capability to enter special material specifications by project and material type. As tests are performed, the special specifications will be used rather than the standard specifications for determining material compliance.

- Maintain Approved Materials List - To assist in screening materials, the Materials Section maintains a list of approved special materials such as epoxies and cement additives. The system will provide on-line maintenance and inquiry of the approved materials list so that any node on the network can access the information.

- Maintain Traffic Material List - The Traffic Engineering section of the Highways Division maintains a list of approved manufacturers of traffic materials. The system will provide on-line maintenance of the traffic materials manufacturers list, as well as inquiry capabilities so that any node on the network can access the information.

- Track Plants or Materials Source Supplying a Project - The system will allow inquiry of a plant to determine the projects that it is supplying materials to.

- Track Number of Tests - The system will keep track of statistics such as number of tests performed by test type. These statistics will be available for reporting or feeding to other systems.

- Maintain Tables - Several types of data maintained within the system will require codes to be assigned for system integrity. For example, materials will be assigned codes to identify each unique material type. These tables will be used for validation of the data entered in the system. The codes will be maintained in tables in the system. For each required table, an on-line code maintenance capability will be provided. Alphabetic search capabilities will assist in the identification of codes so that users can easily find the codes that they need or the data associated with the code.

System Interfacing

The Construction Materials System will require interfaces to other systems so that data needed for material testing can be passed from the other systems, and so that data maintained in the Construction Materials System can be passed to other systems should the need arise.

- Contracts and Specifications Data Base Maintenance System - Contract bid items are maintained in a system on the mainframe. The bid items and quantities will be used to generate the sample checklist. An interface between the Contracts and Specs System and the Construction Materials System will allow generation of the sample checklist.

- TRACS - Project numbers entered into the Construction Materials System will be validated against a pre-established project number table. TRACS is the originator of the project number and so will be used to establish the project number table. An interface between TRACS and the Construction Materials System will allow timely creation of the project number table to be used for validation.

- Pavement Management System (PMS) - Pavement Services would like to maintain average material characteristics by route and mile post. These characteristics result from materials tests performed on the material being used during construction. An interface between the Construction Materials System and PMS will allow materials data to be transferred to PMS on a periodic basis.

- Contracts and Specs WANG System - Contractor code, name, and address are maintained on a WANG computer by Contracts and Specs. To distribute material test results to contractors, the system will need access to contractor name and address so that the name and address can be automatically printed with a copy of the test results. An interface between the WANG and the Construction Materials System will allow name and address access.

Management/User Reporting

- Laboratory Test Results - Laboratory test results will be available to all authorized users of the system through on-line inquiry by sample number, project number, material type, and other selected key fields. Hard copy reports of test results will be printed automatically at the project office printer. Hard copies will be available on request at any other node on the network.

- Electronic Mail - The system will provide users with electronic mail capabilities to facilitate sending messages between any nodes on the network and to allow document transfer.

- Statistical Analysis - The system should have a statistical analysis capability so that users can produce distribution curves, straight line charts, histograms, and other graphical representations of data by entering specific parameters such as project number, date range, and material type.

- Comparative Reporting - Reports comparing acceptance tests with independent assurance and correlation tests will be available from the system.

- Exception Reporting - Some users will be interested in receiving a hard copy report when there is an exception to normal procedures, e.g., an area engineer may wish to see failed tests only for a specific project or contractor. The system will be designed to allow hard copy reports to be printed on request with parameters entered by the requesting user. Other exception reports will be printed automatically depending on the circumstances.

II.2 GEOGRAPHIC LOCATION - ADOT OFFICES

ADOT district, area and project offices are geographically dispersed across the state. The size of the state of Arizona complicates the current communication of material testing requirements and results between each office. Exhibit II-3 presents a map of the state with each ADOT district, area, and project office identified. This exhibit includes the district, area, and project offices in place at the time of this report. One of the primary concerns in providing access to the Construction Materials System is the ability to support the frequent relocation, movement, or creation of a project office or materials testing laboratory. These facilities may be moved or shut down based on the location of the ADOT construction projects. The selected construction materials testing alternative must support timely movement and installation of computer and communication equipment at these locations.

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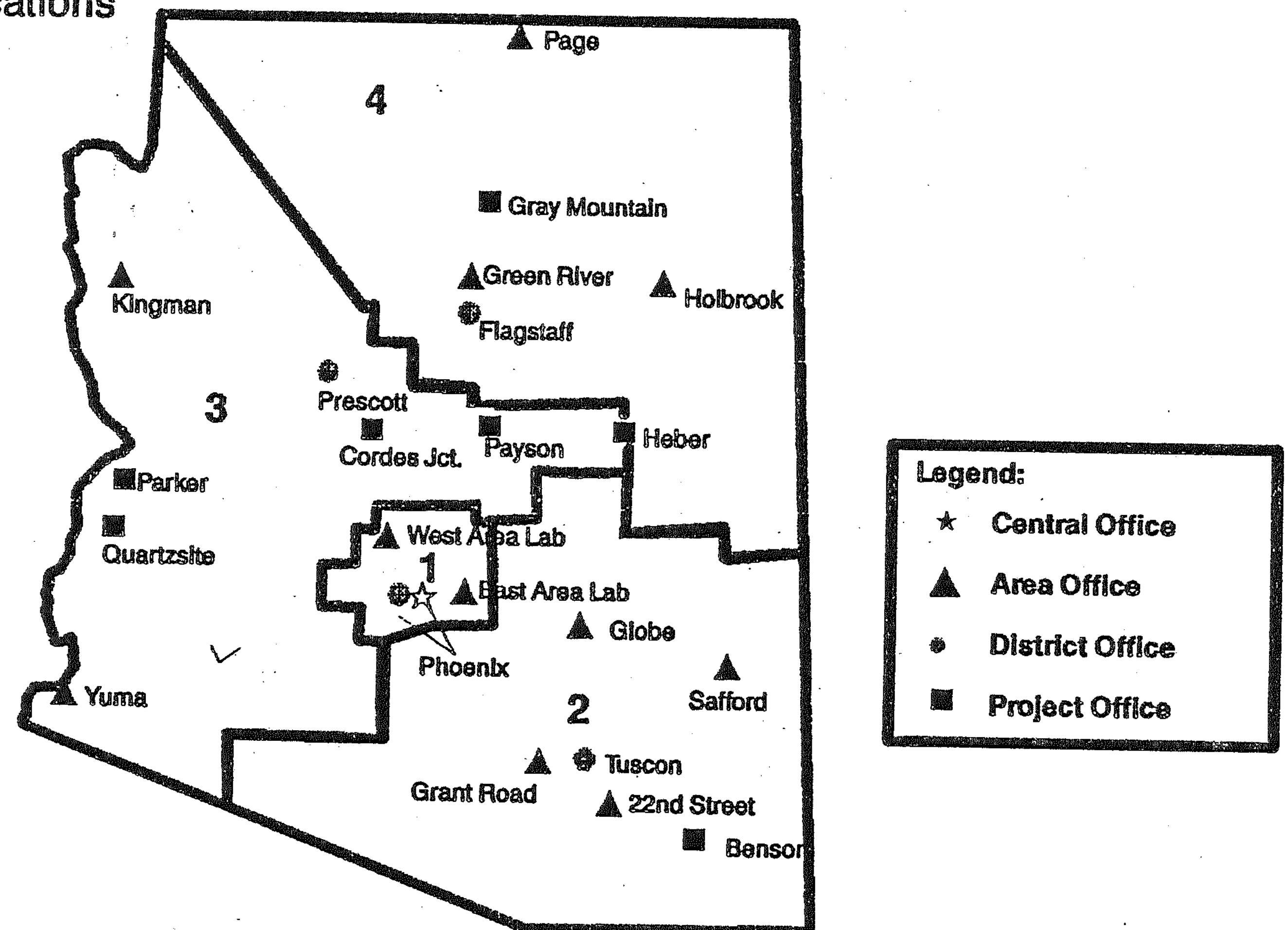
Arizona Department of Transportation
Construction Materials Testing and Quality Assurance Infrastructure
System Access Locations



