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CONSTRUCTION OFFICE AUTOMATION VOLUME I

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16. ABSTRACT

This research project was aimed at increasing the productivity of construction, office, and laboratory functions. Application of microcomputer procedures in highway construction has replaced existing manual procedures for construction progress estimate processing and material test computations.

The project has enhanced the information flow to project engineers, area engineers, district engineers and headquarter managers in an efficient manner. It has developed a total microcomputer hardware/software configuration that enables interfacing with the mainframe computer. The existing field office personnel can operate each of the systems with less than one week training of each system.

The final report of this study is divided into three volumes:

Volume I. - Final Report
Volume II. - Construction Progress Estimate Manual
Volume III. - Construction Material Testing Manual

Volume I - Final Report describes the system hardware selection process and the development, implementation, training, conclusions, and recommendations for each of the Construction Progress Estimate and Construction Material Testing systems.

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INTRODUCTION

The Arizona Department of Transportation construction program has gone through a substantial increase during the recent years. This increase has been proceeded by a workforce reduction resulting in a substantial workload with fewer experienced personnel to perform the construction related activities. The need for leveraging the effectiveness of existing personnel had to be matched by the development of appropriate technology in the form of personnel computers.

Administration, Construction, and Maintenance activities of ADOT are divided into four Engineering Districts as follows:

District I - located in Phoenix
District II - located in Tucson
District III - located in Prescott
District IV - located in Flagstaff

Each District is headed by a District Engineer operating under the authority of the Deputy State Engineer of Highway Operations Group. The uniqueness of each District's administrative needs is addressed through Area Engineers and their staff. The primary function of Area Engineer administration is to administer the resources in construction and maintenance of state routes throughout each individual area of the District.

Each Engineering District Area operating thru several construction field offices performs the following activities related and supported by this research study:

1) Initiate and submit intermediate and final estimates as a basis of payment to the contractor for work performed.
2) Write reports and evaluate the utilization of the various types of products or construction practices during the construction phase.
3) Recommend acceptance of a completed construction project after assuming that a project has been completed in accordance with all contract requirements.

All of the information generated by construction field offices used to be recorded, processed and transmitted manually. These procedures were slow and unresponsive to the dynamic needs for information during the construction project. They required repetitive manual calculations and posting, caused many errors and were difficult to learn. For these reasons the construction office procedures were labor intensive, requiring additional staffing during peak work loads. They created delays of contractor payment

submittals and monthly estimates. The generated information was not in a format that could be readily used by management for revenue forecasting and manpower allocation. Engineering use of the data was very difficult.

The technical information is provided to construction engineering staff by project contract documents. Changes in these materials used to require transmission of these documents back to the main office through the appropriate channels. The construction engineering staff has not had access to the software technical capabilities available only at the main office. For these reasons many of the contractor questions and concerns could not be handled at the field office level.

Construction offices are also frequently moved due to changes in the physical locations of active projects. As a result of that telecommunication links to the ADOT mainframe computer system were unreliable for an on-line processing of analytical data from remote locations.

Background and Significance of Work

This research project was aimed at increasing the productivity of construction office and laboratory functions. Microcomputer procedures have replaced existing manual procedures for contract progress estimate processing and material sample test computations/log procedures.

Successful application of these procedures resulted in substantial improvements in contract administration and material testing. In addition, the presence of a microcomputer at the construction site makes it possible to continue work method improvements for surveying, inspection and project management functions as well.

Objectives of the Study

The objective of this study was to evaluate the applicability of microcomputer use in the construction field office, to enhance the information flow, improve productivity, and increase the technical capabilities of the field office staff.

Specifically, the following items have been studied:

1) Development of standardized procedures that can be easily used by construction project personnel.

2) Establishment of procedures for collecting, entering, and editing information related to all

projects within a construction installation as the field work is in progress.

3) Ability to produce and transfer information to project engineers, area engineers, district engineers and headquarter managers in an efficient manner.

4) Development of a total microcomputer hardware/software configuration that enables interfacing with the mainframe computer and allows information to be shared with other users.

