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A Multimedia Construction Delay Management System

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Abstract: *The need for acquiring, storing, processing, and presenting quality data in a timely manner in support of construction project management is well recognized. Therefore, a properly developed information system that manages the required data is crucial to the success of project management. However, one type of useful data and information, namely, multimedia (pictures, videos, and audio), has not been appropriately acquired and/or managed in construction. Researchers are just beginning to explore and evaluate the benefits of multimedia information in construction applications. This paper discusses some of the potential applications of multimedia in construction and describes the implementation of a prototype multimedia information system for construction delay management. The system tracks a variety of data types related to delays, including pictures, videos, and audio.*

1 INTRODUCTION

The main objective during a construction project is to deliver a quality product in a timely, cost-effective, and safe manner. However, due to the risky and competitive nature of construction contracting, conflicting objectives among the different participants lead to changes and claims that have a direct impact on the completion time and/or cost of a construction project.[3,6] Therefore, to effectively manage delay and potential claims situations, a system for providing access to and control of data, especially data pertaining to the performance of a construction project, is needed. However, one such type of useful data and information, namely, multimedia (pictures, videos, and voice), has not yet received appropriate attention in construction project control. Researchers are beginning to explore and evaluate the benefits of multimedia information in project controls. The proper design and development of an automated system for managing multimedia data in support of project management has been lacking. Therefore, the primary objective of this paper is to discuss the development of a prototype automated multimedia information system that addresses one promising construction multimedia application, namely, delay management.

1.1 The role of pictorial information in construction

Pictorial information (photographs and videotapes) is one sort of multimedia data that should play an important role in construction management. Some companies require that appropriate field personnel (a superintendent or a foreman) take pictures of layouts and situations (such as a critical activity or an activity with a new construction method) that the company feels need attention or special observation.[11] The following is a list of some potential uses of pictorial information in construction[4]:

- Pictures are very useful visual reports that trigger problem areas that need special analyses and decisions. Management receives summary reports with certain highlights of activities that demonstrate poor performance (overbudget expenditures or delays or both). Accompanying such reports would be visual reports (pictorial data) that show the troubled activities in progress. Management views the pictorial data, analyzes them, and decides on remedial actions.
- Pictorial information can play an important role in settling on-site disputes between contractors and subcontractors or between the owner and contractor. Some disputes result from delays, while others are associated with progress payment estimates. Such disputes can in some instances be resolved without litigation. However, a number of disputes become claims in courts and are resolved by court decisions. In court cases, pictures become physical evidence.
- Pictures can be used to motivate workers to improve their practice. This is accomplished by organizing meetings that involve both management and workers. Workers look at the pictures, and management solicits their input for im-

provement suggestions. The workers' involvement in improvement programs motivates them and helps make these programs successful. It also improves communications between workers and management.

- Archival pictorial information can be very useful in training workers to do certain complex construction operations. A complete set of pictures that captures the overall process can be displayed in training workshops.
- Accidents and failures at construction job sites occur occasionally. In the case of an accident, pictures may play an important role in determining the cause of the accident. Thus safety measures can be improved to prevent future accidents from occurring. In cases of structural failures, pictures taken before and after a failure play an important role in determining the causes of the failure and serve as input for future research studies and investigations for improving construction methods or materials.
- Pictures play an important role in initial site investigations when a company is in the process of preparing a bid. Pictures are taken to determine the site conditions that have to be dealt with, the type of adjacent buildings, the access to the site, and other obstacles that need to be accounted for when a bid is prepared.
- Pictures can play a key role in maintenance and inspection of constructed facilities such as bridges. An inspector captures on film all the images he or she needs and later reviews these images in the office to prepare the inspection report.
- Pictures and videos have been used successfully in conducting productivity studies of various construction operations using a variety of analysis techniques.
- Pictures also can serve as a marketing tool for construction companies by showing innovative construction methods and serving as a portfolio of projects constructed by the company.

