ARIZONA DEPARTMENT OF TRANSPORTATION

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CONSTRUCTION MATERIALS TESTING AND QUALITY ASSURANCE INFRASTRUCTURE

Specification Report

Prepared by:
Catherine Pomanti
Tom Wilson

Peat, Marwick, Main & Co.
1600 Market Street
Philadelphia, Pennsylvania 19103

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Phoenix, Arizona 85007
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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 general specifications for automating the construction materials testing and quality assurance function.

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1.0 INTRODUCTION

This section of the report provides background information to be used in reviewing and understanding the requirements and specifications for a Construction Materials System. It describes the organization of the Arizona Department of Transportation (ADOT), describes the functional operations to be supported by the system, provides background information about the system to be implemented, describes the business problems, and provides an overview of the proposed solution.

1.1 ORGANIZATION OF ADOT

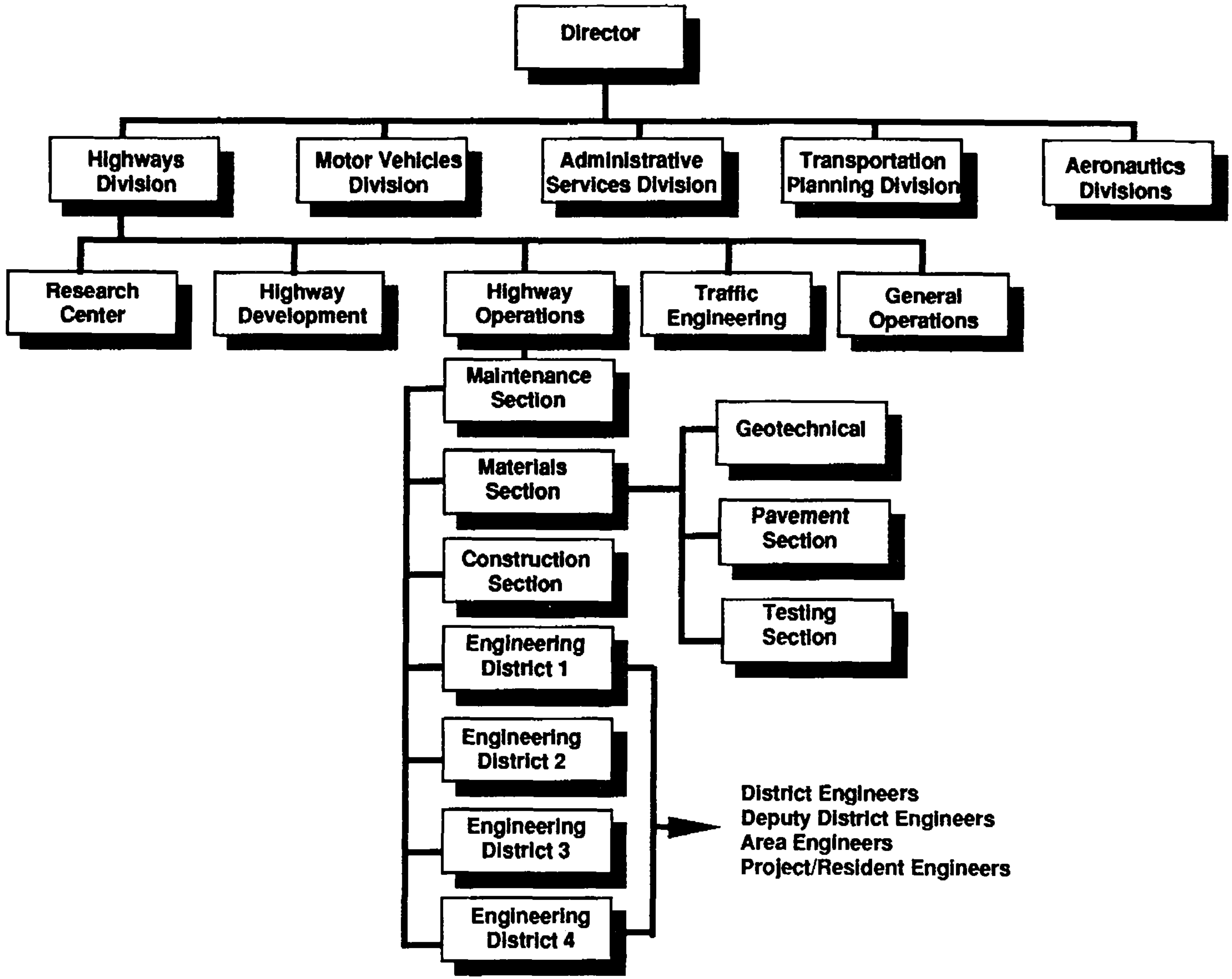
The organization of the ADOT is depicted in Exhibit 1-1. ADOT is headed by a director who reports to the Governor of Arizona. As shown in Exhibit 1-1, ADOT is comprised of five divisions, each headed by a division director. The Highways Division, whose director is called the State Engineer, is responsible for the construction and maintenance of Arizona's 16,000 miles of state highways and bridges. The Highways Division is composed of five operational groups including:

- Highway Development Group
- Research Center
- Highway Operations
- Traffic Engineering
- General Operations.

The proposed system will primarily serve the Highway Operations group. The Highway Operations group is made up of the following functional sections:

Arizona Department of Transportation

Organization Chart



- Maintenance Section, which is responsible for budgeting and bidding of maintenance materials, administrative duties relating to maintenance, some highway and bridge maintenance.

- Materials Section, which is responsible for design activities as related to naturally occurring materials at the construction site and materials to be used in the construction project, and for assuring that materials meet established specifications for quality.

- Construction Section, which is responsible for the collection of information for all contracted construction projects, maintenance of specifications, quality control, project planning, project documentation, and the administration of claims not handled by the districts.

- Four engineering districts, each of which is responsible for the construction projects and maintenance of the completed highway or structure in the geographic area of the district. The four engineering districts encompass the entire state.

The proposed system, the Construction Materials System, will support the materials management functions performed by the Highway Operations group.

1.2 FUNCTIONAL OPERATIONS OF MATERIALS MANAGEMENT

Materials Management functions can be categorized into two major functional areas: Material Testing and Quality Assurance. Each area is explained below.

Materials Testing

All materials to be used in a road or bridge construction project must meet established specifications for quality. Soils and sub-soils in roadbeds, embankments, and shoulders must be of the proper quality to provide support for roadways and structures. Materials management functions performed by the Highway Operations group are targeted to ensuring that all materials are of adequate quality. Toward this goal, the Highway Operations group performs engineering design activities and laboratory testing of materials. A number of laboratories have been established throughout the State of Arizona to support materials testing. Test procedures have been established by AASHTO, ASTM, and ADOT. The Federal Highway Administration (FHWA) monitors materials management and has established guidelines that must be adhered to in order to receive federal funding. All testing guidelines have been approved by FHWA. Following is a summary of the major types of materials tested by ADOT laboratories:

- Soils and aggregates
- Asphaltic concrete
- Asphalt
- Concrete
- Cement and cement additives
- Steel reinforcing bars and other metal materials
- Geotextiles
- Chemical products such as epoxies and paints
- Miscellaneous materials such as traffic control materials and other specialty items.

Quality Assurance

ADOT operates several laboratories throughout the state. A quality assurance program has been developed to ensure that each laboratory is performing tests in the same way according to established testing procedures.

Functionally, materials tests can be categorized as follows:

- Project Acceptance Tests are tests performed on materials used in the actual construction project. These tests may result in rejection of material, removal of material already in place, or a reduction in payment to contractors.

- Information Tests are used to evaluate materials sources, provide preliminary design information, or verify proposed material mixes.

- Independent Assurance Tests are mandated by FHWA and are used as Quality Assurance measures against which project acceptance tests are compared. The Independent Assurance Tests must be performed independently of the project acceptance tests.

- Correlation Tests are used to perform quality assurance on laboratories. For every five project acceptance test samples, one sample is sent to a laboratory other than the one performing the project acceptance tests to provide a measure for result comparison.

The Independent Assurance Sample Tests and Correlation Sample Tests provide ADOT with a means for ensuring that test results are accurate. The Independent Assurance Tests are performed in a ratio according to the number of acceptance tests performed, for example, for every forty acceptance samples, one independent assurance sample is taken and tested in a laboratory other than the one performing the acceptance testing. Independent Assurance Testing is mandated by FHWA and monitored by FHWA representatives. Correlation Testing has been established by ADOT to provide internal control over the testing performed at the multiple laboratories throughout the state. For every five acceptance samples tested, one correlation sample is sent to a different laboratory. The results of the correlation and acceptance samples are compared to each other and major differences in results are investigated.

1.3 GEOGRAPHIC LOCATION OF ADOT OFFICES

The Construction Materials System will support operations in four types of offices:

KPMG Peat Marwick

Arizona Department of Transportation

Construction Materials System

System Access Locations

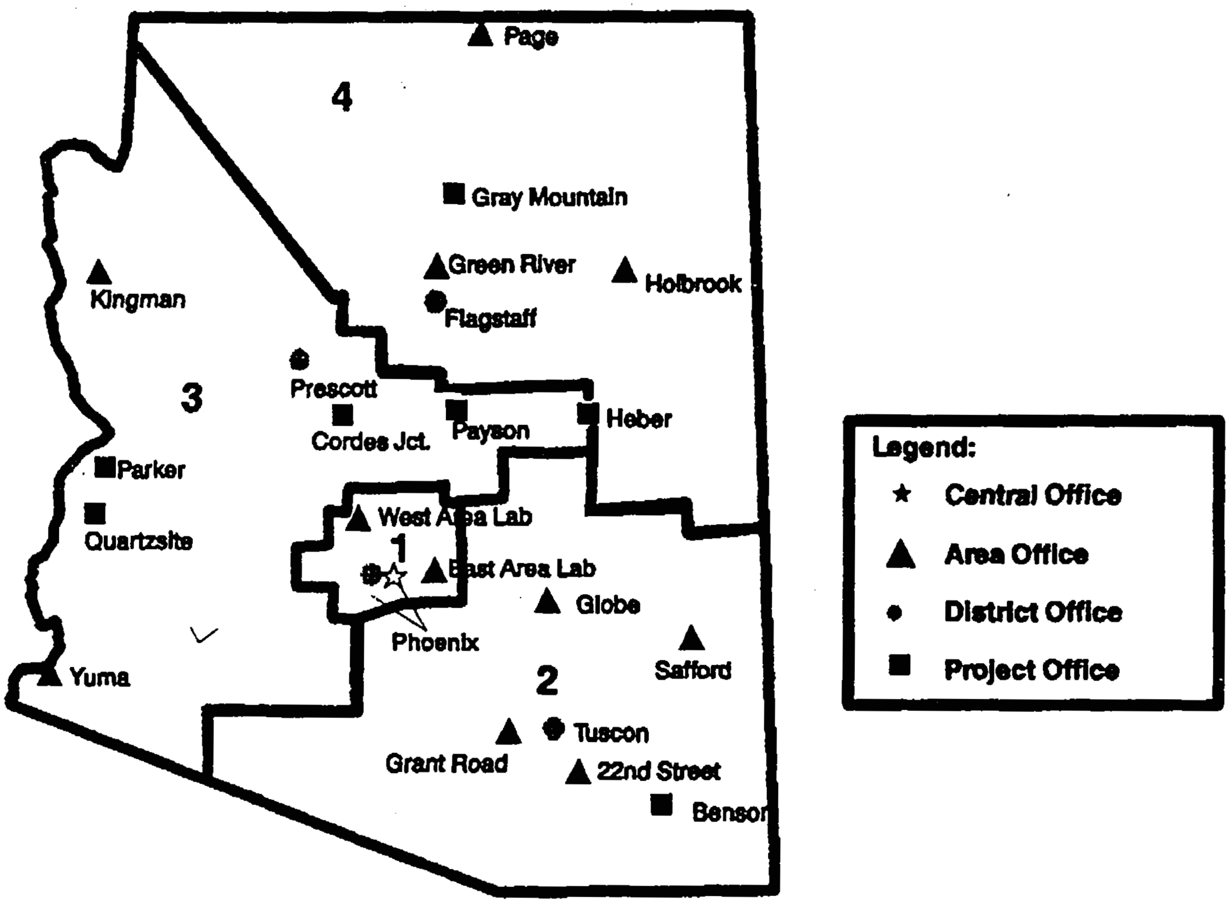


Exhibit 1–2

- Central office located in Phoenix contains a large laboratory and several administrative sections
- Four district offices which contain a large laboratory and support their respective districts
- Area offices which contain smaller laboratories and support testing for multiple projects
- Project offices which are set up at a specific construction site and contain very small laboratories that support testing for the project.