One way to ensure the availability of field equipment is to purchase several spare system workstations and reserve them for new project offices, laboratory sites, or replacement of equipment under repair. As project offices or temporary laboratories are closed, the equipment may be transferred to a central warehouse facility until another project office or temporary laboratory is opened. The management of this equipment inventory must be by the central office to ensure that equipment is properly distributed and controlled.

The geographic distribution of ADOT offices must be considered during the design and implementation of the construction materials system data communications network. There are a number of phone companies and services which provide ADOT with voice and data communication facilities. In order to support a reliable data network, ADOT must obtain quality communications services. Data communications will be discussed in further detail in the Data Network subsection.

II.3 EXISTING SYSTEMS

Several of the ADOT laboratory sites have acquired a microcomputer to support the Construction Materials Testing (CMT) system. This system represents the first attempt to automate the capture of material test results in the field laboratory. However, the system has not provided adequate functionality to support ADOT's information and reporting requirements. The system has several major shortcomings including:

- Missing and inaccurate test calculations
- Lack of the ability to easily add or change a CMT calculation, screen, or test process. The program is sparsely documented and was not designed in a structured fashion
- Lack of adequate reporting mechanisms
- Inability to access data from other offices

- Duplicate data entry - test data is first entered on the work card and then entered into the CMT system
- Inability to enter data in the order that test procedures dictate
- Lack of data management facilities - several CMT users have filled up their hard disk storage area with CMT data. This forces the user to manually delete data from the hard disk in order to keep using the system
- Added complexity resulting from user initiated uploads - CMT users are supposed to dial in to the Amdahl mainframe computer and upload CMT results on a weekly basis. Many users are not performing this upload process due to the inability to access and use the mainframe data following the microcomputer upload
- Inability to extract or access CMT data using microcomputer software products such as DBase III or Lotus 1-2-3

Many potential users of a Construction Materials System have developed their own DBase III and Lotus 1-2-3 applications to assist them with daily reporting and analysis requirements. Most of these users have chosen this route due to the CMT shortcomings listed above.

There is no central direction or control over the development of materials testing programs. Each user develops his/her programs as a specific need is identified. Some programs have been shared among many offices, e.g., DBase III End Product, however, the data captured by each individual office is not available to any other office. In some cases laboratory offices are using Procomm communications software to transfer data files from one location to another. This process can be time consuming and may require several file transmission attempts before the files are sent without a communication error. Even when the data transmission is complete, there is no central data source from which every office may access test results. Therefore, the project sites and district offices rely heavily on telephone and radio communication to obtain test results from the laboratory that performed the test.

Exhibit II-4 presents the current distribution of CMT microcomputer equipment. Most district and area laboratories have access to the CMT System on a microcomputer. The typical microcomputer configuration is as follows:

- 512 kbytes of memory
- 10 megabyte hard disk storage
- 1200 baud internal modem

Use of this equipment has been considered in the development and evaluation of the four alternatives.

ARIZONA DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING AND QUALITY ASSURANCE INFRASTRUCTURE
LABORATORY MICROCOMPUTER INVENTORY
(AS OF JULY 1, 1988)

LOCATION		COUNT	TYPE
Central	Materials Lab	3	IBM XT
		1	Tandem AT
District	District 1	1	IBM XT
	District 2	1	IBM XT
	District 3	1	COM 286
	District 4	1	IBM XT
Area	East Area	1	IBM XT
	West Area	1	COM 286
	Holbrook	1	COM 286
	Green River	1	IBM XT
All Others		0	
TOTAL		12	

III. REQUIREMENTS OF CONSTRUCTION MATERIALS SYSTEM

This section of the report discusses the requirements and features of the proposed automated system.

III.1 GENERAL CAPABILITIES OF SYSTEM

Following are some of the capabilities that should be part of any system that is developed for materials management. These capabilities address high level needs of the laboratory and were taken into account when the conceptual solution was formulated.

- The system should be capable of supporting RS232 interfaces between testing equipment and computers so that automatic retrieval of instrument readings is possible.
- The system should be menu driven with full formatted screen input capabilities. Menus should be optional, i.e., users who are familiar with the system can bypass menus.
- All input fields should be edited with interactive correction capabilities and highlighting of erroneous fields.
- The system should be capable of supporting bar code reading and bar code generation at selected workstations.
- The system should allow automated interfaces to existing ADOT application systems, regardless of the computer that those systems run on.
- The system should support statistical analysis and graphics capabilities.
- The system should provide word processing and electronic mail capabilities.
- Remote printing capabilities must be a feature of the hardware and software configuration so that users can obtain hard copies of reports, queries, and screen images at all nodes on the network from local printers.
- Controls must be designed into the system to ensure that data is not accessible until authorized by the originator of the data.
- On-line help screens must be designed into the system.

III.2 DATA COMMUNICATIONS NETWORK

The proper design and implementation of the data communications network is critical to the success of the Construction Materials System. The data communications network is the pathway used to transfer data from one ADOT location to another. The CMT system currently uses the existing voice-grade telephone line, Procomm communications software, and internal microcomputer modems (1200 buad) to create a data communications network between the laboratory site and the ADOT mainframe computer. The terminal operator must initiate this communication link by making the appropriate menu selection on the CMT Menu. In addition to CMT file transmission to the mainframe, some laboratories send Lotus 1-2-3 and DBase III files using a data communications setup similar to the one used by CMT. This file transfer process requires at least two terminal operators, one on a microcomputer at each end of the data transmission, to start the Procomm software, initiate the file transfer at the sending site, and initiate the file receipt process at the receiving site.

The existing data communication network, as discussed above, raises the following concerns:

- There is a relatively slow data transmission rate. Transferring data using a 1200 baud modem yields an effective transmission rate of approximately 120 characters per second. With transmission techniques available to support 4,800 or 9,600 baud, a 1,200 baud transfer provides relatively slow transmission speed.