5) Testing of prototypes of the system in each of the four engineering districts of ADOT.

HARDWARE SELECTION PROCESS

Project Initiation

Prior to funding of this research project the work was initiated in 1981 with the purchase of a Radio Shack TRS-80, Model II microcomputer by the Arizona Department of Transportation. The microcomputer was purchased with State funds and located in the District IV office in Flagstaff.

Original Hardware Configuration

Due to this HPR project funding in January 1984 four IBM-XT microcomputers were purchased and installed in four different field offices, one in each of the ADOT Districts. The IBM-XT microcomputer was selected because of the project requirement that each automated field office be able to communicate electronically with the ADOT mainframe computer located in the main office in Phoenix. The communication protocol selected was Remote Job Entry (RJE) via an AST 3780 RJE emulator using synchronous/asynchronous CODEX 5212 1200 bps modems (used for the Construction Progress Estimate system). The IBM-XT's were equipped with two diskette drives and an expansion unit with 2-10 megabyte hard disks. AST SixPak memory boards were installed to bring the total system memory to 640K RAM. IBM RGB monitors and Plantronics color/graphics adapters were installed for video output. Okidata 93 parallel printers with an IBM extended graphics chip installed provided hard copy output.

Subsequent Hardware Configuration

Subsequent hardware expansion as described below was not performed as a part of the original HPR project.

In May 1985, ADOT management authorized a purchase of five more IBM microcomputers. Two microcomputers were placed in District I, and one in each of the other Districts. The configuration of these units was similar with the following differences: two half height diskette drives were installed in the system units, thus leaving a slot for a tape backup unit to be added in the future. The standard IBM graphics adapter was substituted for the Plantronics board at a saving of about $100 per unit with no observable difference in video output quality.

In December 1985, ADOT management authorized a purchase of $50,000 worth of additional equipment. This amounted to seven more systems with five allocated to District I, one to District II, and one to Field Reports Section for monitoring progress and final estimates. The configuration changed substantially with the purchase of IBM-XT system units with two half height diskette drives and a half height Seagate 20 megabyte hard disk. This left one slot for a tape backup unit to be added later. Okidata 193 printers with the IBM extended graphics chip were used instead of Okidata 93's which had become obsolete.

In May 1986, ADOT management authorized an additional $50,000 worth of equipment to be purchased. This also amounted to seven more units with the following differences: The new IBM-XT's were purchased with the enhanced keyboard, 640K RAM on the system board, one half height diskette drive and a three quarter height IBM 20 megabyte hard disk. Irwin 10 megabyte tape backup units were purchased for all 23 systems now in the field. Codex 5212 modems were superceded by a later model 208.

As of August 1986, ADOT has field offices automated as follows:

District I - 10 construction field offices

District II - 4 construction field offices
1 area laboratory

District III - 3 construction field offices

District IV - 4 construction field offices

Field Reports Section - 1 system installed

From this point the report is divided into two parts, each describing the Construction Progress Estimate system and the Construction Material Testing system.

CONSTRUCTION PROGRESS ESTIMATE

This section of the research report presents the process of development and implementation of the Construction Progress Estimate system, the training of ADOT personnel, conclusions, and recommendations.

Objectives

The objective of the Construction Progress Estimate (CPE) system is to use current hardware and software technologies in order to maximize the flexibility, efficiency, timeliness and user friendliness of the information processing. These objectives have been grouped for purpose of clarity into four categories: general, functional processing, reporting, and data processing.

The General Objectives of CPE System are to:

- Incorporate uniform definitions of ADOT financial policies and procedures as they relate to construction progress estimates.
- Determine accurate, well documented progress estimates for contract payments.
- Provide adequate user and technical documentation covering all aspects of the systems.
- Develop a user training program to support the needs of the Department.

The Functional Processing Objectives of CPE System are to:

- Allow entry of daily quantities of performed work as they are reported;
- Compare planned and reported quantities of performed work to detect duplicate or omitted entries;
- Maintain "staked" quantity measurements from cross-section books and other field measurements for comparison to plans and reported quantities;
- Cross-reference item tabulation by structure number for structure summaries;

- Maintain discrete elements of each item that can be described by plan description or location.