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 among offices. Exhibit 1-2 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 construction materials system and supporting architecture must support timely movement and installation of computer and communication equipment at these locations.

1.4 SUMMARY OF BUSINESS PROBLEMS

The proposed computerized system will support the materials testing and quality assurance functions performed by Highway Operations. Currently, automated support of these functions is limited. Through the proper use of technology, many of the business problems that exist can be eliminated. These business problems are summarized below.

- 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.
- 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 relevent 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 private consultant laboratories used by ADOT since procedures are completely manual.

1.5 BACKGROUND INFORMATION

Laboratory testing is currently supported by an automated system that runs under MS-DOS on IBM or compatible microcomputers. This system, called Construction Materials Testing (CMT), represents the first attempt to automate the capture of material testing results in the field laboratories. Several of the ADOT laboratory sites have acquired a microcomputer in order to use this system; however, the system has not provided adequate functionality to support ADOT's information and reporting requirements.

In 1987, ADOT performed a study to determine a strategy to improve the consistency and timeliness of construction materials reporting and quality assurance on construction projects. The study identified and documented business problems related to materials management that could be improved upon or eliminated through proper use of technology.

In 1988, ADOT initiated a project with objectives to develop a technical concept and specifications for the concept that will best support materials management. The concept and specifications are described in this report.

1.6 CONCEPTUAL OVERVIEW OF IDEAL ARCHITECTURE

The architecture that will provide automated support of the materials management functions includes the following components.

Central Processor

A central processor will support the major laboratory information management system functions. The central processor will hold all validation files, specifications, calculations, and on-line screens that will support laboratory testing. The central processor will act as the repository for all data in an immediate, near real time mode. Instruments used for testing, e.g., balances, will eventually be connected to microcomputer workstations or proprietary instrument couplers through RS232C ports for automatic data retrieval.

Intelligent Universal Workstations

Intelligent microcomputers will act as workstations in the proposed system. These workstations will allow access to the laboratory system central processor, ADOT's existing Amdahl mainframe, and ADOT's existing Wang VS minicomputer. Users with access to the laboratory system on the central processor should not be required to use a different workstation to access another system running on a different host computer. The laboratory system workstations will also be able to act as stand-alone microcomputers which can process data downloaded from the laboratory system central processor. The universal workstation will have the capability to be networked on a local area network. The workstation will also be used as a backup processor for critical functions of the system in the event that the central processor is unavailable.

Data Communications Network

A data communication network will 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 will be in the same location for a year or more, should be included in the network through a leased line connection, multi-drop or point-to-point. An appropriate network must provide reliable communication among the central, district, area, and project laboratories in a timely and dependable manner.

Package Laboratory Information Management System

Several off the shelf software packages have been developed to provide laboratory automation support. The proposed system should be based on a commercially available laboratory information management system (LIMS) package that can be customized to meet the needs of ADOT's material testing functions. The package must be a commercially available package that runs on a central processor and is in production at multiple sites.

2.0 HARDWARE/SYSTEM SOFTWARE SPECIFICATIONS

This section of the report describes the specifications for the system. In subsection 2.1, each component of the architecture is explained. Subsections 2.2 and 2.3 provide supporting detail and general requirements for the entire architecture.

2.1 SPECIFICATIONS FOR COMPONENTS OF ARCHITECTURE

The hardware and software architecture will consist of a central processor communicating with intelligent workstations located in the laboratories and offices throughout the state. The Construction Materials System will be built around a Laboratory Information Management System on the central processor.

Central Processor with Intelligent Workstations

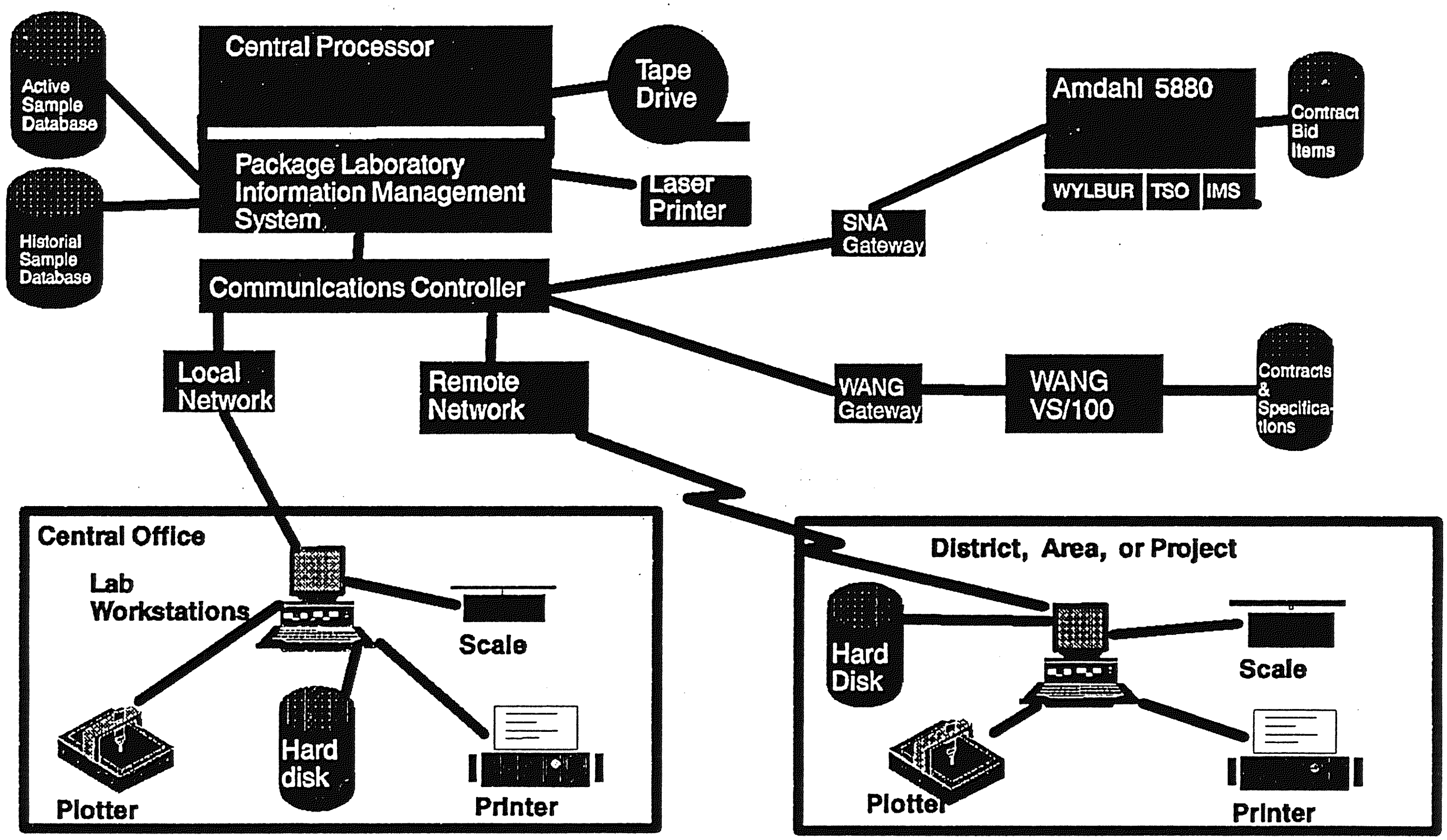
The ideal architecture to support the Construction Materials System consists of a processor in the central office serving as the data storage hub for a network of construction materials intelligent workstations throughout the state. The intelligent workstations function as a terminal device attached to the central processor. Exhibits 2-1 and 2-2 present graphic overviews of possible architectures that can meet the needs of the system.

The 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 applications such as Lotus 1-2-3 and DBase III, to perform system backups, and to emulate 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

Arizona Department of Transportation

Construction Materials System

Central Processor with Package Software



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Construction Materials System

Central Processor with Package Software

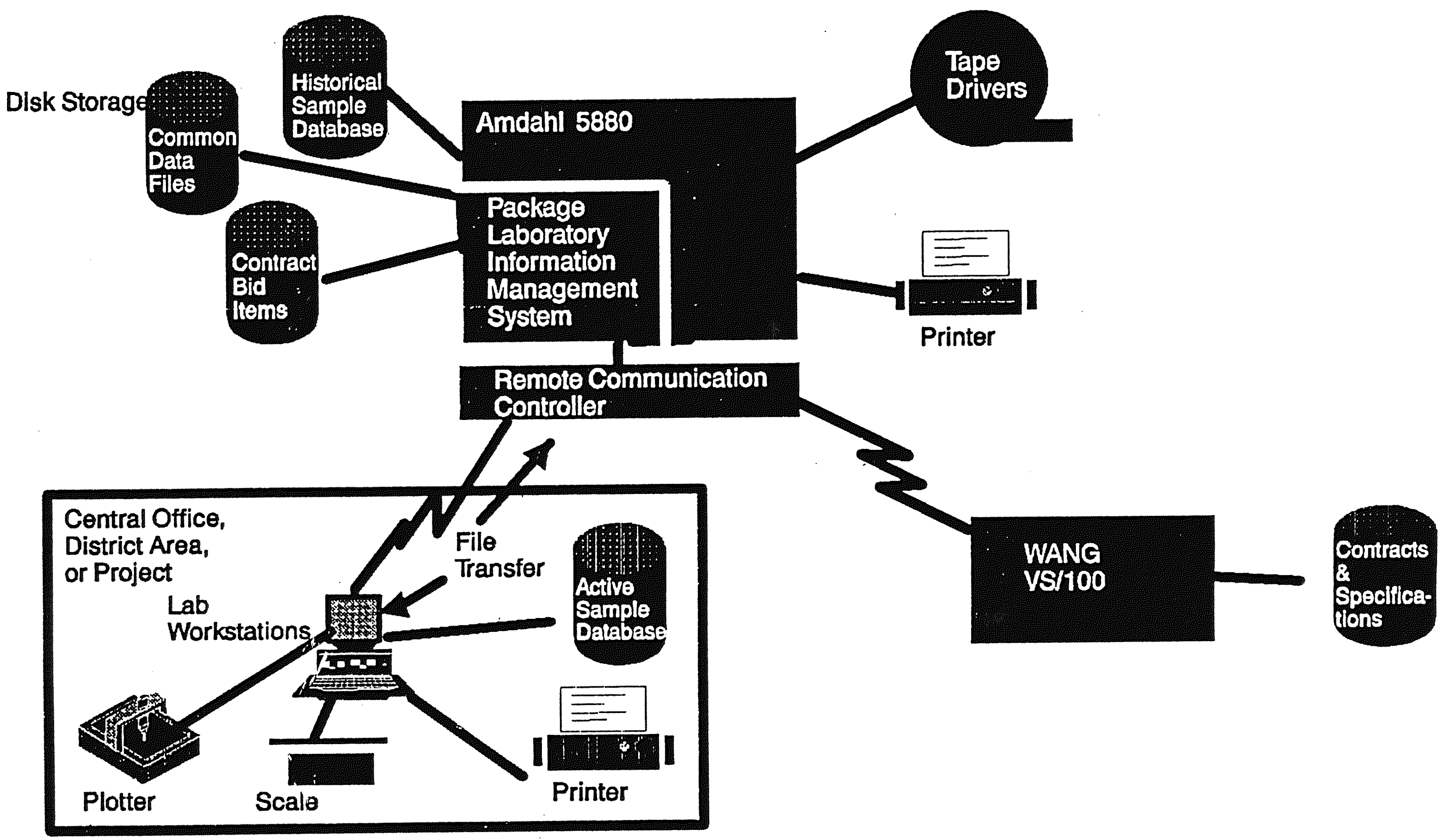

Exhibit 2-2

control device. The central processor may be the existing Amdahl mainframe, a minicomputer, or a comparable central processor. The proposed central processor must be completely justified by the vendor, i.e., why should the mainframe be used or why should a separate processor be used. If the mainframe is proposed, the impact of the new system on current operations must be fully described. 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. 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 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.

The central processor will be located in the central laboratory building or in the computer room and will execute the LIMS software. The hardware requirements for the central processor are as follows:

- Support main memory of at least 16 megabytes
- Support 32 bit word for maximum execution speed and accuracy
- Support a minimum of 60-90 simultaneous users
- One tape drive (1600/6250 bpi)
- A minimum of two disk drives with a total storage capacity of at least 800 megabytes

- One 600 line per minute impact printer
- Ability to connect at least 150-200 workstations and a minimum of 14 RS232 devices
- Protocol converter hardware which supports IBM SNA communication if ncessary depending on type of hardware
- Protocol converter hardware which supports Wang communication if necessary depending on type of hardware
- Support connection of a local area network bridge.