- The current data transmission activity is conducted over voice-grade telephone lines. There is a fluctuation in the level of quality provided by the various phone companies throughout the state of Arizona. A voice channel with a wide variation or distortion in the analog voice signal will cause data to be lost or force the modem to resend a block of data. Both the loss of transmitted data and the resending of data have an impact on the overall reliability of the data communications network.

- There is a requirement for two terminal operators to control data transfer activity between two microcomputer workstations.

- In some laboratories the telephone line must be unplugged from the phone unit and plugged into the microcomputer to support the use of the microcomputer modem.

The design of the data communications network for the Construction Materials System is an important component of the overall technical architecture. Although the Information Systems Group (ISG) has conducted several pilot projects with various communication configurations, no telecommunications strategic plan has been developed. ADOT has contracted Ernst & Whinney to perform a review of information technology needs and develop a five year ISG strategic plan. Based on the results of the Ernst & Whinney review, it is anticipated that ADOT will perform a telecommunications study aimed at developing a telecommunications strategic plan. Since there is no strategic network plan in place at the time of this report, the Construction Materials System data communication network should be designed independent of the existing network facilities.

Exhibit III-1 presents three basic methods available to connect the remote offices with the central office computing facilities. A brief explanation of each method follows:

- Dial-In - direct dial over voice-grade telephone lines. This is the method currently in use by materials testing laboratories. Charges for the use of these lines are generated based on length of connect time. This is an anlog (voice) line.

- Leased Line - the terminal is attached to the central office over a dedicated phone line. These lines are leased from the phone company on a monthly rate schedule that is not dependent on actual minutes of use. These lines may be conditioned to minimize the loss of data during transmission and improve the transmission quality. This is an analog line.

Exhibit III-1

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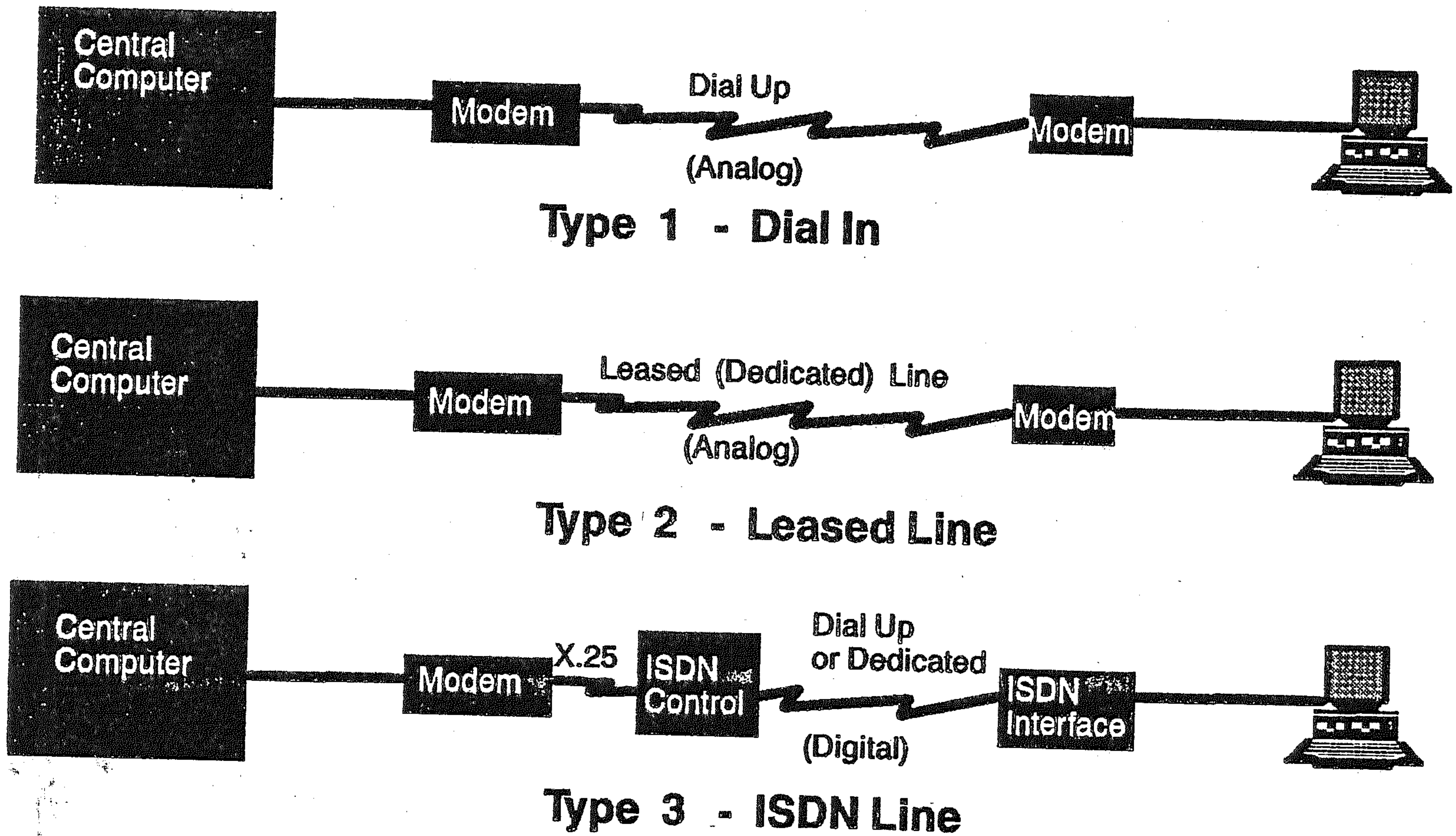
Arizona Department of Transportation
Construction Materials Testing and Quality Assurance Infrastructure
Data Communications Facility Options



- Integrated Services Digital Network (ISDN) - the data is transferred over a digital line. The advantage to using a digital network over an analog line is the improved quality of data transmission. Computer equipment operates on digital signals. The use of analog signals (phone lines) requires the conversion of a digital computer signal from the host, to an analog signal over the telephone line, and conversion back to a digital signal at the remote terminal. This process requires an additional amount of overhead to convert the data during transmission and introduces the potential for lost data or error since an analog signal may become distorted. ISDN communication is a relatively new method of sharing voice and data communication over the same digital telephone network. Since ISDN is a new technology and is still being installed by the phone service companies, it is not feasible to attempt to use it in the remote areas of the state for the Contruction Materials System.

Dependent upon the Construction Materials System alternative selected by ADOT, either dial-in or leased lines should be used to design the data communications network. If the majority of construction material testing is supported on a distributed microcomputer in a standalone environment, each workstation could require one or two hours of phone connect time during the week. If the majority of construction materials testing is supported by a central computer, each workstation could require over 40 hours of phone connect time during the week. The dial-in cost associated with the distributed microcomputer alternative would be minimal; however, the dial-in costs associated with the permanent connection of a remote terminal to a central computer could be high. In the case of the permanent connection, it would be more economical and reliable to acquire a leased phone line.