- Automatically maintain the relationship between partial payments for the delivery of materials and progress payments for the installation of the materials in the finished product.

- Revise and cross-reference planned quantities and cost of supplemental agreements (Change Orders, Force Accounts, and Fiscal Variance Reports);

The Reporting Objectives of CPE system are to:

- Provide timely and accurate project cost and quantity information to aid in the effective management and cost control of the Department highway construction program;

- Provide for the reporting of monthly progress estimates as a basis for intermediate contract payments;

- Evaluate "overrun" and "underrun" conditions on an exception basis and provide a Final Balance Report at the conclusion of the contract;

- Provide standard exception reporting of variances in the database structure;

- Provide standard edit and field checklist reports as required;

The Data Processing Objectives of CPE system are:

- Utilize current microcomputer technology to provide real time processing techniques including editing, update, and inquiry;

- Define the data requirements necessary to support mechanical interfaces from other Department systems such as the Contracts and Specifications Database and Monthly Estimate Transmittal Systems;

Research Procedure

This section of the report on the Construction Progress Estimate (CPE) System presents a description of the research procedures used in the development of the system.

Evaluation of Database Software

This research project followed an initial effort by ADOT to automate construction office procedures on a Radio Shack microcomputer (model II). Although the equipment available at the time proved inadequate, the experience in basic programming and definition of system needs was beneficial.

The earlier effort was attempted with a computer that had 64k memory, VisiCalc spreadsheet software, and basic computer language firmware. When it was determined that the spreadsheet software could not handle the complexity of the system, the only remaining choice was basic language programming. The next limitation was the 64k memory capacity of the Radio Shack Model II computer. It was difficult to develop good programs with the small amount of memory available. Funding of this research project provided the opportunity to overcome these problems.

The new equipment has a memory capacity of 640k (ten times greater). Software products for the MS-DOS operating system are much more powerful. The CPE system requirements could probably be satisfied with a database application environment. However, there was a good database software on the market.

Several weeks were spent reviewing database software. Demonstrations and interviews were used in the process. A software call REVELATION by Cosmos was chosen. The REVELATION Database Applications Environment provided for a query language, data dictionary and vocabulary definitions, and a programming language.

Six weeks were allowed for determining if the application could be developed with the database software and still remain on schedule. At the end of the six week evaluation period it was decided that there were too many unknowns remaining to guarantee a product on schedule.

It was decided instead to convert the basic programs from TRS-DOS to the new PC-DOS operating system and utilize the basic programming language.

Conversion of (TRS-DOS) to (PC-DOS)

A software for converting basic language programs from TRS-DOS to PC-DOS was purchased and used to save the effort of re-typing the code in the IBM equipment. Although there were substantial differences in the command structure, the conversion software did save time. Search and replace functions of a good full screen editor were also beneficial in converting the differences in command syntax.

System Structure Design

The storage requirements for the CPE system included:

- o basic program file
- o project index file
- o one project planning file for each project
- o one transaction file for each project
- o one structure cross-reference file for each project

The project planning file is a random access file and uses a sorted index matrix to maintain the record locations.

Compiling the Programs

The program conversion, testing, and user documentation was ready for initial training the first week of July, 1984. The first training session was in Tucson, Arizona. During the second day of training the program quit running. The computer had run out of memory. It was discovered the first time that the basic programming applications were limited to a 64k partition regardless of the memory capacity of the computer. There was only one/tenth (64k) of system memory (640k) available for loading the program, memory variables and index matrix. With the program stored in interpretive basic, the index matrix could keep track of only a couple of hundred records before it exceeded the 64k limit. A couple of hundred records was only a fraction of the number required when the system was in full production with large projects. The system needed to handle up to 5000 records per project to be safe.