The software requirements for the central processor include:

- Third Generation Language Compiler (e.g., FORTRAN or COBOL)
- SNA Gateway - software required to support protocol conversion from the central processor protocol into SNA format for communication with the Amdahl mainframe
- Statistical Analysis - a statistical analysis package must be installed to support laboratory analysis, reporting, and graphics
- File Transfer - software must be installed to support the following transfers of information:
  - Microcomputer to central processor
  - Central processor to microcomputer
  - Central processor to Amdahl mainframe
  - Amdahl mainframe to central processor
  - Central processor to Wang minicomputer
  - Wang minicomputer to central processor.
- Database - contingent upon the LIMS software selection, the appropriate data base management software must be installed.
- Performance Monitor - Utilities must be installed to support the monitoring of a performance "bottleneck" on the central processor. This monitor must be capable of reporting on at least:
  - Active programs
  - I/O activity
  - CPU usage by program
  - Memory usage
  - Terminal usage by user.

The central processor is the major component of the day to day data capture for the laboratory testing process. It is imperative that the selected central processor be capable of supporting the peak testing work load in the laboratory. The selected processor must provide enough excess capacity to handle peak period processing in the laboratory and a growth in activity on the system which should be expected to occur at a rate of 10% annually.

The microcomputer workstations will function as:

- Standard standalone microcomputer (e.g. to execute Lotus or DBASE applications)
- Central processor terminal
- Mainframe terminal
- Wang minicomputer terminal.

The workstations will also have the capability to share peripherals, software, data, and functions available from local area network application software. The hardware requirements for the workstations are as follows:

- Upgrade the existing microcomputers and add new 386-based MS-DOS compatible workstations so that each workstation contains at least:
  - 640K of memory (RAM)
  - 20 megabyte hard disk
  - Color graphics card
  - Color graphics monitor
  - One RS232 card (only for workstations to be interfaced to testing equipment)
  - 132 character parallel printer (minimum speed 200 characters per second draft quality)
  - Microcomputer oriented hardware/software to support connection to central processor (e.g., controller, modem, Ethernet card).

  The microcomputer workstations will initially run the MS-DOS microcomputer operating system. We have recommended 386-based microcomputers because of their processing speed and support for memory expansion. The typical laboratory user will use a set of microcomputer tools (e.g., spreadsheet, word processing, etc.) to supplement the Construction Materials System. The efficiency and expandability of the 386-based series of microcomputers provides a strong foundation for the laboratory computing requirements.

Exhibit 2-3 provides a summary of the proposed workstations and their locations.

<u>Laboratory Information Management System (LIMS) Package</u>

The ideal architecture includes a packaged LIMS product to manage the update and inquiry of materials test results on the central processor. This architecture also requires 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.

The LIMS package should support as much as possible the inputs, processes, logical data structures, and outputs described in Sections 3, 4, and 5 of this report. In addition, the LIMS package should have the following capabilities:

- Set of modifiable menus that control LIMS processing
- Ability to add custom user routines written in a third generation language
- Ability to accept and process RS232 input with minimal code modifications
- Ability to store active and historical samples in separate data bases

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Exhibit 2-3

MICROCOMPUTER WORKSTATION DISTRIBUTION

	COUNT		USERS		EXISTING
LOCATION	IW	DTW	IW	DTW	
DISTRICT I					
OFFICE	7	0	1-DE,2-DDE,4-AE		7 IW
DISTRICT LAB	3	6	1-DME,2-LAB	6-LAB	2 IW
EAST AREA LAB	1	4	1-LAB	4-LAB	1 IW
WEST AREA LAB	1	4	1-LAB	4-LAB	1 IW
CONSTRUCTION	11	0	11-RE		11 IW
DISTRICT II					
OFFICE	4	0	1-DE,2-DDE,1-AE		2 IW
DISTICT LAB	2	4	1-DME, 1-LAB	4-LAB	1 IW
22ND STREET	3	3	1-AE,1-RE,1-LAB	3-LAB	2 IW
GRANT ROAD	2	3	1-RE,1-LAB	3-LAB	2 IW
SAFFORD	3	3	1-AE,1-RE,1-LAB	3-LAB	2 IW
GLOBE	3	3	1-AE,1-RE,1-LAB	3-LAB	2 IW
CASA GRANDE	2	3	1-RE,1-LAB	3-LAB	1 IW
PORTABLE	1	2	1-LAB	2-LAB	0
DISTRICT III					
OFFICE	4	0	1-DE,2-DDE,1-AE	0	2 IW
DISTRICT LAB	2	4	1-DME,1-LAB	4-LAB	1 IW
YUMA	3	2	1-AE,1-RE,1-LAB	2-LAB	1 IW
KINGMAN	3	3	1-AE,1-RE,1-LAB	3-LAB	1 IW
PAYSON	2	2	1-RE,1-LAB	2-LAB	1 IW
CORDES JCT.	2	2	1-RE,1-LAB	2-LAB	1 IW
PORTABLE	1	2	1-LAB	2-LAB	0
DISTRICT IV					
OFFICE	5	0	1-DE,2-DDE,2-AE	0	3 IW
DISTRICT LAB	2	4	1-DME,1-LAB	4-LAB	1 IW
AREA LAB	1	3	1-LAB	3-LAB	0
AIRPORT	2	2	1-RE,1-LAB	2-LAB	1 IW
GREEN RIVER	3	2	2-RE,1-LAB	2-LAB	3 IW
HOLBROOK	4	3	1-AE,2-RE,1-LAB	3-LAB	3 IW
PORTABLE	1	2	1-LAB	2-LAB	0
CENTRAL OFFICE					
CONSTRUCTION	3	0	1-CE,2-QC	0	3 IW
RESEARCH	1	0	1-GROUP	0	1 IW
MATERIALS	1	0	1-ME	0	1 IW
TESTING SERVICES	15	31	FOR USE IN		5 IW
PAVEMENT SERVICES	8	11	MATERIALS		5 IW
GEOTECHNICAL SERVICES	2	9	SECTION		1 IW
SPARES	6	6	4-DIST,2-CENT		0
TOTALS	114	123			68

LEGEND:
Central offices are local to central processor, others are remote.
Based on staff complement as of July 1989.

DE-District Engineer	LAB-Lab Workstation
DDE-Deputy District Engineer	AE-Area Engineer
DME-District Materials Engineer	QC-Quality Control
RE-Resident Engineer	CE-Construction Engineer
IW-Intelligent Workstation	DTW-Dumb Terminal Workstation

- Security features which restrict the functions (e.g. inquire versus update) a user may perform within the LIMS based on a set of criteria associated with the user's logon identifier

- Utility to build extract files for processing outside of the LIMS package

- A set of "base" reports which ADOT can build on. These base reports must include:

  - Worksheets
  - Sample tracking reports
  - Test results

- Batch data base update and reporting

- Ad hoc reporting and query capabilities

- Ability to easily add or change calculations performed for any given laboratory test without recompilation of programs.

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.

Since the choice of LIMS software is limited by the hardware configuration, the central processor hardware and LIMS software should be proposed as complimentary products.

Communications

The central processor communications equipment should be able to handle a high volume of network traffic. Construction materials users will 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 should contain the appropriate hardware and software components to support communication with the existing ADOT computers, specifically, the Wang minicomputer and the Amdahl mainframe. 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 will function as a terminal to all application systems.

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 phone lines, purchase communication controllers for the laboratory, purchase 9600 baud modems, and provide connections to the ADOT communications front end processor in the data center.

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 laboratories. 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.

High volume use of balances occurs during coarse and fine aggregate testing in the central, district, and area laboratories. Exhibit 2-4 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 will include a requirement for an RS232 port. The Construction Materials System and architecture should include support for automated data capture for those high volume testing devices which have a digital readout, and the potential to support additional devices as mechanical devices are replaced by digital readout devices.

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.

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Exhibit 2-4

INSTRUMENT HARDWARE INVENTORY

Laboratory	Testing Area	Description	Interface	Notes
Central	Coarse Aggs	Toldeo 30kg	None	
	Fine Aggs	Mettler PE11	RS232	Cable + PC card
District 1	Coarse Aggs	Mettler PE24	RS232	Cable + PC card
	Fine Aggs	Mettler PE16	RS232	Cable + PC card
	Cyl. Breaks	Forney QC400D	RS232	Custom interface
District 2	Coarse Aggs	Toledo 20kg	None	
	Fine Aggs	Toledo 5kg	None	
	Cyl. Breaks	Forney FT31DR	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	Cable + PC card
	Fine Aggs	Am. Sci. SP20	RS232	Calbe + PC card
	Cyl. Breaks	Forney FT400	None	

NOTES:

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

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. 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 district offices, using a microcomputer workstation to generate the actual label at a local printer. The architecture should support generation and reading of bar code labels at each district laboratory and at the central laboratory, for a total of five workstations. Additional workstations should have the capability for adding the hardware and software necessary for bar code label generation, for future use.

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 architecture should include support of hand held data collection devices with the following specifications:

- Can be attached to serial or parallel port on workstation
- Contain at least 64K RAM storage
- Support a development language (e.g., BASIC)
- Contain at least a 32 character display
- Support data transmission at 1200 bits per second (bps)
- Support attachment of a bar code scanner.

The number of hand held data collection devices has not been estimated at this time, however, the vendor's architecture should describe the proposed hand held data collection device, the method for interfacing to the Construction Materials System, and provide a cost per complete unit.

2.2 GENERAL CAPABILITIES OF SYSTEM

Following are characteristics that must be part of the Construction Materials system and supporting architecture.

- 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.

- The architecture must be configured such that the central processor can be expanded with minimal service disruption. The impact of the addition of intelligent workstations to the network should be determinable.

- The architecture must allow automated job scheduling, performance measurement and tuning, problem diagnosis and tracking.

- The LIMS package should be structured around a DBMS which provides backup and recovery features. The DBMS should support programming in a third generation language, in addition to the language that the LIMS package is written in. Several of the users of the system will desire to write additional applications in a third generation language. The DBMS should support both interactive and batch access.

- The architecture must address disaster recovery, e.g., what is a reasonable time for replacement of components in the event of a partial or complete disaster.

- The architecture must include hardware and software to allow Construction Materials System data to be transferred to the intelligent workstations for use in microcomputer software, and the Amdahl mainframe for use in other automated applications and the Wang minicomputer.

- The architecture must address backup capabilities. To ensure continued support for laboratories in the event of hardware, communication, or software problems, major tests will be supported through backup software on the intelligent workstations.

2.3 RESOURCE REQUIREMENTS

Following are the basic resource requirements to be used in sizing system components.

- Number of System Users - based on interviews and analysis, the estimated 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 based on this estimated number of concurrent users.

- Number of Transactions - based on the expected volume of 100,000 tests per year, the Construction Materials System will perform approximately 400-500 laboratory transactions per day and 100-200 inquiry transactions per day. Response time requirements are to be based on the relative complexity of a transaction. A sample/test inquiry or update screen should be processed with a one to five second response time. An ad hoc query or report that requires the system to process many 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.

3.0 SYSTEM INPUTS

This section provides a description of system inputs. There are two types of input to the system including data entry on system workstations consisting of bar coded label reading and keyboard entry into formatted screens, and automatic capture of data from interfaced instruments.

3.1 INPUT FORMS AND DATA ENTRY

Sample Identification Information

Description:	A pre-printed identification card will be associated with each sample to be tested at the laboratories. The identification card will contain sample characteristic information such as unique number, project code, material type, date of sample, and location sampled. A unique identification number will be pre-printed and bar coded on the form when the form is printed. Other information will be written on the form or generated in a bar coded label that will be attached to the identification card.
Origin:	Construction project, district, design unit
Platform:	On-line entry and bar code reading of information at site closest to origin of sample
Frequency:	Daily
Volume:	75,000/year
Edit/Validation Required:	Project number Material Type Pit number Station number

Table Maintenance

Description:	Several pieces of data will be validated against validation tables containing all available values. These tables will be created automatically through interfaces to other computer systems, or created and maintained by system users through on-line data entry screens. These tables include material types, test specifications, and test codes. Each table will contain the code and an optional description.

Origin: Material system users

Platform: On-line entry into central processor

Frequency: Updates as required

Volume: Minimal after initial creation

Validation: Codes edited for format, e.g., code must be numeric

Sample Checklist Modifications

Description: The sample checklist will be automatically generated by the system (see System Outputs); however, the system must allow on-line modification of the sample checklist so that district materials engineers and resident engineers can make changes and updates as necessary.