A phone line may be leased either point to point from city A to city B or multipoint from city A to several other cities. Exhibit III-2 illustrates the difference between a point to point and multipoint leased line. In general, a point to point line requires a leased phone line for each location to be

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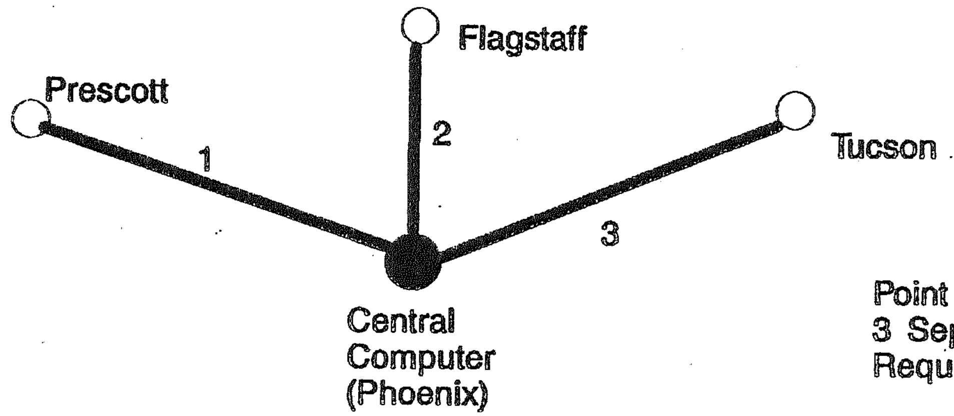
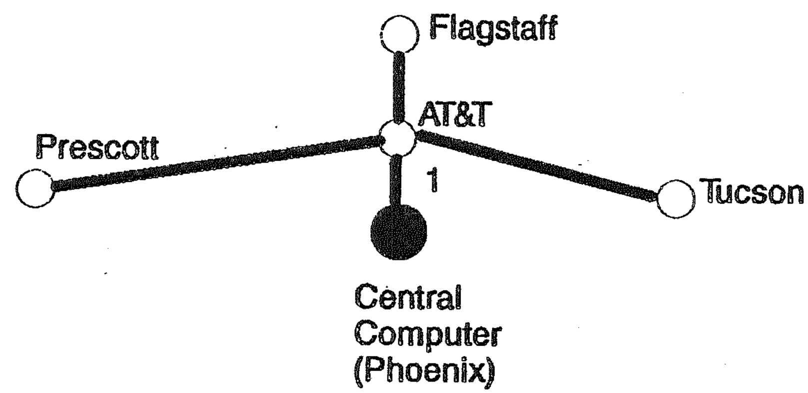
Arizona Department of Transportation
Construction Materials Testing and Quality Assurance Infrastructure
Point to Point vs. Multipoint Leased Lines



Point to Point Leased Lines
3 Seperate 4800 Baud Lines
Required



Multipoint Leased Line
1 9600 Baud Line Required

Exhibit III-2

serviced by the network. A multipoint line may serve several locations. The number of locations serviced by a multipoint line is determined by user's response time requirements, transmission rate (e.g. 4,800 or 9,600 baud), and the number of remote communication controllers supported by the central computer. In the exhibit, three separate locations share the same communication line. If the communication line runs at a high enough speed (e.g. 9,600 baud), users at each location will not notice any response time impact. In most cases some economies of scale may be achieved by using a multipoint leased line, resulting in a cost savings over the point to point network configuration.

The design and installation of a leased line network is a very sophisticated process. Once a technical alternative is chosen, ADOT must analyze the network requirements for the Construction Materials System. Appendix B contains a list of approximate charges for leased line facilities. These charges are only estimates and will vary depending on usage of various communication technologies such as satellite and microwave transmission. These charges are used to provide approximate communication costs for the conceptual solution.

III.3 AUTOMATED DATA CAPTURE

The most important requirement of the automated Construction Materials System is to capture and disseminate construction materials testing information to ADOT locations throughout the state. In addition to storing and reporting materials related information, the system will provide support for automated data capture from test equipment in the laboratory. Since computers are designed to communicate using a digital signal, the leading candidates for automated data capture are the devices which produce a digital readout. Many Mettler and American Scientific balances located at the ADOT laboratory sites across the state produce a digital readout. Digital signals produced by these balances may be captured by attaching an RS232-C cable from the back of the balance to a microcomputer workstation or a proprietary instrument coupler. The proprietary instrument coupler will allow up to eight devices to be attached to a single RS232 port on a microcomputer or minicomputer. Any balance that has a 15 pin or 25 pin connection port located at the rear of the device may be interfaced to a computer for automated data capture.

Each LIMS screen or menu that uses data that is captured automatically will require customization to obtain input from the interfaced equipment. This customization requires that special source code routines be added to the system to allow the existing LIMS program to obtain data from a source other than the workstation. For this reason, ADOT should concentrate on using automated data capture only on those pieces of equipment where a high volume of testing occurs. Based on our research, high volume use of balances occurs during coarse and fine aggregate testing in the central, district, and area laboratories. Exhibit III-3 presents a list of the high volume testing areas in each laboratory and the equipment that is currently in use at each of these sites. The exhibit shows that many laboratories have mechanical balances in the coarse or fine aggregate testing areas that will not support the automated capture of balance readings. As ADOT prepares to replace the older mechanical balances, the specifications for replacement equipment should include a requirement for an RS232 port. If possible, ADOT should select a standard vendor for the balances used in the laboratory. Once the instrument interface software is developed for one balance, it may be used to interface all balances produced by that vendor. Even though many vendors offer RS232 support, different vendor's balances may require testing and modification of the instrument interface software.

Exhibit III-3

ARIZONA DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING AND QUALITY ASSURANCE INFRASTRUCTURE
INSTRUMENT HARDWARE INVENTORY

Laboratory	Testing Area	Description	Interface	Hardware Cost	Notes
Central	Coarse Aggs	Toledo 30kg	None		
	Fine Aggs	Mettler PE11	RS232	$300	Cable + PC card
District 1	Coarse Aggs	Mettler PE24	RS232	$300	Cable + PC card
	Fine Aggs	Mettler PE16	RS232	$300	Cable + PC card
	Cyl. Breaks	Forney QC400D	RS232	$1,000	Custom Interface
District 2	Coarse Aggs	Toledo 20kg	None		
	Fine Aggs	Toledo 5kg	None		
	Cyl. Breaks	Forney LT700	None		
District 3	Coarse Aggs	Toledo 20kg	None		
	Fine Aggs	Toledo 5kg	None		
	Cyl. Breaks	Forney FT31DR	None		
District 4	Coarse Aggs	Am. Sci. SP41	RS232	$300	Cable + PC card
	Fine Aggs	Am. Sci. SP20	RS232	$300	Cable + PC card
	Cyl. Breaks	Forney FT400	None		
TOTAL COST				$2,500	

NOTES:

(1) Exhibit does not include costs for software or optional instrument coupler hardware.

(2) District 1 cylinder breaker interface represents approximate costs to obtain an RS232 interface card for the Forney. Pricing for the new Forney terminal has not yet been released.