Two actions were taken in the following week to allow the implementation and training to proceed on schedule. The basic program was divided into separate and smaller modules and the programs were compiled. After adjusting the matrix dimensions, the system could now handle up to 2000 records per project. This was adequate for the projects currently loaded on the four machines. Complex projects however, may require up to twice as many records.

Decimating the Files

Our first choice for increasing the number of records the system could handle was to find a software that did not limit the memory to 64k. Interviews with vendors however, indicated that other basic language compilers would not breach the 64k partition for another year or more. Another conversion to different software was considered too expensive. A decision was made to reorganize the data files to keep the size of the index matrix less than 2000 records.

The project planning file originally contained all planning records.

- Project records
- Section records
- Item records
- Change Order records
- Force Account records
- Sub-Item records

Two-thirds of the project planning file was sub-item records. It was necessary to not only separate the sub-item records from the rest of the planning records but also segregate the sub-items into item categories; each item category was a different sub-item file. The item categories were determined by using the first digit of the item number as follows:

2 - Grading
3 - Subgrade, Subbase, and Bases
4 - Surface Treatments and Pavements
5 - Drainage Facilities
6 - Structures
7 - Traffic Control Facilities
8 - Roadside Development
9 - Incidentals.

A prediction was made that increasing the number of files and thereby increasing the input/output overhead would slow the response time considerably. However, the response time turned out to be quicker. Although the system had to handle more files, each file had fewer records. The index matrix was smaller and more efficient.

Communications

Due to the accomplishment of the initial project objective, the creation of monthly progress estimates on a microcomputer, the field office was able to function more efficiently and accurately. However, the estimate document was still sent to headquarters via mail and had to be manually validated prior to issuing payment to the contractor.

Contract and Specifications Section responsible for evaluating and awarding highway construction contracts, had a mainframe database in place at the time the field offices were automated. A few changes were made to the mainframe database in order to include those data elements required by the microcomputer estimate program. When the changes were made the project structure of contract items, costs and quantities could be transmitted via telephone line to the

field office. This saved both time and considerable re-entry of data as well as input errors.

The final link necessary to completely automate the process was to transmit the completed progress estimate from the field office to the mainframe computer for payment. Some changes to the mainframe database were necessary to accommodate the progress estimate. These changes were made and enabled headquarter personnel to quickly check the progress estimate for validity and authorize payment to the contractor. This improvement enabled Field Reports Section to save 75-80% of the time required to validate the progress estimates manually.

Installation and Training

Training materials consist of training objectives, training outline, user manual and a sample project computer file for demonstration.

The CPE system was the first user application trained at construction field offices. The training session included setup of equipment, equipment orientation, and the CPE application training. The CPE application training consisted of system objective discussion, demonstration of reports and transactions, and loading of contract planning elements (build).

Two days were devoted to the first session. A one day follow-up session was conducted a week later. The construction office staff was successful with the three days training and a few follow-up calls for a month or two.

Conclusions

The CPE microcomputer system has met all of the planned objectives. The existing field office personnel can operate the system with less than one week training. The microcomputer equipment has performed with minimum maintenance for the last three years. The system has produced an annual savings of three man-months in each construction office. The benefits amount to about $5,000 annually and indicate a one to two year pay-back period.

A partial man savings such as this allows time to be spent on other activities and reduces the probability of additional personnel being assigned during peak work loads. However, this may not demonstrate an immediate overall payroll reduction.

Recommendations

The CPE system has proven beneficial and has been recommended for incorporation into the standard procedures of ADOT. Due to the required large capital investment a phased implementation has been suggested. An average of twelve computer units per year have been installed for a total of 23 units to date. The remaining field offices should be reviewed for the need of additional microcomputers to be added to the CPE automated system and for the evaluation of cost effectiveness of such an operation.

CONSTRUCTION MATERIAL TESTING

This section of the final research report presents the development and implementation of the Construction Material Testing system, training of ADOT personnel, conclusions, and recommendations.

Background

District II joined with the other three Highways Division Engineering Districts to explore the effectiveness of employing a microcomputer to automate some of the procedures used in the construction field offices. Our contribution to the joint effort was to take a set of existing material testing programs, written in TRS-80 Basic, to convert and to improve them for use on a larger, more powerful microcomputer.