Origin: Resident engineers, district materials engineers

Platform: On-line entry into central processor

Frequency: Daily

Volume: 120 Checklists/year

Validation: Materials type, format as needed

Contractor Test Results

Description: Contractors perform tests on materials used in the construction process. Some users may wish to maintain contractor test results for comparison to internal test results. The system must allow for the entry of contractor test results.

Origin: Contractors

Platform: On-line entry or file transfer

Frequency: Daily

Volume: Lower volume than internal tests

Validation: Format as needed for various test types, e.g., numeric checks, range checks, etc.

Approved Materials

Description:	The Materials Section maintains a list of approved materials. The approved materials will be entered and maintained in the system through on-line data entry screens.
Origin:	Materials section
Platform:	On-line entry into central processor
Frequency:	As needed
Volume:	1,000 total entries
Edit/Validation Required:	Material type

Material Design Memorandum

Description:	The Pavement Services unit of the Materials Section creates the Material Design Memorandum which contains information used by the project designer. The system will allow on-line access to the document so that it is available to the resident engineer who is ultimately responsible for the project.
Origin:	Pavement services
Platform:	Word processing document that is either directly entered into the central processor or transferred to the central processor
Frequency:	Access as needed
Volume:	400 memorandums/year
Edit/Validation Required:	Project number must be valid

Test Data

Description:	The most critical feature of the system is material testing support. Raw test data will be entered into the system where calculations and comparison to specifications will be performed.
Origin:	Test equipment, laboratory technician
Platform:	Automated interface between test equipment and system (see subsection 3.2), on-line entry for tests performed on equipment not interfaced.

Frequency: Daily

Volume: 125,000 tests/year

Edit/Validation
Required: Numeric edits, range and reasonableness edits

Sampling Frequency Specifications

Description: Sampling frequency specifications will be maintained in the system and used to generate the sample checklist. For example, for each 1750 tons of asphalt cement, 17 acceptance tests are needed.

Origin: Material system users

Platform: On-line entry into central processor

Frequency: After initial system implementation, as needed

Volume: 100-200 material types

Edit/Validation
Required: Must be a valid material type

Calculation Modifications

Description: Calculations are performed on raw test data to produce test results. As test procedures change, users should have the ability to make on-line modifications to calculations.

Origin: Material system users

Platform: On-line entry into central processor

Frequency: As needed

Volume: Minimal after initial system installation

Validation Format as needed

Mix Design

Description: Contractors submit concrete and asphaltic concrete mix designs to resident engineers for approval and verification through testing. The system must provide for the entry and maintenance of mix designs.

Origin: Contractors submit to resident engineers

Platform:	On-line entry into central processor
Frequency:	As needed
Volume:	200-300 mix designs/year
Edit/Validation Required:	Format of fields

3.2 INSTRUMENT INTERFACES

All communication with the LIMS will be conducted through microcomputer workstations to a central processor. Menus which control both the automated instrument interfaces and the LIMS data input will be displayed on these workstations located throughout the state in laboratories and offices (reference workstation distribution shown in Exhibit 2-3).

Exhibit 2-4 presents an inventory of the laboratory instruments from which an automated interface process to capture data would be beneficial. Equipment with RS232 capability in the project laboratories can be added at any time once the interface software has been developed. As this exhibit illustrates, instrument interface inputs will be captured using an RS232 connection on the microcomputer workstation. The majority of the laboratory areas will have one microcomputer workstation per instrument. For these areas, an RS232 card will be installed in the microcomputer workstation to allow the interfaced instrument to be connected directly to the workstation. For areas (primarily larger laboratories) where multiple instruments could be interfaced into a single microcomputer workstation, an instrument coupler device could be installed. The instrument coupler will attach into a single RS232 port (card) on the workstation. Multiple RS232 devices may be attached to an instrument coupler. The instrument coupler device contains the logic required to manage data collection from multiple instruments.

The following bullet items discuss the input interface required for the instruments listed in Exhibit 2-4.

- Mettler, Toledo, American Scientific Scales - Several scales are used prior to testing and hence do not require interfacing, (e.g., weigh 12 oz. of material for subsequent testing). Many of these scales do not support RS232 upgrades; however, since an interface is not beneficial, upgrades are unnecessary. Scales used to obtain weights used in calculations will provide benefits by being interfaced. Several scales contain an RS232 port at the back of the unit, and others may be upgraded to support RS232 communications by adding a circuit card to the scale. For these scales, RS232 input will be captured by connecting a 25-pin RS232 cable from the back of the scale to the RS232 port on the microcomputer workstation (or instrument coupler). The input from the scale readings may be captured by pressing a function key on the workstation keyboard or pressing a special switch at the scale depending on placement of equipment and workstations. Once the input reading is captured at the workstation it will be handled like an item of data entered at the terminal (e.g., edits or calculations may be performed). The information will then be stored on the LIMS data base.

- Forney - Forney equipment is used to perform concrete cylinder breaking. The Forney equipment requires an analog to digital interface to support data capture using an RS232 port on the workstation. Once the equipment is connected, the data input process will be similar to that used for the scales.

There are several pieces of equipment that cannot be interfaced to computers because the equipment is mechanical and does not produce an analog or digital readout. In some laboratories, scales with digital readouts are available but are being used for weighing that is not part of the actual test. These scales can be moved into the areas that are doing the testing that will benefit from instrument interfacing. In other laboratories, the interface cannot be established until the equipment is upgraded.

An RS232 interface requires the development of some computer software to interpret the RS232 signals sent to the computer. Standardization of equipment will allow the interface software to be developed for a specific type of equipment and then used on all other equipment of the same type.

4.0 PROCESSES, INTERFACES, DATA STRUCTURES

This section of the report provides conceptual descriptions of processes, system interfaces, and logical data structures.

4.1 PROCESSES

This subsection of the report presents high level data flow diagrams which depict the data generated and moved through the system and the processes to be performed by the system. Three symbols are used on the data flow diagram. A square is used to represent a source or destination of data, such as a user, another system, or a location. A rectangle with rounded edges represents a process performed on the data. An open ended rectangle represents a data store, such as a report, database, or filing cabinet. Data moving among the sources, processes, and data stores is shown on the arrows.

Each process shown on the diagrams is numbered. The processes are explained in narrative following the data flows diagrams. During the detail design of the system, each process should be further decomposed and the corresponding inputs and outputs should be depicted in screen and report layouts so that users can review and approve them. Another task in design will be to define the physical data structures and data elements to be maintained in the system.

The processes have been logically grouped together in an attempt to make the flow of the system understandable. The processes have been grouped into functional areas including:

- Laboratory Testing
- Management/User Reporting
- Quality Assurance

- Administration
- Field Office Functions
- Central Office Functions.

Each functional area is depicted in a data flow diagram. The data flow diagrams are included as Exhibits 4-1 through 4-6.

Laboratory Testing

Process 1: 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.

Process 2: 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.

Process 3: Modify/Setup Data - 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.

Process 4: 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

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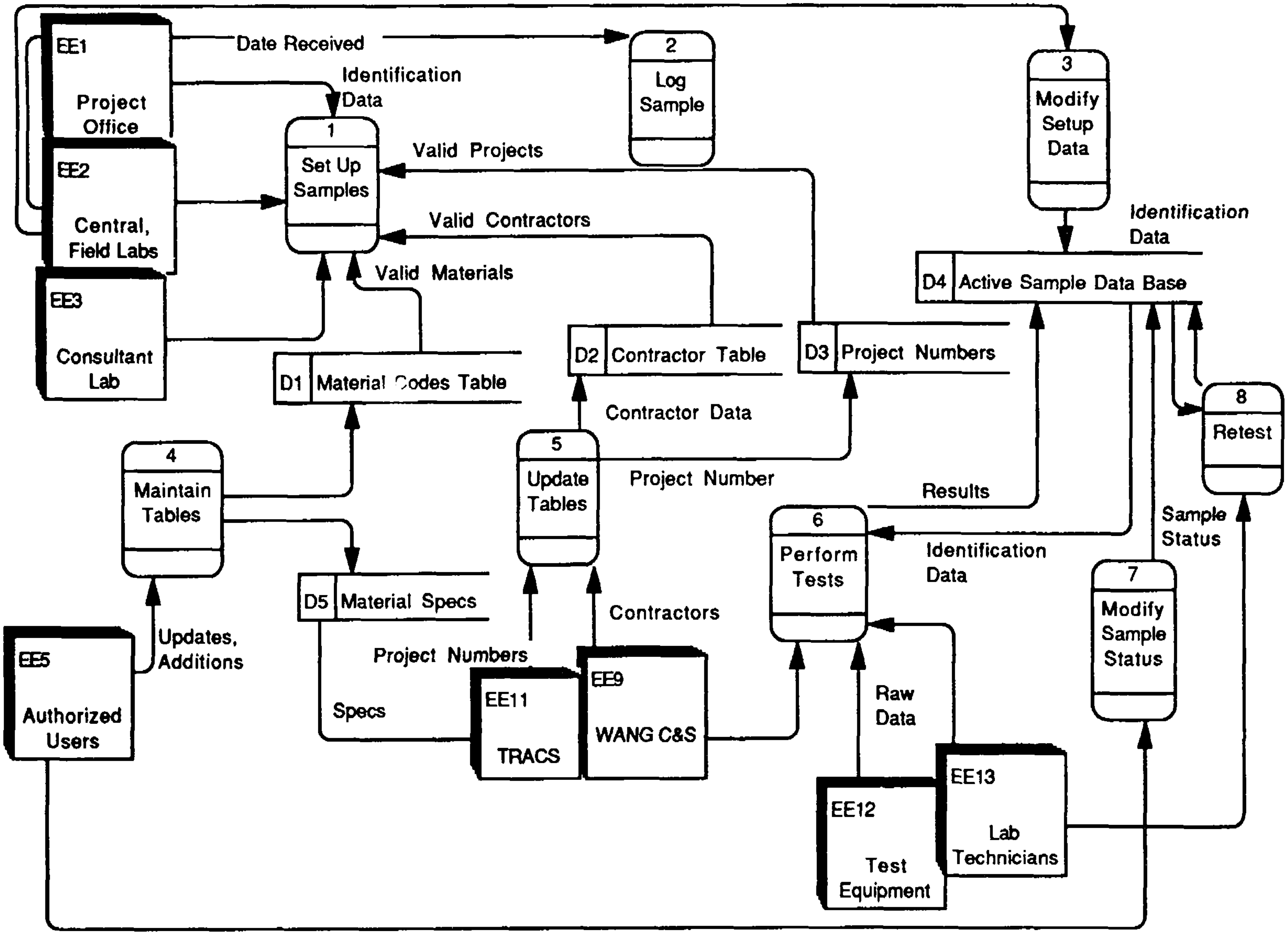

Laboratory Testing Data Flow Diagram

Exhibit 4-1

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.

Process 5: Update Tables From External Systems - Some of the tables needed for validation of the Construction Materials System data will be created in batch processes by extracting data form other systems.

Process 6: Perform Laboratory Tests - All tests performed in the laboratory have work cards associated with them. The work card information collected as the test is performed will be entered in the system on formatted screens and through automatic data retrieval through equipment interfaces. Calculations associated with each test will be performed. Results will be compared to specifications and tests 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.

Process 7: Modify Sample Status - The status of a sample will be maintained by the system and modifiable by the authorized system users, e.g., the system will keep track of whether the sample has been tested, the results verified, etc. Results will not be available for general inquiry until approved by the user.

Process 8: 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.

Management/User Reporting

Process M1: Obtain Results - Authorized test results will be available to system users. A hard copy result report will be automatically printed in the project office after the results are authorized. Individual sample results will be available for on-line inquiry.