(3) The Toledo scales and Forney machines in Districts 2, 3, and 4 are mechanical and cannot be interfaced to computers.

As mentioned earlier, ADOT should concentrate on automating the laboratory instruments that are used to perform high volume testing. In addition to the balances used for aggregate testing, the Forney concrete cylinder breaker in the District One laboratory performs a high volume of tests. This piece of equipment produces a digital readout on the Forney terminal. The Forney terminal does not have an RS232 port to allow capture of the digital readout, however, an RS232 interface card can be adapted to the Forney device to allow capture of the digital readout. Adoption of this interface card will cost approximately $1,000. Forney is in the process of designing a new terminal for the model QC400D cylinder breaker. This terminal will contain an RS232 port that could be used to capture the digital readout. At this time Forney cannot provide a price for the new terminal device. The price will be available by September 1988.

As discussed in Section I, the automated data capture of instrument readings should be addressed during a later phase of the Construction Materials System implementation. The first phase of the implementation will provide a central data repository for materials test results and the on-line screens required to capture these test results.

III.4 BAR CODE GENERATION

The Construction Materials System is designed to greatly enhance the laboratory's throughput of sample testing by using state-of-the-art computer technology. We believe that certain data elements can be identified for bar code label printing (e.g. project number, sample number, etc.) to support additional streamlining of the sample log and data retrieval process. These bar code labels would be created in the project offices, using a microcomputer workstation to generate the actual label at a local printer. Bar code labels are typically printed on a laser printer using commercial sheets of gummed labels. Several brands of bar code scanners can support the scanning of labels generated by high quality dot matrix printers.

The following costs are associated with bar code printing at the project offices:

- One high quality printer per location (may already exist) at $800
- The necessary software required to generate standard bar code labels at $500 per workstation.

III.5 HAND HELD DATA COLLECTION

There is a large volume of Construction Materials System data that is collected at the project site. Currently there are no terminals available at these sites during the testing process, however, the implementation of a hand held data capture device would allow project staff to directly enter their test results in a computer unit, return to an office and upload the collected data to the Construction Materials System using a microcomputer and a modem. In addition, the hand held computer could be programmed to perform any calculations that are currently being done by hand. The approximate costs required to add this support include the following:

- Hand held data entry terminal which meets the following specifications:
  - Contains at least 64K RAM storage
  - Supports a development language (e.g., BASIC)
  - Contains at least a 32 character display
  - Supports data transmission at 1200 bits per second (bps)
  - Supports attachment of a bar code scanner

  These units range in price from $1,000 - $3,000. ADOT should consider how many inspectors will require a hand held device.

- Use of hand held data collection will require that software be developed to interface hand held device collected data with the Construction Materials System. Since the data being captured by the hand held devices will have a corresponding data entry screen in the Construction Materials System, this development process will produce a routine that uploads the hand held device collected data file and places each data item into the appropriate data base. The cost should be approximately $16,000 (200 man hours at $80 per hour).

III.6 RESOURCE REQUIREMENTS

Following are the basic resource requirements used in estimating sizes of components for the conceptual solution. These requirements represent estimates based on the original ATS study, our review of the current environment, and approximations of future system activity.

- Number of System Users - based on our interviews and analysis we estimate the number of users during the first two years will be approximately 150-200 total users and 60-90 concurrent users during the day. The processor must be sized base on the estimated number of concurrent users.

- Number of Transactions - based on an expected volume of 100,000 tests per year, we estimate the Construction Materials System will perform approximately 400-500 laboratory transactions per day and 100-200 inquiry transactions per day. Response time requirements should be based on the relative complexity of a transaction. For example, it is reasonable to expect that a sample/test inquiry or update screen can be processed with a one to five second response time. An ad hoc query or report that requires the system to process 40,000 samples/tests may reasonably take well over a minute to complete.

- Disk Storage - based on the estimated volume of 100,000 tests per year and the requirement to store two years of data online, the estimated disk storage requirements are 700-800 megabytes for the application data base and approximately 50 additional megabytes for the system and application files. Each additional year of online data will require approximately 400 megabytes.

Appendix C contains a list of the estimated number of microcomputer workstations and their locations.

IV. CONCEPTUAL SOLUTION

This section of the report presents a detailed discussion of the conceptual solution.

IV.1 CENTRAL PROCESSOR WITH INTELLIGENT WORKSTATIONS

The conceptual solution consists of a processor in the central office serving as the data storage hub for a network of construction materials intelligent workstations throughout the state. The intelligent workstations function as a terminal device attached to the central processor. Exhibits IV-1 and IV-2 present graphic overviews of possible conceptual solutions.

The technical architecture is comprised of a set of microcomputer workstations located at central, district, area, and project offices across the state. The workstation acts as a standalone microcomputer to run Lotus 1-2-3, DBase III, backup software, or other microcomputer software, and as a terminal to access the central processor. The central processor manages the storage and retrieval of construction materials information. The central processor hardware consists of a large processing unit connected to a series of direct access disk devices, a tape drive unit, and a communications network control device. Each laboratory and ADOT office may access the test results by dialing into a terminal multiplexer. Those ADOT offices that perform a high volume of materials testing or need essentially full-time access to the Construction Materials System can be connected to the central processor by a leased line facility as discussed in the data communications network subsection in Section III. Once the remote user is connected to the central processor, he/she has access to the Construction Materials System and data bases as well as all other central processor software products such as