The existing material testing calculations and preparation of weekly reports were being accomplished by a calculator and a typewriter. The file storage and retrieval was represented by a manual hard-copy laboratory work sheet. Information retrieval was based solely on extracting the hard copies and recalculating perhaps a whole group of like tests to obtain statistical information. This was a very labor consuming process.

Objectives

The goal of the Construction Materials Testing (CMT) system was to use the easiest and fastest method to learn existing hardware and programming software to produce a materials testing process that would be non-threatening to the user, work efficient, and productive in new ways. All of that had to be accomplished in a timely manner. The goal was reached by objectives as fully described on the following pages and have been grouped into four categories; general, functional processing, reporting and data processing.

The General Objectives of the CMT System are to:

- Incorporate existing ADOT material testing policies, standards, and accepted project laboratory procedures into the system development.

- Produce accurate reports for documenting project materials quality assurance.

- Provide adequate user and technical documentation covering all aspects of the CMT system.

- Develop a user training program to support the needs of the Department.

The Functional Processing Objectives of the CMT System are to:

- Use existing ADOT material testing laboratory forms and documents.

- Design a system that would be used within the testing and work area of a complete project laboratory.

- Allow entry and permanent storage of material tests into computer at time of testing.

- Organize material production phases, sources, specifications, within the computer, in a manner natural and best suited for a specific project.

- Quickly access, by means of an electronic menu, and execute any of the material modules associated with a specific testing procedure.

The Reporting Objectives of the CMT System are to:

- Provide timely and accurate weekly project material testing reports to engineers

- Provide complete project history reports continuing results of all tests attributed to a particular quality control testing activity, such as soil gradation, asphalt, or concrete.

- Provide some report capabilities for statistical analysis of like records within the same project.

The Data Processing Objectives are:

- Use current, microcomputer technology to provide real time processing techniques including editing, updating, deletion, and inquiry.

- Define the data requirements necessary to match an old existing main frame data base for future development.

Research Procedure

This section of the report on the Construction Progress Estimate (CPE) system presents a description of the research procedure used in the development of the system.

Evaluation of Database System Software

An earlier effort at automating material testing was attempted on a Radio Shack microcomputer. Our original charter was to convert these programs to run on an IBM machine, evaluate the system and expand the programs where necessary. Jointly, District II and IV reviewed a number of data base systems software along with other high level programing languages which had the necessary structure to convert the old programs. Independently, both districts came to the same conclusion, to continue to reprogram in basic.

Evaluation and Improvements of Data Base Software

After converting the existing programs from TRS-DOS Basic to PC-DOS Basic, various material technicians first as educators, later as design consultants, and eventually as testers of the programs were involved in the process.

The expertise of the material technicians enabled modification of the initial programs making changes and corrections in logic, in individual project flexibility, and in greater user control. In the final product, very little of the original programs are left intact.

System Structure Design

The storage requirements for the CMT system include:

- Sixteen basic program files
- One project numbering reference file
- Three holding or suspense files for uncompleted tests
- One gradation specification file for each project
- One asphaltic concrete mix design file for each project
- One concrete mix design file for each project
- One proctor density file for each project
- One daily log file containing all tests completed that day
- One weekly log file containing all tests transferred from daily log file

- Eight project history files for each active project being serviced

Compiling the Program

The original system structure design was one weekly file and one project history file. As a result of the CPE experience, which used all the available memory within its system file structure, the file structure as shown above was created.

The program conversion, enhancements, testing, and user documentation on the CMT system was ready for initial training in the last week of October, 1984. The first training session was in Phoenix, AZ. A number of problems emerged. These were:

- Office computers, installed first for Progress Estimates and used primarily for that function, were virtually inaccessible. In many cases, these computers were serving a large number of projects. In others, the materials testing laboratory was far from the construction office. In all cases there was a definite sense of "Work Territory Invasion" with the office staff assuming sovereignty and the materials technicians being viewed as trespassers.