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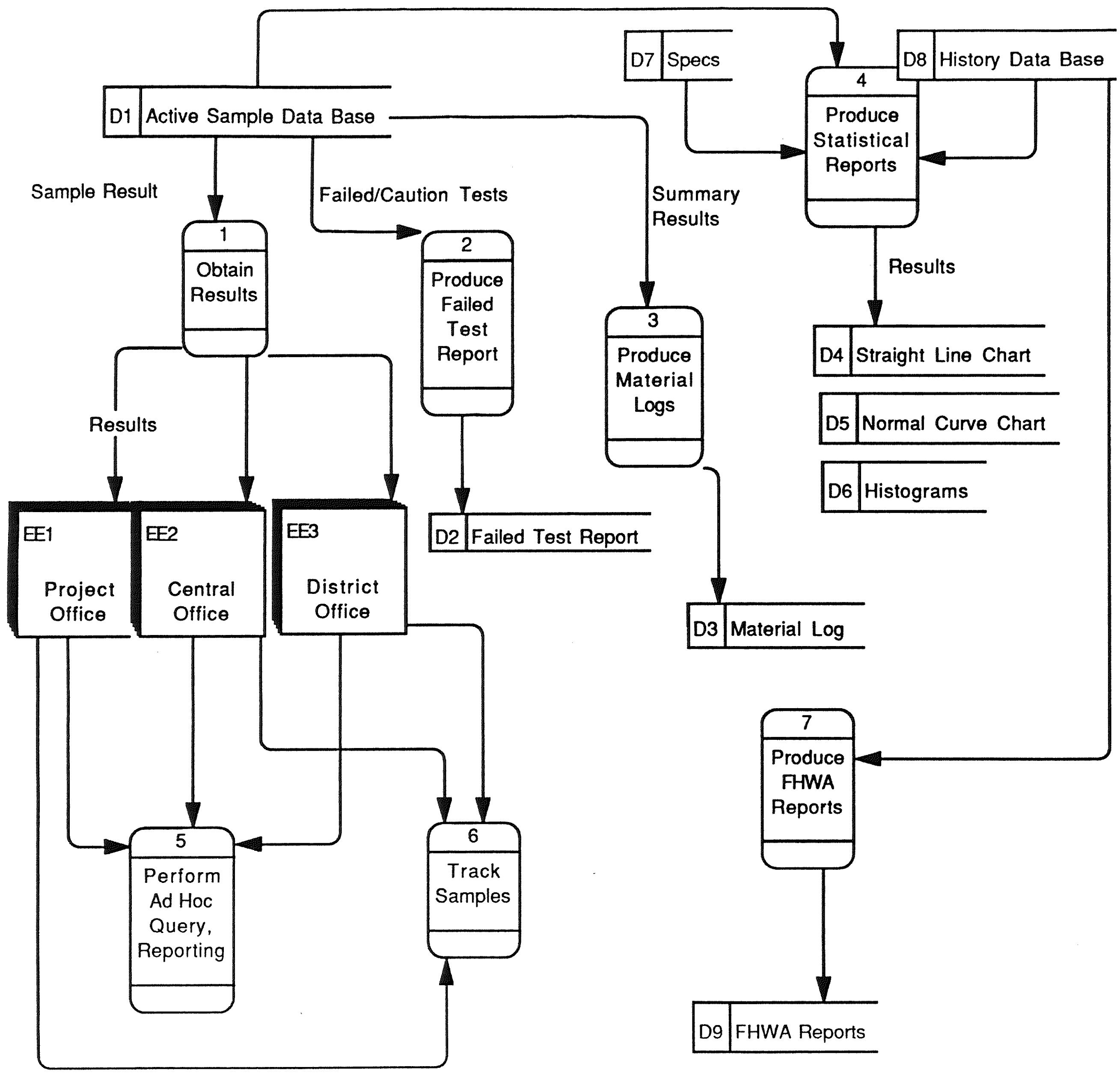

Management/User Reporting Data Flow Diagram

Process 2: Produce Failed Test Report - Failed test and cautionary test results will be printed on a failed test summary report and printed in the project office. The system will automatically determine the status of a test by comparison to material specifications maintained by the system.

Process 3: Produce Material Logs - Summary material logs which show test results for a particular material type will be produced by the system. These summary logs will be based on parameters such as date range, material source, contractor, and project.

Process 4: Produce Statistical Reports - The system must be capable of producing statistical reports such as straight line charts, histograms, and normal curves. The capability to print these reports will be limited to those locations with the adequate graphics printers; however, they may be generated from any location. Users must be able to select parameters such as material type, date range, contractor, or project for a statistical report.

Process 5: Perform Ad Hoc Query, Reporting - The system must have ad hoc query and reporting capabilities so that users can perform querying and develop reports without requiring assistance from information systems professionals.

Process 6: 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.

Process 7: Produce FHWA Reports - The availability of the materials data will allow reports to be developed as necessary for FHWA.

Quality Assurance

Process Q1: 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

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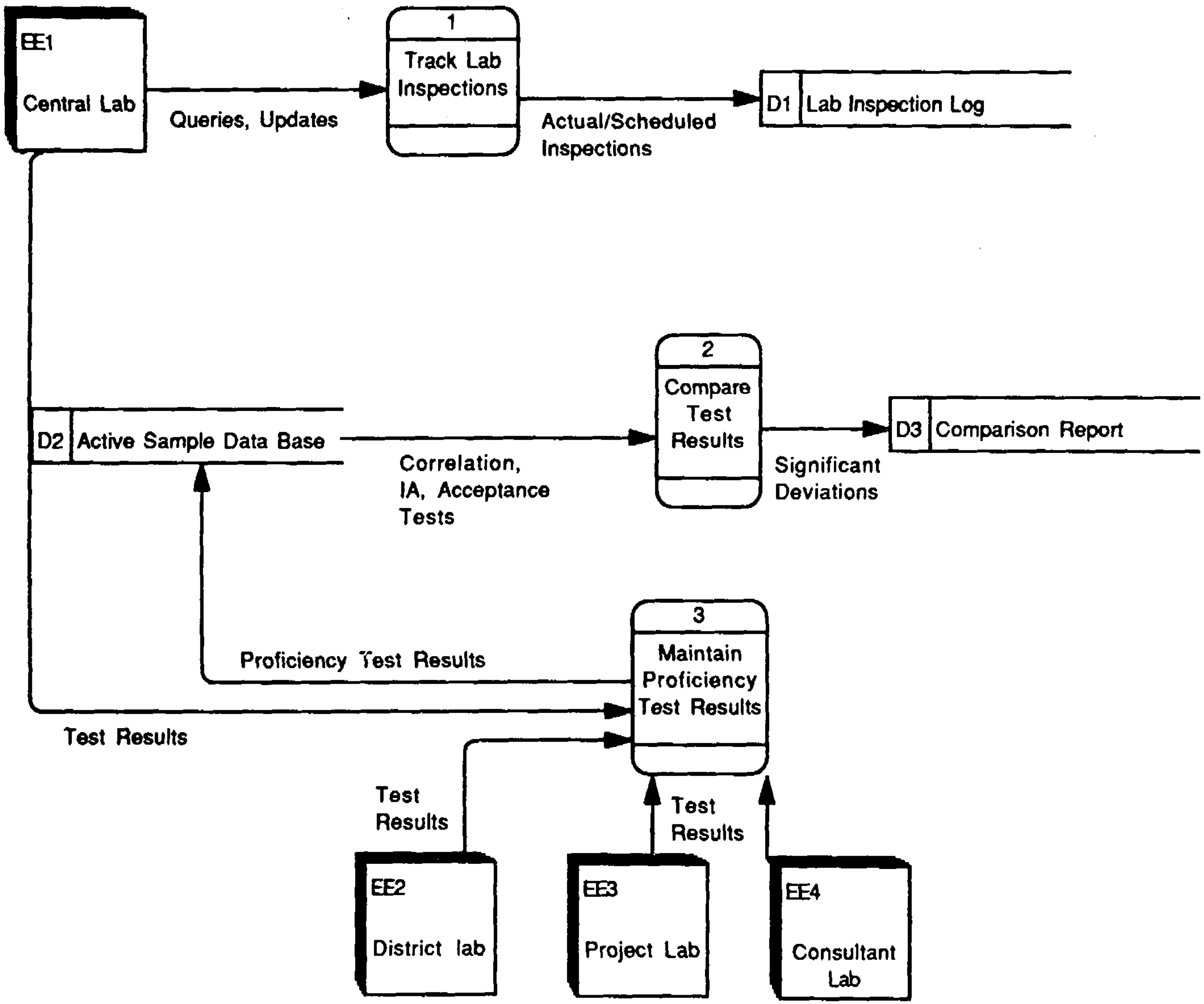

Quality Assurance Data Flow Diagram

Exhibit 4-3

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.

Process 2: <u>Compare Test Results</u> - 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. Therefore, the system must have the capability of relating samples to other samples, e.g., when a sample is split for correlation testing.

Process 3: <u>Maintain Proficiency Test Results</u> - Central Laboratory prepares samples and sends them to area and district laboratories to be tested as a quality control measure. These tests are called proficiency tests. The system will include the ability to maintain and analyze proficiency sample test results.

<u>Administration</u>

Process 1: <u>Modify Sample Checklist</u> - The project office is responsible for maintaining the sample checklist (See Section 5.0) and updating it as the project progresses, or at the end of the project. The checklist will be available to project office personnel for on-line review and modification or in hard copy form by request.

Process 2: <u>Modify Sample Checklist</u> - The system will automatically update the sample checklist as samples are tested. Failed test results will be associated with the sample checklist so that explanations for materials in non-compliance can be incorporated.

Process 3: <u>Modify Calculations</u> - As test procedures change, the system must have the flexibility to allow calculations to be adjusted by the users.

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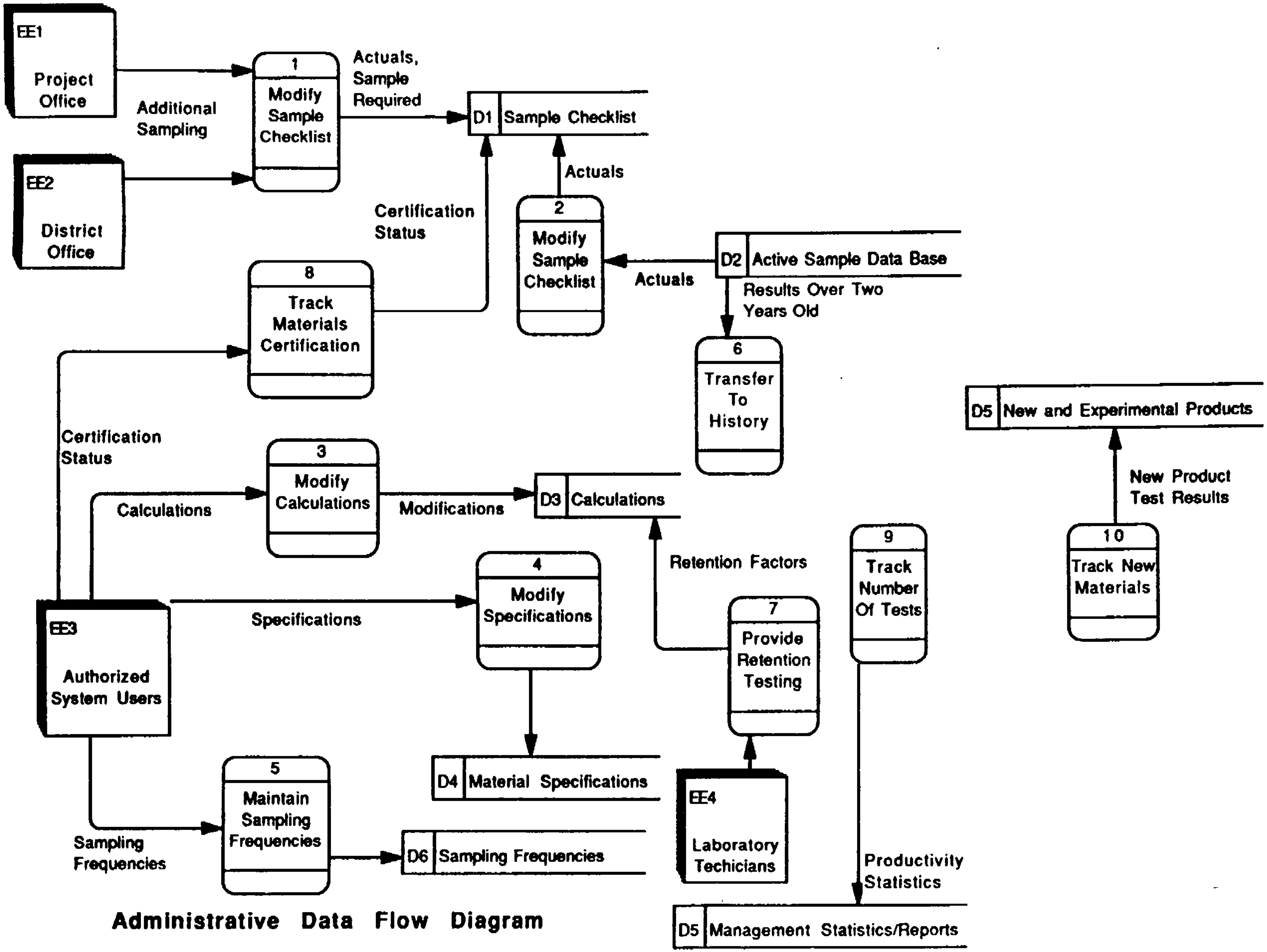


Administrative Data Flow Diagram

Exhibit 4-4

Process 4: <u>Modify/Develop Specifications</u> - 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.