1.2 Issues and needs

From a careful study of the benefits of the preceding listed potential applications, it has become clear that visual information is very useful in construction. Automation of this data-acquisition and storage process should encourage contractors and owners to take pictures more often than current practice. By such automation, visual information will become an important reported item. Furthermore, adding digitally stored audio comments on the activities in the various control accounts should provide additional details to the different reports. This paper, therefore, addresses a key issue that is needed in achieving effective project control: the proper design and development of an automated system for the acquisition, storage, and retrieval of mutlimedia data. In particular, the paper discusses the development of a prototype multimedia information system in support of delay management.

1.3 Work by others

A number of researchers are beginning to evaluate the role of pictorial information in construction. One example of a research project dealing with pictorial information is an as-built information system developed as a joint effort between the University of Illinois at Urbana-Champaign and the U.S. Army Corps of Engineers.[7] In this system, as-built drawings are captured and stored as digital images along with numerous other data items pertinent to the as-built information management system such as shop drawings, materials used, equipment, and others.[8] A second example deals with managing documents for strengthening the design-construction interface using digital imaging.[14] In this system, a document produced in design is digitally captured by the system. Then the digital image becomes electronically available to the other parties involved in a project such as the project manager. Such an approach enhances communications between all parties involved. Moreover, a well-recognized application of pictorial information is the study of construction productivity through the use of time-lapse video and photography techniques.[6,10] From a careful study of these research efforts, it is clear that automated pictorial data management is becoming a key component of future information management systems.

2 METHODOLOGY

The research project discussed in this paper addresses construction delay management. To develop an automated information system solution for the management of multimedia data in support of delay management, a four-step process, briefly described below, was used.[1,3] The process is shown in Fig. 1.

Step 1: The first step in the modeling effort, *problem definition*, involves identifying the data items needed in the delay management process and describing their relationship with the overall project control process.

Step 2: The second step, *conceptual modeling*, is a graphic representation of the problem formalized by step 1. The outcome of this step was a conceptual data model that represents the design of the system and demonstrates the integration of multimedia information with other project management data.

Step 3: The third step, *computational modeling*, transforms a conceptual data model from step 2 to a computational model (relational) suitable for implementation in automated environments.

Step 4: The fourth and final step of the modeling process, *computer modeling*, implements the computational model developed in step 3 to develop the automated computer system solution to the problem.

The focus in this paper will be on steps 3 and 4.

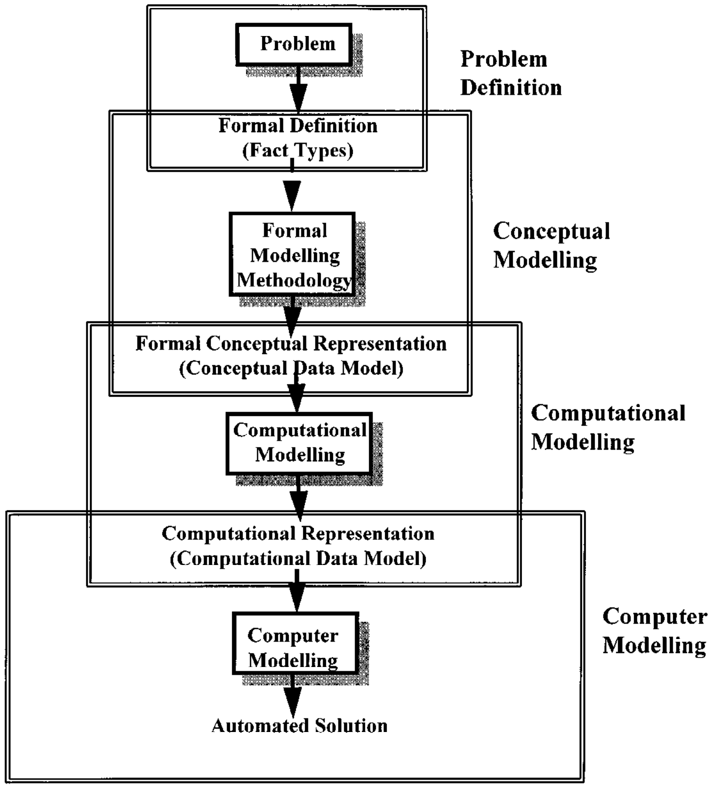

Fig. 1. PIMS development methodology.