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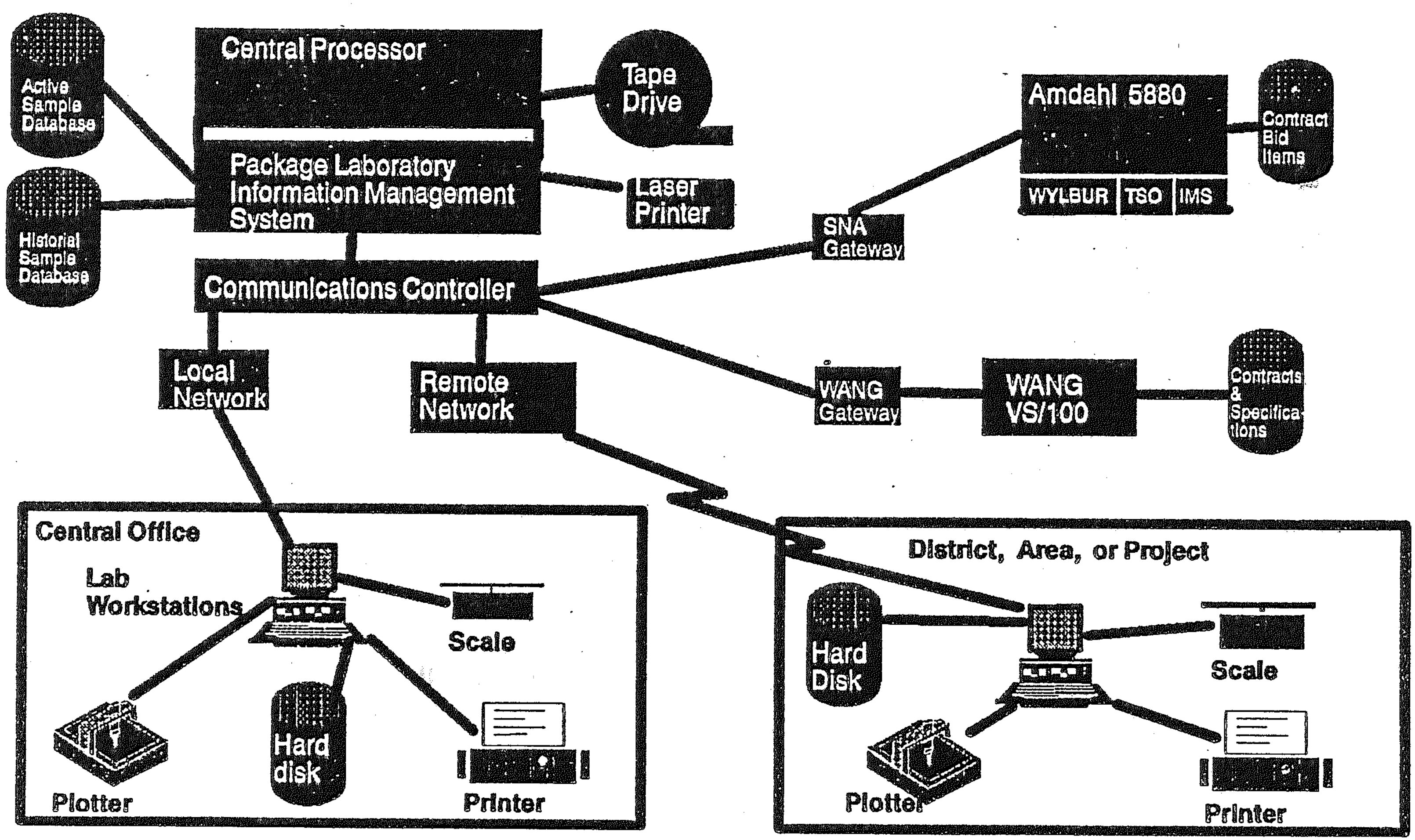
Construction Materials Testing and Quality Assurance Infrastructure

Conceptual Solution - Central Processor with Package Software



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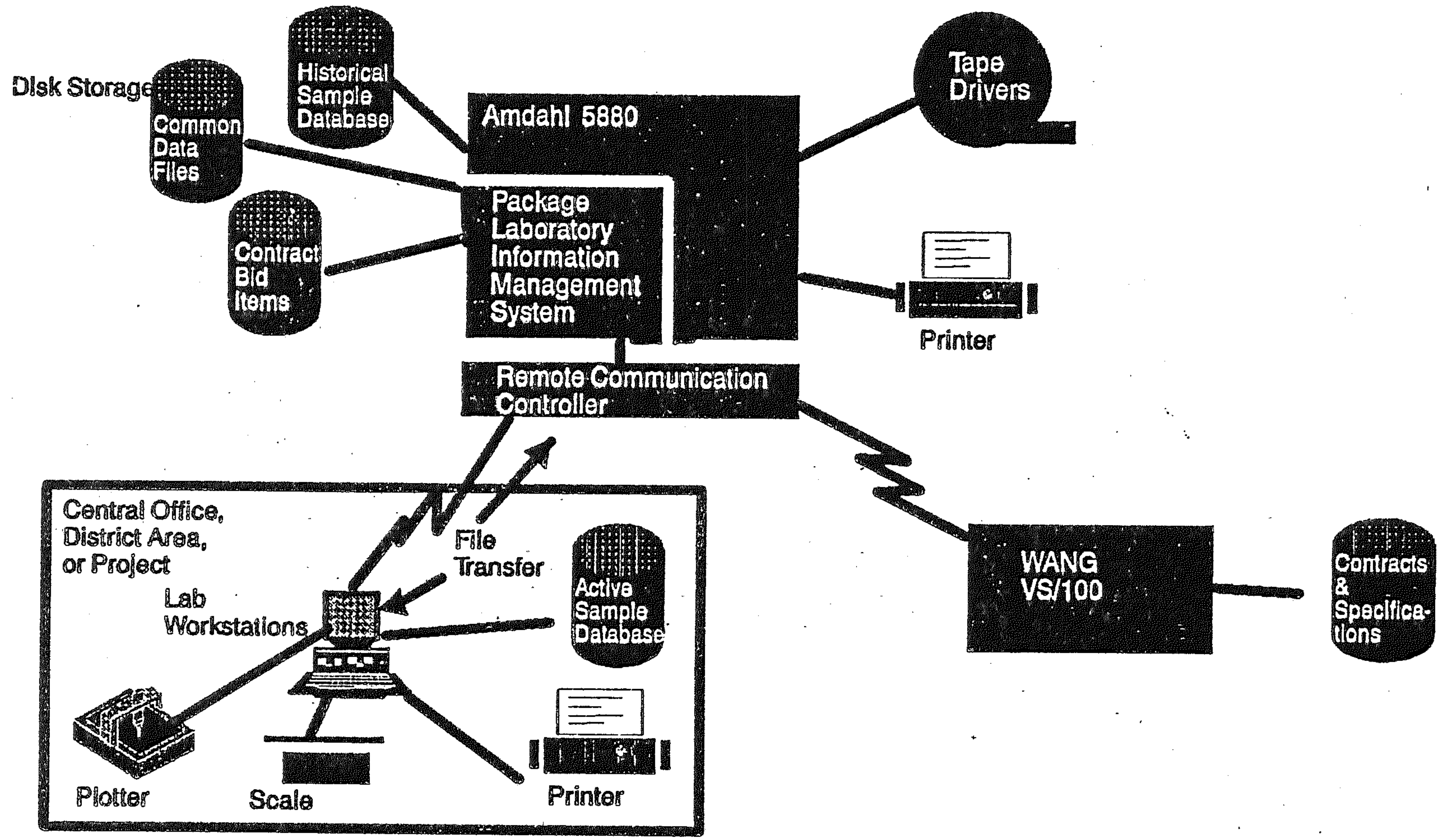
Conceptual Solution - Central Processor with Package Software



electronic mail. Authorization for the Construction Material System and files is controlled by a set of system security tables. The user is required to enter a valid user identification and password prior to being granted system access.

IV.2 LIMS PACKAGE

The conceptual solution includes the purchase of a packaged LIMS product to manage the update and inquiry of materials test results on the central processor. This solution also includes the development of backup software for the microcomputers to allow remote laboratories to continue testing with automated support should the central processor system be unavailable. Since it is to be used for backup only, the microcomputer software will only support major testing functions. This backup software will only be used if the host system is unavailable; normally the central processor system would be used to support laboratory testing.