Process 5: <u>Maintain Sample Frequency Specifications</u> - The ability to automatically generate the initial sample checklist requires the maintenance in the system of sampling frequencies for acceptance and independent assurance sample 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.

Process 6: <u>Transfer to History</u> - Two years of test result data must be available in the active sample data base. The specifications used for the tests must be associated with the test results to provide complete information about the tests. An additional five years of historical test results data should be maintained in a history data base. The system must provide for the migration of data from the active to the history data base, and from the history data base to tape.

Process 7: <u>Provide Retention Testing</u> - 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.

Process 8: <u>Track Materials Certification</u> - 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.

Process 9: <u>Track Number of Tests</u> - 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.

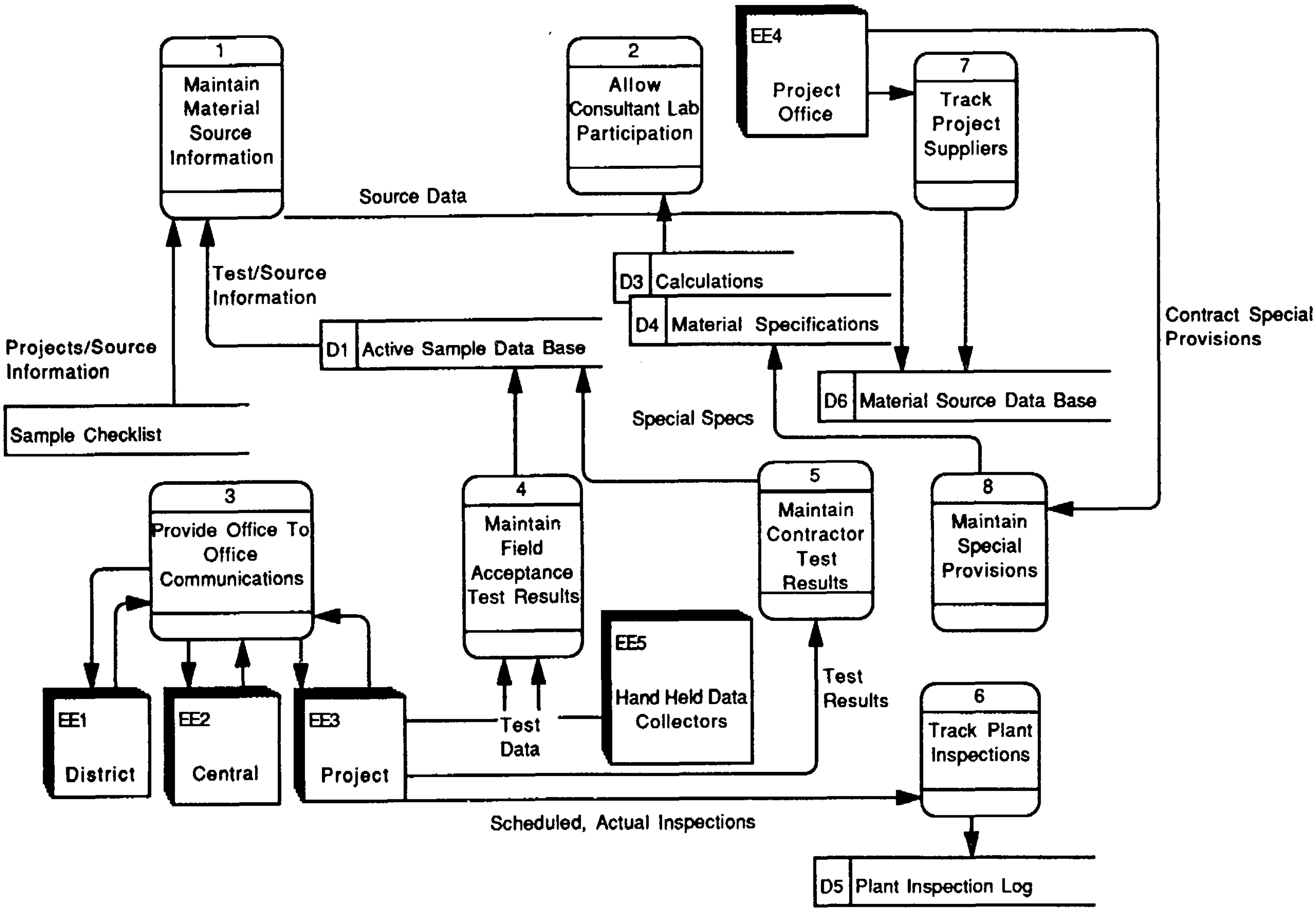
Process 10: <u>Track New Materials</u> - New materials being tested by the Department must be tracked. The system should allow for the addition of new material codes and the tracking of new material test results.

<u>Field Office Functions</u>

Process 1: <u>Maintain Material Source Information</u> - 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.

Process 2: <u>Allow Consultant Laboratory Participation</u> - 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.

Process 3: <u>Provide Office to Office Communication</u> - 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.



Field Office Functions Data Flow Diagram

Exhibit 4-5

Process 4: <u>Maintain Field Acceptance Test Results</u> - Several field tests are performed at the construction site including nuclear 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. Hand held data collection devices are available; however, there are significant costs associated with adequate devices. The system will include the capability to enter the data at workstations as well as be modifiable to collect the data from hand held data collection devices without major revisions.

Process 5: <u>Maintain Contractor Tests Results</u> - 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's internal tests. Samples and 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.

Process 6: <u>Track Plant Inspection</u> - Commercial plants require periodic inspections by ADOT personnel. The system will track plant inspections and provide tickler reports when inspections are due.

Process 7: <u>Track Project Suppliers</u> - The system will allow inquiry of a plant to determine the projects that it is supplying materials to.

Process 8: <u>Maintain Special Provision Specifications</u> - 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 that the standard specifications for determining material compliance. Since the specification used for the test is to be maintained in the test result data base, the system must also allow special provisions to be associated with test results.

Central Office Functions

Process 1: 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.

Process 2: 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, selected by project number, and viewed or printed at the project office.

Process 3: 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 test result status, i.e., pass or failure of tests. The system must keep multiple versions of specifications since on-going projects could be using different specification versions.

Process 4: Maintain Mix Designs - Mix designs, which describe the types and ratios of the raw materials that make up concrete or asphaltic concrete, are verified by both central laboratory and district laboratories. The system will provide the capability to verify and maintain mix designs by contractor or manufacturer. The mix design can be reviewed or printed at any node on the network.

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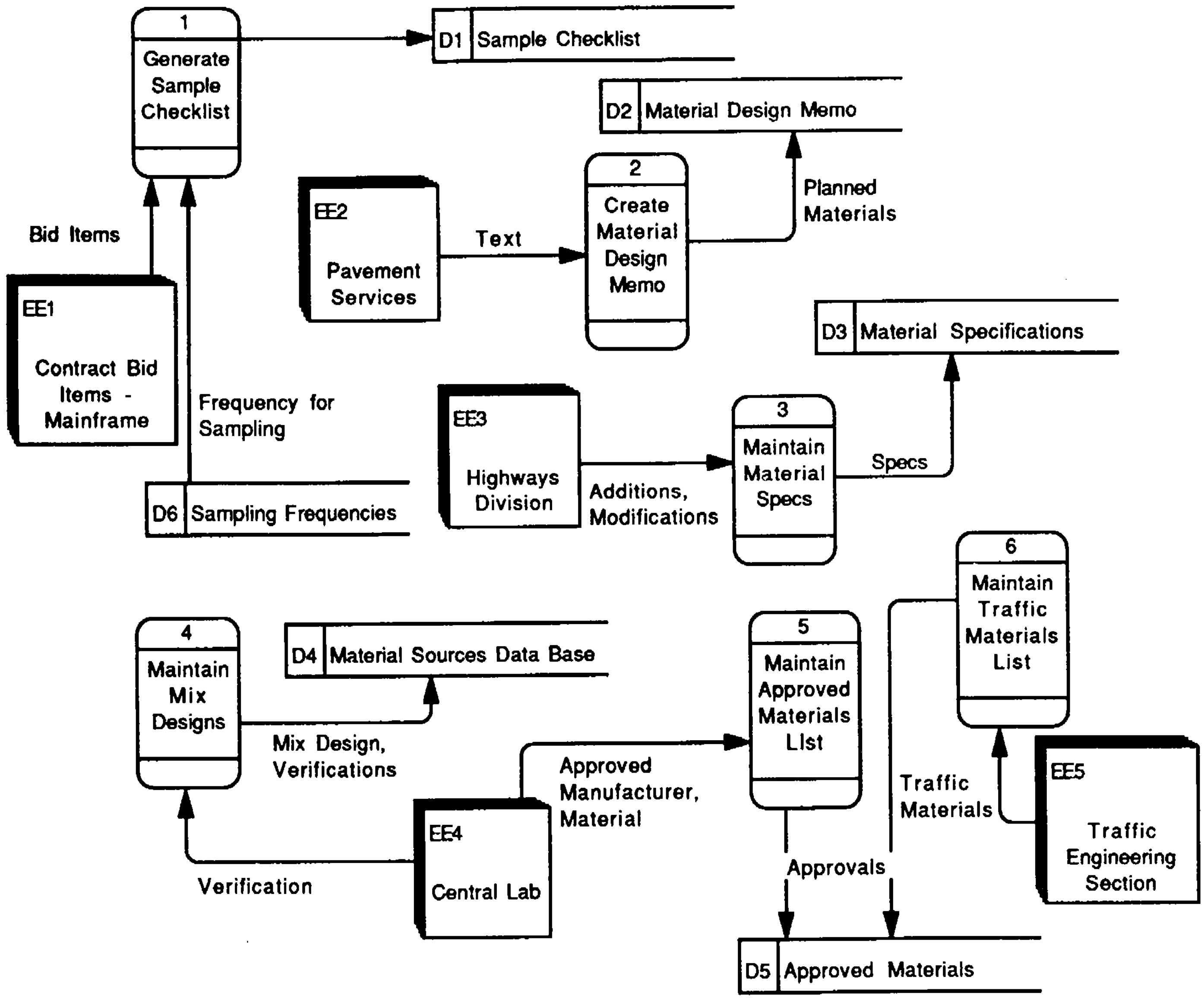

Exhibit 4-6

Central Office Functions Data Flow Diagram

Process 5: <u>Maintain Approved Materials List, New Product List, Experimental Product List</u> - To assist in screening materials, the Materials Section maintains a list of approved special materials such as epoxies and cement additives. The Transportation Research Center also keeps track of new and experimental products. The system will provide on-line maintenance and inquiry of the approved materials, new, and experimental products lists so that any node on the network can access the information.

Process 6: <u>Maintain Traffic Material List</u> - 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.

4.2 SYSTEM INTERFACES

The Construction Materials System will require interfaces to other systems so that data that is needed for material testing and related functions 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. Following is a list of the systems to which an interface is required.

- <u>Contracts and Specifications Data Base Maintenance System</u> - 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.

- <u>TRACS</u> - 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.

4.3 LOGICAL DATA STRUCTURES

This subsection provides a list of logical data structures. Until the LIMS package software is selected, the physical data structures cannot be defined. This list provides logical groupings of data and logical keys.

- Material Code Table - Contains all materials for which there is a specification and material test and includes material type codes, descriptions.

  Primary Key: Material code
  Secondary Key: Alpha description

- Contractor Table - Contains contractor name and address, contractor code.

  Primary Key: Contractor code
  Secondary Key: Alpha name

- Project Number Table - Contains valid project numbers and associated information such as district, location, duration, start date, cost, etc. Projects are associated with material source data including source of the material, mix designs used, etc.

  Primary Key: Project number

- Active Sample Data Base - Contains all sample data including setup information, raw test data, calculated data, reference to spec used, mix design used.

  Primary Key: Sample number
  Secondary Key: Material type
  Sample type (acceptance information, independent assurance, correlation, etc.)
  Project
  Contractor

- History Data Base - Contains five years of sample data prior to the current two years which is maintained in the active sample data base.

- Material Specifications - Contains multiple versions of material specifications used in determining material compliance. Also contains special provision specifications determined at the time of contract which are project specific.

  Primary Key: Material type, Version
  Secondary key: Project number

- Laboratory Inspection Log - Contains information regarding laboratory inspections performed under the quality assurance program.

  Primary Key: Lab number

- Sampling Frequencies Data Base - Contains information regarding sampling frequencies by material type and quantity.