3 DATA NEEDS

Presently, construction data are acquired using a variety of forms. A number of data-collection forms are available in the literature and in construction firms, such as the R. S. Means Company forms[9,10] Because of their extensive and detailed data item content, the Means forms were selected for identifying what data are currently being collected in construction delay management. A subset of the Means forms was identified as being used to acquire data in support of delay management. This subset of Means forms was analyzed to determine its unique data content. The following is a list of some of the data items that resulted from this analysis and from studying the needs of delay management.

- *Control account*: This data item is an account that serves as a depository of control data acquired during the management of a construction project. Each control account represents an operation or task, has definite start and end times, and consumes resources (material, labor, and equipment). Delay data will be identified and tracked by the control account experiencing the delay.
- *Delay type*: This data item identifies the type of delay encountered by a control account. Delay types include differing site conditions, interference, defective prior work by others, weather, defective plans and/or specifications, delay in owner-furnished materials, and changes in scope of work. Each type will have a unique code.
- *Visual record*: This data item deals with acquiring a digital image of the activities in each control account. The image can be one picture or a sequence of pictures (a video clip).
- *Audio record*: This data item deals with providing a mechanism for digitally storing a verbal description of the activities in each control account.
- *Day*: This data item provides a date for each acquired daily record.
- *Status*: This data item identifies the delay record as started, in progress, or finished. This data item provides a mechanism for tracking the duration of a specific delay in a control account.

4 THE DATABASE SCHEMA

In developing the database schema for the multimedia information system, the four-step modeling process described earlier was used. The first two steps yielded a graphic representation of the information system using a modeling methodology called *NIAM*.[12] Figure 2 is a portion of the overall NIAM model for the prototype system.[1] Next, the NIAM model was transformed into the relational database schema (step 3 of

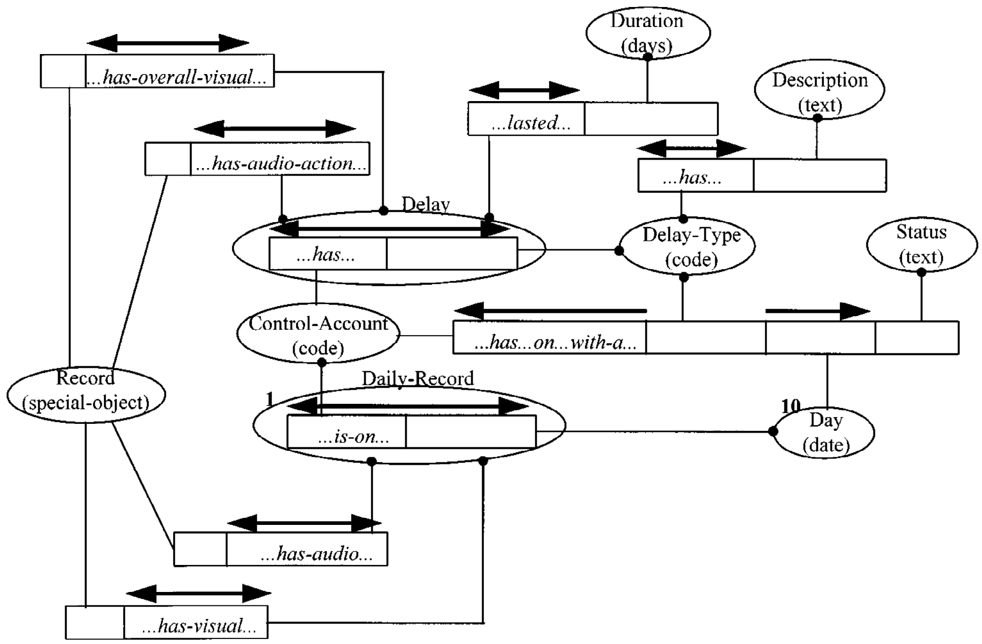

Fig. 2. A portion of the NIAM model for PIMS.

the modeling process). This section discusses the relational database schema of the information system that resulted from step 3.