Some LIMS packages use a relational data base to store and report laboratory test results. The relational data base structure supports more flexible reporting and query capabilities by users because of its less rigid structure. LIMS software packages are written in several different high level programming languages including FORTRAN, Pascal, PL/1, and fourth generation languages. The packages that use relational data base storage also use the structured query language (SQL) which has become the industry standard for data base access. SQL consists of a series of English-like commands that allow the user to easily inquire and report on the data stored in relational data bases.

A package will require some degree of customization to support the following:

- Automation of instrument data collection
- Tailoring of screens and menus

- Tailoring of test procedure screens and calculations
- Addition of statistical analysis reports
- Creation and printing of standard reports.

IV.3 STAFF SUPPORT

The conceptual solution solution requires the following levels of staffing and training to support the implementation effort and provide ongoing maintenance:

- One staff member with operating system experience on the selected processor to provide support for the construction materials central computer, communications network, and various laboratory computer hardware. This position will be referred to as technical support.
- One staff member with computer application system development experience to assist during the development and implementation of the system. This individual would be responsible for ongoing maintenance and support of the application system following implementation. This person will also be responsible for maintaining the backup microcomputer software. This position will be referred to as systems analyst.
- A part time staff member to function as the LIMS administrator. The staff member is responsible for adding new users to the system security tables, managing system updates and enhancements, and coordinating all training programs with the system users.
- Six staff members will attend the LIMS vendor's training session. This session will cover the installation and use of the selected LIMS package. The six staff members include the three positions listed above plus a representative from each central office testing area. These individuals will be responsible for developing the Construction Materials System training program for all other laboratory sites.
- The technical support staff member requires a training overview course on the selected central processor operating system required to support the LIMS.

IV.4 COMMUNICATIONS

In the conceptual solution, communication access to the central processor is managed by a communication controller. This controller is similar to the terminal multiplexer. The central processor communications equipment is able to handle a high volume of network traffic. Construction materials users access the network by connecting a workstation to the communication controller over a dial-in line using a modem. If the user is connected to the central processor by a leased line, the terminal does not require a dial-in procedure and the user may access the system directly entering his/her userid and password.

The central processor contains the appropriate hardware and software components to support communication with the existing ADOT computers. The Wang minicomputer and Amdahl mainframe contain several of the contracts and specifications system files required to create the materials sample checklist. The Amdahl mainframe also contains most of the existing ADOT production applications which may need to be interfaced to the Construction Materials System in the future. By supporting communication with existing computers, a single physical workstation may function as a terminal to all application systems.

The decision to use leased lines versus dial-in lines requires consideration of the following factors:

- Dial-in lines do not require extensive network management since the only network equipment required is a relatively inexpensive modem running at 1200, 2400 or 4800 baud.

- Dial-in lines are more suceptible to variations in line noise and voltage. The fluctuations may result in loss of data or disconnection of the terminal session. Although most modems and terminal emulators provide some form of parity checking and retransmission facilities, these facilities cannot detect or correct every possible transmission problem.

- If the remote site connects for a short period of time each day, existing voice grade lines may be used to make the connection.

- If the remote site dials in to the host for periods of six or more hours per day, the amount of dial-in phone charges will approach the monthly charge for a leased line. If charges are expected to be this high, the site should install a leased line.

- Dial-in modems running at 1200-4800 baud do not provide the response time of a 9600 baud modem running on a leased line. Essentially, the modem response time should correlate to the baud rate being used, e.g., 4800 baud modems transmit data 4 times faster than 1200 baud modems.

If a specific remote site requires constant access to the central computer during the business day, the use of a leased line will provide the most cost effective and reliable data communication connection. The primary benefits of a leased line connection follow.

- Leased lines have higher data transmission rates than dial-in lines, therefore providing optimal end user response time.

- Leased lines will provide more reliable communication facilities than dial-in lines because the line will be dedicated to ADOT usage.

- Leased lines may be conditioned by the phone service companies. Conditioned lines are accomplished by a contract with descriptions of service levels.

If the selected hardware is IBM, then ADOT may use the existing network facilities to expand and support the Construction Materials System. The Amdahl communications front end processor (Comten) has exceeded its capacity. For the current network to support the laboratory and construction sites, the communications processor load must be redesigned or shifted to a more powerful communications processor. None of the materials laboratories are currently supported by the ADOT network. In some locations, e.g., in district one, network support would require installation of several additional coaxial connections to the laboratory. In most other locations ADOT will be required to lease new phones lines, purchase communication controllers such as 3174s for the laboratory, purchase 9600 baud modems, and provide connections to the ADOT communications front end processor in the data center.

If the selected hardware is not IBM, then ADOT must prepare a standalone network to provide communication support for the various construction materials locations. Depending on the type of communication connection used by the existing ADOT network, e.g., T1, microwave, satellite, etc., the Construction Materials System network may share communication bandwidth among certain sites. For those sites where there is no existing connection or bandwidth, appropriate communication controllers and 9600 baud modems should be purchased for each site to provide communication connection to the construction materials central processor in Phoenix.

APPENDIX A

STATE DOT SURVEY

ARIZONA DEPARTMENT OF TRANSPORTATION

Construction Materials Testing and Quality Assurance Infrastruture
State DOT Survey

State	Materials Management Support
Arkansas	Keying central lab test results into mainframe. Nightly, downloading results to personal computers in resident engineers' offices. Have PC programs for mix design calculations. Developing program for generation of sample checklist. No instrument interfacing.
California	Planning to develop some type of system. Looking at ADOT and PennDOT studies.
Colorado	Using microcomputers to do nightly transfer results from central lab to district labs. No instrument interfacing. Key in numbers from cylinder breaking to microcomputer. In process of installing mainframe and network which may be used in the future.
Connecticut	Using a ten year old reporting system to enter results, which are then available to projects. Projects key in identifying information for samples, central lab keys in results. System interfaces with Construction System. System is not doing calculations. No instrument interfacing.
Delaware	Have two PCs which are connected to a Department DEC/VAX minicomputer. Will develop a system on the minicomputer. No system now.
Georgia	Entering central lab test results and contractor and producer test results into mainframe. Districts can then access results. Considering having districts enter results at branch laboratories. No calculations performed. No instrument interfacing.
Idaho	Doing engine oil analysis for maintenance equipment. Results get entered into mainframe. Also have some equipment used for resilient modulus testing and road surface checking that contains HP 85 microcomputers. The HP 85s produce tapes which are then loaded to the mainframe. All other testing is completely manual. Interested in further automation but have not planned anything yet.