- Material handling, laboratory methods, logging, and report preparation responsibilities are not the same from district to district or even org to org within the same district. Each district has its own method and system, usually quite valid given their individual logic.

A complete installation and comprehensive training of the CMT System occurred in Prescott and Holbrook in November of 1984. Following this experience, a number of system and programming changes were made. These mostly dealt with trying to satisfy each installation's individual needs. Some of the problems were definitely programming and design errors and these were immediately corrected.

The Anex System

At the time of purchasing the first IBM XT, many vendors were advertising products that would enable a PC to support an additional slave or dummy terminal (monitor and keyboard). This configuration was appealing as it would allow a materials testing laboratory to share the microcomputer, permanent storage, and printer in the construction office by means of a cable link. This was attractive for two reasons. One, it would eliminate

subjecting the microcomputer processing unit, magnetic storage devices and printer to the harsh environment of a materials testing laboratory; and two, it would be a very economical method to provide automation to each work location. However, initial investigation of these concepts led to the conclusion that too many problems with each of the systems would have to be resolved before they would accommodate the required needs.

Since the material programs continued unused because the assigned microcomputer was not within the work area, multi-function software/hardware was reexamined.

A product named The Anex System seemed the only promising system that could accommodate ADOT needs. After numerous demonstrations and a loan of the software/hardware Anex System to the Department for testing, one unit was installed in a Tucson construction field office in June, 1985. At first, everything went well. Simultaneously, the lab with the slave terminal, some 200 feet away from the microcomputer, was inputting material tests as the office staff was using the main console in running progress payment estimates. This continued for approximately three weeks. At this time the office logs main frame data base was ready for production use. This involved uploading and downloading using an AST-3780 board in the PC and an external asynchronous modem. After this equipment was installed in the Anex unit, problems immediately arose that were insurmountable in making these two systems compatible. Since the communication package was essential to the CPE system, no other choice was available but to remove the Anex system from the unit.

Installation and Training

Training materials consist of training objectives, a training outline, a user/reference manual and a sample project with all material tests addressed in the CMT system.

The CMT system was the third user application trained at construction field offices. The training included equipment orientation and the CMT application training. Personnel receiving and using the CMT system were a completely different group than those using the CPE. The CMT application training consisted of:

- system objective discussion,
- demonstration of reports and program organizational structure,
- student hands-on entering, calculating, logging and retrieving of sample tests.

Two days were required to train all aspects of the CMT system. A one day follow-up session was conducted within two to three weeks. Telephone support was encouraged during this time. In all districts, the use of a local technician as a liaison and prime contact for answering questions and in general support of the system was utilized.

Conclusions

The existing materials laboratory personnel can operate the system with less than one week training. In a relatively few laboratories where microcomputers have now been placed, the equipment is performing well with very little maintenance.

Implementation and acceptance of the program within ADOT has not been successful at this time for the following reasons:

1/ There was not sufficient number of microcomputers in laboratories (only one microcomputer in District II) prior to releasing the CMT programs to Materials Pavement Services section.

2/ The programs were not completely debugged because of insufficient feedback from potential users.

3/ Very little remedial work on the original programs has been accomplished leaving the entire CMT system unproven.

Considering only those things that the system does well and comparing them to a manual system, it is safe to estimate that one unit in each laboratory saves two man-months per year. Further constructive effort to improve and develop the system could double or triple the man-hour savings.

Recommendations

It is recommended to:

- Install a microcomputer in each materials testing laboratory. The CMT system and associated programs are designed to be of maximum benefit when used as the tests are being run.

- Establish an advisory committee at such management funding level as to manage, coordinate, prioritize and submit reprogramming request to the Department's Information Service Group (ISG). All levels of users

should have access to members of the committee through some predefined structure.

- Develop a much larger project scope directed at total quality control containing such objectives as monitoring enforcement of Department policies, uniformity of methods, standard testing procedures, work products, and data evaluation. The CMT system is successful within the objectives as originally outlined, but it does not meet the expectations or automation needs of all existing laboratories.