  Primary Key: Material type

- Calculations - Contains calculations used in various tests. Prevents recompilation of program should calculation change.

  Primary Key: Test code.

- Test Code Tables - Contains valid test code for each test supported in the system.

  Primary Key: Test code

- Material Source Data Base - Contains information about material sources (commercial plants and pits) such as mix design, test result history, projects using source.

  Primary Key: Material source

- Plant Inspection Log - Contains information regarding ADOT inspections of commercial plants such as actual and planned inspection dates, inspection results.

  Primary Key: Material source

- Sample Checklist Data Base - Contains the sample checklist information which consists of material type, planned quantity, number of samples to be taken, actual samples taken, comments.

  Primary Key: Project number

- Approved Materials Data Base - Contains materials approved by central office Materials Section and Traffic Engineering Section. Information includes material type, suggested use, manufacturers.

  Primary Key: Material type

- New and Experimental Products Data Base - Contains materials that are new or experimental. Information includes material type, suggested use, manufacturer. Items from this database may eventually be moved to the approved materials data base or the material code table which contains all materials tested by the Department.

5.0 SYSTEM OUTPUTS

This section contains a description of the outputs to be available from the system. Layouts of reports and screens should be developed during design, after the LIMS package software is selected. Additional outputs will be defined by users during design.

Sample Status

Description: Provides users with information regarding the status of a sample, e.g., set up, received at laboratory, testing in progress, tests complete, results available.

Medium: On-line inquiry

Frequency: As needed

Sample Status Report

Description: Provides an active sample summary for samples not yet completed and samples completed since last reporting period, by laboratory, for district and central laboratory samples.

Medium: Hard copy or on-line

Frequency: Daily

Individual Test Results Reports

Description: Provides a hard copy report of individual sample test results for project records.

Medium: Hard copy report produced on project office printer

Frequency: Daily

Failed/Cautionary Test Report

Description: Provides a hard copy exception report listing failed or cautionary test results.

Medium: Hard copy report produced on project office printer

Frequency: Daily

Tables Listing

Description: Provides a complete list of codes and descriptions in each table, e.g., material type codes, specifications.

Medium: Hard copy by request, on-line inquiry

Frequency: As needed

Sample Checklist

Description: Provides a list of materials and suggested sampling frequencies for each project. It is produced before the project begins based on contract bid item and quantities and is used as a material sampling and testing guide.

Medium: On-line maintenance, hard copy by request

Frequency: 120/year depending on number of projects

Bar Coded Labels

Description: Bar coded labels containing identifying information about material samples will be produced at the district office. These labels will be attached to sample identification forms and read at the district and central laboratories.

Medium: Hard copy

Frequency: Daily

Work Cards

Description: Work cards contain raw test data and calculations performed for each material test. Since raw test data will be entered into or automatically collected by the system, work cards will be replaced by on-line screens; however, the work cards should be available in hard copy format if requested.

Medium: On-line, hard copy on request

Frequency: Daily, one work card/test

Approved Materials List

Description: The Materials Section maintains a list of approved materials that have been tested and approved for use on construction projects. This list should be available to system users through on-line inquiry.

Medium: On-line, hard copy on request

Frequency: As needed

New and Experimental Product List

Description: The Transportation Research Center maintains a list of materials that are being reviewed for general use by the Department. This list should be available to system users through on-line inquiry.

Medium: On-line, hard copy on request

Frequency: As needed

Materials Design Memorandum

Description: Document containing materials information. The document should be accessible on-line by the resident engineer responsible for the project.

Medium: Word processing produced document available through electronic mail or file access

Frequency: 120/year depending on number of active projects

Material Logs

Description: Contains a summary of test results by material type for a specified date range, by project

Medium: On-line, hard copy on request

Frequency: As needed

Statistical Reports

Description: Straight line charts, normal curves, histograms showing test results for a particular material for a specified date range, optionally for a specified project, contractor, or material supplier.

Medium: Hard copy by request

Frequency: On request

Ah Hoc Query, Reporting

Description: The system must have an ad hoc query and reporting capability which is usable by end users without data processing expertise.

Medium: On-line, hard copy

Frequency: On request

Comparison Report

Description: Acceptance tests must be compared to Independent Assurance and Correlation sample test results. This shows a comparison among the related test results for each district.

Medium: Hard copy

Frequency: Daily

Specifications

Description: Material specifications are maintained by the system. Specifications must be available for on-line inquiry.

Medium: On-line

Frequency: As needed

6.0 CONTROL, AUDIT, AND SECURITY REQUIREMENTS

This section describes the security, audit, and control features required for the Construction Materials System. These controls must be designed into the system to ensure accuracy, auditability, reliability and overall system integrity. Proposals should address the requirements for control, audit, and security by describing the approach that the vendor wishes to pursue and any exceptions to the suggested requirements.

6.1 CONTROL

The primary objective of control features is to ensure data integrity. Control features will support:

- Data base integrity
- Data base recovery
- Data base and file restoration
- Tracking of program modifications
- Data base and file backup
- Tape retention periods
- Construction Materials System restart and recovery
- Offsite tape storage.

The following control features will exist on the central processor:

- Nightly backup of all critical system and applications files
- Nightly backup of jobs and programs necessary to recover or restore the Construction Materials System data bases and any related files
- Program change control procedures to allow tracking of program modifications.

Backups will be performed using the central processor tape drive. Tapes will be stored in the same room that houses the central processor. The backup tapes will be kept for 180 days to support system recovery for any specific file for up to six months. In addition, annual backups of the laboratory test data will be created and retained for seven years to support legal requirements. To properly plan for the event of a disaster (e.g., fire, earthquake, etc.) it is imperative that backup copies be sent to an offsite storage facility.

Restart and recovery procedures must be in place to support the timely and accurate restoration of the Construction Materials System in event of a system outage or abnormal program termination. By implementing the proper utilities and procedures, system downtime will be minimized and data recovery will be maximized. Since restart and recovery procedures are different for each major type of hardware, these procedures are discussed in a general manner that can apply to a mainframe or minicomputer.

The following recovery procedures should be available in the selected configuration:

- Tape backup support
- Dual recording of data base records
- Transaction backout support in the event of an abnormal program termination.

During a system failure the laboratory data base could be damaged and become unreadable. The above recovery procedures support the restoration of the lab data bases from a backup tape or, in the case of dual recording, the ability to "switch" to a second copy of the data base.

Minicomputer data bases may not support the extensive recovery facilities provided by mainframe data base management systems such as IMS. Proposals must include complete explanations of the available recovery facilities provided by the vendor's proposed hardware and software.

6.2 AUDIT

The intent of audit features is to provide an audit trail of Construction Materials System access. This audit trail includes a record of document creation and Construction Materials System data flow through the system.

The following audit features should exist on the central processor:

- Record of who accessed the Construction Materials System by date, time, terminal name, and userid

- Record of each update in the LIMS by date, time, terminal name, and userid. This mechanism must be incorporated into the selected LIMS software package if it is not a feature of the purchased software

- The above records will be backed up and stored on magnetic tape for 180 days. This retention period may be extended if a longer period is required by the internal audit department of ADOT

- Reports on the above records should be available on request. These reports will be produced through batch job requests

- Batch validation controls will produce a one page report containing the number of records processed, the number of records rejected and the reason, and the total number of records read for all batch jobs.

6.3 SYSTEM SECURITY

System security requires the automated control of access to the transactions, data bases and files within the Construction Materials System. Access is to be controlled by assigning each central processor user a unique user identification and password. There are two sets of access control software used to control security on the central processor as follows:

- Central Processor Security Software - Software that runs as part of the operating system to control logon access to the central processor and access to files. All access controls are enforced by associating a userid and password with authorized levels of access.

- LIMS Security Software - The major LIMS software packages come with a set of tables to allow the laboratory security administrator to control access to each laboratory transaction (screen). LIMS security enables the administrator to allow or prevent a user from accessing any LIMS transaction. The LIMS security routines also allow the security administrator to restrict access to test results by laboratory area or cost center. These security access levels are controlled by the userid and password combination.

Using a combination of the software tools listed above, the Construction Materials System security administrator will control security of the following resources on the central processor:

- System Access - Verification that the user has entered a valid userid/password combination and is allowed to access the central processor.

- File and Data Base Access - Verification that the userid attempting a file access has been defined with the appropriate authorization levels in the security tables. If not, the file access is not allowed. File access may be restricted to read, write, allocate, delete, or any combination of these four.

- Transaction Access - Verification that the userid requesting to execute a specific transaction within the Construction Materials System has been defined to the security tables with the appropriate authorization. If not, the user will not be allowed to execute the transaction.

7.0 TRAINING AND SUPPORT REQUIREMENTS

The installation of new computer hardware and software will entail training of all persons affected by the installation, both internal and external to ADOT. A significant level of support will be required by internal ADOT staff and by the vendors supplying hardware and software. This section of the report identifies each type of training required and the level of support needed for on-going maintenance of the system. Proposals must explain the approach that the vendor will take for each of the training and support requirements.

7.1 USER TRAINING

The system will impact users in the central office and laboratory and remote sites including district and project offices and laboratories. Users will be required to learn how to operate the microcomputer workstations and use the new screens and reports. Existing manual procedures will be modified or eliminated. Following is a summary of the training anticipated for each major group of users. Since there will be varying degrees of user involvement in the operation and use of the system, training should be structured so that appropriate levels of expertise can be acquired, e.g., management will not be trained in the operation of the laboratory testing portion of the system.

All users will require general training including:

- A general overview of the entire system
- Training in the operation of the microcomputer workstations, e.g., power on/off, keyboard, sign-on/off
- Training in the general use of the system including how to select transactions, how to obtain on-line help, how to navigate through the system, how to print screens and reports, how to interpret error messages, how to use documentation.

Following general training, users should be divided into the following functional groups and trained in the specific applications that they will be required to use.

- Laboratory technicians from central, district, and project area laboratories will require training in the laboratory testing support functions including operation of interfaced equipment, use of on-line screens for entry of test date, printing of identification cards and work lists, and inquiry of calculated test results.

- District, area and project engineers will require training in the use of inquiry transactions, ad-hoc query and reporting capabilities, statistical analysis capabilities, and logging and record keeping capabilities of the system.

- Materials section personnel will require training in the use of central materials management functions.

- High level management personnel should be trained in the general capabilities of the system so that they are aware of the information available from the system.

Training of users should be accompanied by user documentation. We suggest that the training of individual groups of users be accomplished in one day, e.g., district area, and project engineers will require no more than one day of training.

7.2 APPLICATION SYSTEM TRAINING

Application support personnel will require training in the following:

- Central processor system utilities such as file transfer and file manipulation utilities

- The workstation communication procedures

- The Laboratory Information Management System (LIMS) package

- The statistical analysis software if separate from the LIMS

- The backup microcomputer applications.

7.3 TECHNICAL SUPPORT TRAINING

The technical support personnel will require training in the following:

- The central processor operating system and related utilities
- Software to transfer files between the central processor and other ADOT computers and microcomputer workstations
- Instrument interface software
- System startup/shutdown
- Emergency procedures
- Backup procedures for microcomputer and central processor data
- Communications network operation and configuration
- General hardware maintenance and problem diagnosis.

7.4 ON-GOING MAINTENANCE AND SUPPORT

The selected vendor(s) will be required to provide the following:

- Hardware maintenance agreements that include two hour on-site response for central processor hardware and system software problems, 24 hour 7 day/week maintenance support
- LIMS package support agreements and clearly specified new package release arrangements
- Post-implementation support for an agreed upon time period (at least one year) from the system implementation vendor, i.e., the consultant or LIMS vendor responsible for implementation services
- Software problem resolution available via a 24 hour hotline service over the phone
- System software and maintenance availability over dial-up services (LIMS and central processor)
- Onsite preparation and support during hardware and system software installation. This support should be available until the initial installation is operational and meets ADOT's satisfaction.

7.5 DOCUMENTATION

The Construction Materials System must include documentation to assist users and maintainers of the system. The documentation will consist of the following:

- User Documentation - Complete user documentation will be required including:
  - Functional Overview
  - Guide to Terminal Operations
  - Functional Processing
  - Screen Processing
  - Report Processing
  - Screen Messages
  - Tips, Shortcuts, and Warnings
  - Glossary of Terms
  - Reference Card.
- Technical Documentation - Technical documentation will be required and will include:
  - complete technical documentation for all hardware and communications equipment
  - complete technical documentation for all system software
  - five sets of complete technical documentation for all application software including LIMS, statistical analysis software, or any other purchased application software.