ARIZONA DEPARTMENT OF TRANSPORTATION

Construction Materials Testing and Quality Assurance Infrastruture
State DOT Survey

State	Materials Management Support
Indiana	Final results are entered in mainframe at district and central labs. Calculations are manual. No instrument interfacing.
Iowa	Final results are entered in mainframe at districts and central labs. Results are automatically printed at districts. Minimal calculations. Computer controls freeze/thaw machine. No other instrument interfacing.
Kansas	Getting microcomputers that will tie into statewide network and mainframe. Looking at developing a mainframe system for material testing support. Not much of a system now.
Kentucky	Entering test results into mainframe system from district and central labs. Using as a storage system and to do analysis and inquiry. As soon as test is complete, results are automatically printed in districts. Looking at tying resident engineers into system.
Maine	Developing a minicomputer system that will support aggregate testing and costs and time. Then will extend to other functions. Calculations will be performed on PCs and then will upload at least twice a day to minicomputer.
Massachusetts	Recently obtained personal computers. Final results are keyed into one PC. Would like to have results available to everyone but nothing planned yet. Would like information resulting from ADOT study.
Michigan	Spent ten years trying to develop a mainframe based system. Never really had an operational system and have since abandoned the effort. Would recommend full time application support to keep the system functioning with changes in specs, screen layouts, test procedures, etc. Really have no system now but would be interested in looking at another state's successful system.

ARIZONA DEPARTMENT OF TRANSPORTATION

Construction Materials Testing and Quality Assurance Infrastruture
State DOT Survey

State	Materials Management Support
Minnesota	Recently performed a study to determine best system to develop. A minicomputer connected on a Local Area Network in the central lab with a package Laboratory Information Management System (LIMS) has been recommended.
Mississippi	Have three PCs, ten more coming. Planning to tie PCs to central minicomputer which will serve more than just materials. Minicomputer has been bid but not selected.
Missouri	No system right now but considering one.
Montana	Entering some results into mainframe. Working on developing a system that will allow results to be entered from districts and area offices. Goal will be to have calculations performed on mainframe as well. Recently hired a computer person to support materials.
Nebraska	Entering final results of tests into mainframe. No calculations are performed on computer. Developing and enhancing system now. Will look at typing PCs directly to mainframe versus uploading from dial-in PCs.
Nevada	No computerization now. Looking at getting a system in the future.
New Jersey	Using PCs for standard testing support but would rather tie everything together with a larger piece of equipment. Limited funds will probably make the mainframe the best alternative.
New York	Have selected minicomputer and LIMS package to support laboratory functions. Installation is pending approval and funding.
North Dakota	Use PCs for reporting test results. No calculations are performed. Looking at using the mainframe or some other form of electronic transfer to distribute test results and provide support.

ARIZONA DEPARTMENT OF TRANSPORTATION

Construction Materials Testing and Quality Assurance Infrastruture
State DOT Survey

State	Materials Management Support
Ohio	Put some results into mainframe. Looking at a complete centralized system in the future. Tried to interface concrete cylinder breaking Tinius Olsen equipment to microcomputer but not happy with speed of program. Can enter results faster manually. No longer using interface.
Oregon	Looking for information on some kind of system. Interested in ADOT results.
Pennsylvania	Will replace existing minicomputer with Local Area Network (LAN) and minicomputer and expand and enhance package Laboratory Information Management System (LIMS).
Tennessee	Want to develop system using PCs and mainframe that everyone is tied into.
Utah	In process of developing a system that will perform calculations on PCs and send results to mainframe. Eventually project labs and district labs will enter data.
Vermont	Looking at putting in a system. Will review PennDOT report.
Virginia	Using microcomputers to produce test reports. Want to collect data for user access and analysis. Probably will build system on minicomputer.
Washington	Have plans to put system in place. Want to purchase a package system. Have some equipment connected to PCs but no system to collect or analyze the data.
West Virginia	Have central lab support on mainframe. Technicians enter final test results and a hard copy is automatically printed. Results are downloaded to district nightly. Contractor and supplier lab test results are keyed into mainframe in district labs. Trying to keep several years of data on system.

APPENDIX B

APPROXIMATE LEASED LINE COSTS

EXHIBIT B-1

ARIZONA DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING AND QUALITY ASSURANCE INFRASTRUCTURE
APPROXIMATE LEASED LINE COSTS
(Monthly Rates)

LOCATION		COST
District 1	Phoenix	$23.30
	Tempe	33.82
	Superstition	77.74
District 2	Tucson *	215.00
	Benson *	275.00
	Globe *	160.00
	Safford *	215.00
	Casa Grande *	80.00
District 3	Prescott	97.12
	Yuma	216.50
	Quartzsite #	190.00
	Parker #	200.00
	Kingman	275.00
	Cortes Jct.	128.34
	Payson	120.00
District 4	Flagstaff	182.54
	Holbrook #	217.00
	Green River	182.54
	Gray Mountain	207.19
TOTAL		$3,096.09

NOTES:
1) Except where noted, estimates provided by Mountain Bell.
2) Installation of each line requires a service charge of $104.88.
3) * denotes those locations serviced by a phone company other than Mountain Bell. Costs for these lease lines were estimated based on mileage.
4) # denotes those locations which reside outside of Mountain Bell's LATA boundaries. These areas are serviced by AT&T. Cost estimates were made based on mileage.
5) Leased lines installed as backup for dial-in lines require a $63 installation fee and approximately $33 per month maintenance fee.
6) Please note that the above communication costs represent estimates included to provide an approximation of actual costs.
Before any lease line facilities are installed, ADOT must contact the appropriate communication service company to obtain specific price quotes.

APPENDIX C

MICROCOMPUTER WORKSTATION DISTRIBUTION

ARIZONA DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING AND QUALITY ASSURANCE INFRASTRUCTURE
MICROCOMPUTER WORKSTATION DISTRIBUTION

LOCATION		COUNT	USER
District 1	Office	7	1-DE,2-DDE,4-AE
	District Lab	3	1-DME,2-lab
	East Area Lab	2	2-lab
	West Area Lab	2	2-lab
	Construction	11	11-PE
District 2	Office	3	1-DE,2-DDE
	District Lab	3	1-DME,2-lab
	22nd Street	1	1 -lab
	Grant Road	1	1-lab
	Safford	3	
	Benson	2	1-PE,1-lab
	Globe	4	1-AE,2-PE,1-lab
	Casa Grande	2	1-PE,1-lab
District 3	Office	4	1-DE,2-DDE,1-AE
	District Lab	3	1-DME,2-lab
	Yuma	1	1-lab
	Quartzsite	1	1-lab
	Kingman	4	1-AE,1-PE,2-lab
	Parker	1	1-lab
	Cortes Jct.	2	1-PE,1-lab
District 4	Office	5	1-DE,2-DDE,1-AE,1PE
	District Lab	3	1-DME,2-lab
	Holbrook	4	1-AE,2-PE,1-lab
	Green River	2	1-PE,1-lab
	Page	1	1-PE
	Heber	1	1-lab
	Gray Mountain	1	1-lab
Central Office	Management	3	1-Dir,1-SE,1-DSE
	Construction	3	1-CE,2-QC
	Research	1	
	Materials	14	1-ME,3-SH,6-PD,4-GT
	Central Lab	14	
Spares		6	1 per district + 2 central
TOTAL		118	

Legend:

DE - District Engineer
DDE - Deputy District Engineer
AE - Area Engineer
PE -Project Engineer
DME - District Materials Engineer

lab - lab workstation
SH - Section Head
SE - State Engineer
DSE - Deputy State Engineer
PD - Pavement Design