8.0 IMPLEMENTATION PLAN

This section of the report provides suggested tasks necessary to implement the Construction Materials System. The tasks have been defined to help ensure that the system can be successfully implemented with minimal disruption to daily activity. If the vendors submitting proposals do not believe that any of the suggested tasks are necessary, they should explain why. The approach to each task should be described in the proposals, as well as the timing of each task. The plan should provide a phased implementation to allow flexibility should there be budget constraints. The tasks should be arranged to provide support and tangible benefits to end users as quickly as possible, at the same time providing a smooth technical transition to the new system and associated hardware environment.

8.1 PLAN OVERVIEW

The implementation tasks are grouped into five major categories of activities. The plan assumes that one prime contractor will be selected and that contractor will be responsible for selecting, installing, and developing all hardware and software necessary to support the Construction Materials System. The major categories of activities are explained below.

A. Preparatory Tasks - These are the tasks that must be performed before the system components can begin to be procured and installed. As examples, senior ADOT management approval must be obtained, field personnel understanding and commitment must be assured, funding must be committed, and the Project Manager and Steering Committee members must be selected and assembled. Finally, the RFP for a prime contractor must be written, proposals reviewed, and a prime contractor selected.

B. Foundation/Pilot Tasks - These tasks provide the basis upon which the remaining Construction Materials System tasks and components can build. They can begin to be performed as soon as the prime contractor is selected and the contract signed. These tasks include assembling the implementation team, preparing conversion plans, training implementation team members, defining pilot users, and testing hardware and software components to be used in development. These tasks will help to ensure a smooth implementation of the Construction Materials System.

C. Application Component Design Tasks - These tasks will be performed during the first three months of the project, as quickly after the start of the project as possible. These tasks must be completed before implementation of the system can begin. These tasks include detail design of the custom developed software, detail design of LIMS modifications, installation of communication software, installation of system software, installation of package software, detail design of system interfaces, and detail design of subsystem interfaces such as file transfers among machines.

D. Application Component Implementation Tasks - These tasks include the development and implementation of the software that will support the laboratories' day to day operations. Customization of any package software, such as a Laboratory Information Management System (LIMS), will be performed.

E. Physical Component Implementation Tasks - These tasks include installation of the actual hardware that will support the laboratory automation. These components include the central processor, communication components and cabling, universal workstations, and associated system software such as operating systems.

Over 40 detail implementation tasks have been identified. More complete descriptions of the individual tasks follow later in this section.

8.2 SCHEDULE

The contractor should estimate the time required to complete the entire project; however, if the estimate exceeds 13 months from the signing of the contract through complete ADOT acceptance of the system, the contractor must clearly explain why.

8.3 RESOURCES

Contractors must provide an explanation of estimated resources required to implement the Construction Materials System including the personnel, both contractor and ADOT, and the one time and recurring costs associated with the hardware, software, and maintenance of the system for a period of five years. Suggested personnel required to implement the Construction Materials System include the following:

- An ADOT Project Team Manager should be committed to the project on a part time basis. This same project team manager should also be in charge of the RFP preparation. He should be able to spend two days per week on the project.

- A Steering Committee composed of personnel from the districts, Materials Section, and other associated personnel should be formed to monitor progress, resolve issues and provide direction to the project team. This committee can be expected to meet monthly. The committee members will also be required to review reports and other deliverables.

- A work team committee consisting of laboratory personnel and selected users should be designated. This team can be expected to meet on a weekly or bi-weekly basis, and should be available for consultation on an as needed basis.

- Prime contractor personnel will include a project team manager committed to the project on a full time basis, a technical team leader committed to the project on a full time basis with assistance from other technical personnel as needed, a development team leader committed to the project on a full time basis, and development team programmer/analysts as needed committed to the project on a full time basis. The technical team leader will be responsible for installation and configuration of the hardware and system software needed to support the application system. The development team will perform the customization of package software and the development of all other application software. The team leader will oversee and assist in the development effort. The project manager will oversee the entire project and ensure that the project is proceeding on schedule.

- ADOT user and system support personnel should be assigned to the project. There should be one user assigned to the project full time. This user will resolve detail design issues, review all screen and report layouts, attend all project related meetings, assist in the development of test plans and test data, perform testing, review system documentation, and assist in development of user documentation. The user will also act as training coordinator and will be the liaison between the rest of the user community and the project team. If possible, one full time programmer/analyst should be assigned to the development portion of the system. The person will be required to assist the contractor in customizing the package software, such as a LIMS package, and in performing custom development of other required programs. One person should be dedicated to the technical team on a full time basis. This person will be used as a technical support person for the operating system, data base management system, and statistical analysis software for the central processor.

8.4 IMPLEMENTATION TASKS

The following are descriptions of the suggested tasks required to implement the Construction Materials System. Included in the tasks are changeover or conversion tasks, hardware and software installation tasks, and application development tasks. Several tasks can be performed simultaneously, however, some must be completed before others can be started. The contractors should provide a plan that includes a logical order for tasks to be implemented, as well as estimated time frame.

Preparatory Tasks

The following tasks should be performed to begin the Construction Materials System implementation process:

- Confirm Funding/Sources - Before beginning the implementation, the availability of funds must be confirmed. The sources of the funds, e.g., FHWA or ADOT, or both must be confirmed. Although the implementation plan assumes a phased implementation, modification of the plan may be necessary if funds are limited.

- Select ADOT Project Team Manager - The ADOT Project Team Manager should be assigned as quickly as possible so that the preparation of the Request for Proposal (RFP) can begin. The Project Team Manager will continue as the ADOT person responsible for overseeing and administering the project.

- Form Construction Materials System Implementation Steering Committee - The Implementation Steering Committee will help to prepare the RFP, evaluate proposals and select a prime contractor, and negotiate a contract.

- Obtain Laboratory Personnel Understanding and Commitment - The project team should make a presentation to various lab personnel to explain the project and obtain commitment and cooperation from lab personnel.

- Obtain Field Understanding and Commitment - The project team should make a presentation to the appropriate field personnel, e.g., assistant district engineers for construction and district materials engineers, to explain the project and its impact on the districts and to obtain commitment and cooperation from them.

Foundation Tasks

The foundation tasks have been defined to help structure the entire project and to ensure smooth implementation. These tasks begin shortly after the preparatory tasks and set the stage for the actual implementation. They are critical tasks that must be planned and performed to avoid implementation snags and pitfalls.

- Select/Assign ADOT Staff - The ADOT staff to be assigned to the project must be selected. This staff includes the user liaison, and the central processor development and technical analysts.

- Form Construction Materials System Work Team - A work team consisting of laboratory users, a district representative, Information Systems representatives and other Construction and Materials Section representatives should be formed. This work team will meet weekly to review status and resolve detail design and implementation issues.

- Test Hardware and Software Communication - Once the hardware and software components are installed, the communication capabilities must be tested before technical training and development can take place. These communication tests include making sure all line, control unit, modem, and terminal connections are in place and working.

- Train Central Processor Technical Staff - The project team development staff will require training in the use of the central processor. The training will be provided by the hardware vendor and the project's technical team.

- Train Project Team on Central Processor Software - The project team development staff will require training on the use of the central processor software including the LIMS, statistical software and data base management software.

- Prepare Laboratory Conversion Plan - As soon as some key hardware and software components have been installed, the conversion plan for the laboratories can be defined in more detail than is contained in the implementation plan. The conversion plan will define the duration of user acceptance testing and when existing automated support of laboratory testing can be discontinued.

- Define Pilot System Users - A subset of users from the central laboratory and the districts will be selected to perform a pilot test of the system as part of user acceptance testing. These pilot users will be the first users of the system and will provide valuable feedback before complete user testing is performed.

Application Component Design Tasks

These tasks include the detail design of the application software and the installation of the logical components necessary before implementation can begin.

- Install Central Processor Utility Software - As soon as the central processor is installed, the appropriate software will be installed including compilers, data base management software and diagnostic software.

- Install LIMS Software Package - Since a LIMS package will be purchased to support the laboratory application system, it will be installed as soon as the central processor utility software is installed.

- Install Central Processor Statistical Software - The software that will be used to develop statistical applications will be installed after the processor is configured.

- Install Communication Software - After the central processor is configured, communication software for the communication between the central processor and other computers will be installed.

- Perform Detail Design for LIMS Customization - The LIMS package must be customized to meet the needs of the Construction and Materials laboratories and users. Following installation of the package and training in its use, the detail design for the required customization will be completed. This will include designing the screens and reports around the package's application structure and designing the files or data base around the package's file structure.

- Perform Detail Design of System Interfaces - Several systems will be interfaced to the Construction Materials System. The detail design of the interface will include the design in the Construction Materials System and in the interfaced system.

- Perform Detail Design of Instrument Interfaces - The instrument interface programs required for receiving data and storing it in the system will be designed in this task.

- Perform Detail Design of Additional Functions - The functions not included in the LIMS, such as generation of the materials checklist, will be designed.

- Perform Data Base Design - The structure of data bases and fields to be included in each data base will be designed. The indexes will be defined. Data elements will be named and sized.

- Perform File Transfer Design - The Construction Materials System may include several different instances of file transfer from one computer to another. The format of the files and the design of the programs necessary for the transfer will be performed.

Application Component Implementation Tasks

These tasks include the implementation tasks for the application software.

- Customize LIMS Programs - The LIMS package will be customized to support testing. This task includes unit testing.

- Develop Additional Programs - Additional programs not included in the LIMS will be developed. This task includes unit testing.

- Develop Conversion Programs for Laboratory Data - Some test data has been stored on the Amdahl mainframe. This data should be analyzed to determine if conversion should be performed. Laboratory data conversion programs will be developed well before final conversion is to take place so that the data can be converted and used for testing.

- Develop System Interface Programs - Construction Materials System programs for system interfaces will be developed following the development of the conversion programs described above. For those system interfaces that will cause a change in the other system, the modification to the other system must be made during the time of this task so that the complete interface can be tested.

- Develop Instrument Interface Programs - This task involves developing the programs necessary to allow the test equipment to be connected to the microcomputers or central processor so that data can be collected and stored in the system.

- Train Pilot Users - The previously selected pilot test users will be trained in the use of the system. These users will then perform training for other system users.

- Conduct Pilot Testing with Selected Users - The previously selected pilot test users will conduct a pilot test of the Construction Materials System including all system functions.

- Modify System Based on Pilot Testing - After the pilot test, feedback received from the users will be incorporated into the system.

- Conduct Training - After the pilot test, the pilot test users will begin training of the other users. The full time user liaison will coordinate the training. Central and field laboratory users, Materials and Construction Section, and district users will be trained in the use of the system.

- Conduct User Acceptance Testing - After users have been trained, a complete user acceptance test will be performed. The acceptance test will be planned so that every function in the system is tested by users.

- Perform System Testing - System testing will include testing of all file transfers, system interfaces, job control language, report distribution, and batch job streams. It will be performed following user acceptance testing.

- Perform Final Conversion of Lab Data - After the user acceptance and system testing is complete, the existing laboratory data will be converted for the last time. Parallel testing should not be necessary for the laboratory portion of the system provided the user acceptance and system testing are thorough, especially since current automated support is limited.

- Perform System Tuning - After final conversion is complete, system tuning will be performed. This task involves resolution of any problems that arise after the system is in production.

- Obtain Final Sign-Off - After final conversion, the project team will obtain final sign-off.

Physical Component Implementation Tasks

These tasks include all tasks required for the installation of the equipment needed to support the Construction Materials System.

- Install Central Processor - If the Amdahl mainframe is not used, the central processor can be installed at any time, however, it should be installed and communication established well before development is scheduled to begin.

- Establish Communications - After the central processor is installed, the communication between the field offices and central processor will be established. Depending on the hardware selected, the amount of communication hardware and software will vary. Regardless, communication to the central processor will need to be established.

- Install/Upgrade Workstations - Additional workstations will be installed and existing workstations upgraded to allow communication with the central processor. The upgrade will include the installation of communication cards, RS232 cards, and additional memory where necessary.

- Establish Central Processor to Mainframe/Wang Communication - Once the central processor is installed, communication to the Amdahl mainframe and Wang minicomputer can be established. This communication capability will allow the workstations to act as terminals to the mainframe and Wang minicomputer, in addition to their functions as LIMS terminals and microcomputers.

- Install Instrument Interface Hardware - This task involves the installation of RS232 cards and laboratory equipment for interfacing the selected instruments with the LIMS.

- Interface Equipment - The equipment to be interfaced to microcomputers and the LIMS will be connected and the interfaces established.

- Install Peripherals - Laser printers, plotters, hand held data collection devices, line printers, and any other peripherals desired will be installed.