Three groups of relations were developed in an earlier research project to address the issue of construction performance evaluation and project control.[3] These groups were identified as the static database, dynamic database, and historical database. The *static database* includes the relations that deal with such data as budgets, definition of the work breakdown structure, and activity network definition. The *dynamic database* includes the relations that deal with the daily data and information acquired by field personnel on resource and time consumption. The *historical database* includes the relations that deal with the creation of historical data records for future reference.

In this research project, an attempt was made to integrate the delay management process with the previously developed project control system. This integration was easily achieved because the delay management data model was developed using NIAM, which allows existing models to expand. Therefore, the delay management model was developed as an extension to the previous data model. Thus the integration of delay management with project control was achieved. New database tables were added to the previously developed databases to address the delay management data needs. These tables also were categorized in accordance with the three groups described above. The following is a partial list of all the tables in each group. A complete listing can be found in ref. 3. The tables that directly deal with the delay management problem are set in boldface type.

Static database

1. Control-Account-Budget-Materials(*Control-Account-Code*, *Material-Code*, Quantity)
2. Control-Account-Budget-Hours(*Control-Account-Code*, *Craft-Code*, Man-Hours)
3. Control-Account-Budget-Equipment(*Control-Account-Code*, *Equipment-Code*, Work-Hours)
4. Control-Account-Information(*Control-Account-Code*, Description, Start, Finish)
5. Material-Codes(*Material-Code*, Description, Units, Budget-Unit-Cost)
6. Equipment-Codes(*Equipment-Code*, Description, Budget-Hourly-Rate)
7. Craft-Codes(*Craft-Code*, Description, Budget-Pay-Rate)
8. Worker-Information(*Worker-ID*, Worker-Name, Craft-Code, Regular-Pay-Rate, Overtime-Pay-Rate)
9. **Delay-Types(*Delay-Type-Code*, Description)**

Dynamic database

1. **Delay-Record(*Control-Account-Code*, *Date*, Delay-Type-Code, Status)**
2. **Control-Account-Audio/Visual-Information(*Control-Account-Code*, *Date*, Visual-Record, Audio-Record)**
3. Control-Account-Actual-Materials(*Control-Account-Code*, *Date*, Quantity)
4. Control-Account-Actual-Equipment(*Control-Account-Code*, *Equipment-Code*, *Date*, Work-Hours)
5. Control-Account-Actual-Hours(*Control-Account-Code*, *Worker-ID*, *Date*, Regular-Hours, Overtime-Hours)

Historical database

1. Control-Account-Historical-Hours(*Control-Account-Code*, *Craft-Code*, Regular-Man-Hours, Overtime-Man-Hours, Regular-Cost, Overtime-Cost)
2. Control-Account-Historical-Materials(*Control-Account-Code*, *Material-Code*, Quantity, Cost)
3. Control-Account-Historical-Equipment(*Control-Account-Code*, *Equipment-Code*, Work-Hours, Cost)
4. **Delay-History(*Control-Account-Code*, *Delay-Type-Code*, Duration, Action, Visual-Record)**

Sample data in some of the above-listed tables are shown in Fig. 3. Note above that the italicized fields in each table represent the key of the table.

5 SYSTEM IMPLEMENTATION

The prototype mutlimedia information system integrates pictorial and voice information with project control data in support of performance evaluation and delay management. The hardware components of the prototype system are shown in Fig. 4. The system's architecture is shown schematically in Fig. 5.

As shown in Fig. 4, the system's hardware components include a video camera, a microphone, a video-capture board (frame-grabber), a sound card (audio digitizer), and a 486-based computer workstation having 16 megabytes of memory and 1 gigabyte of hard-disk storage. The video camera and the frame-grabber serve as the pictorial data-acquisition mechanism. The camera has time-lapse capabilities to allow for compressing an 8-hour shift into a number of shorter durations (e.g., 2 hours). The microphone and the sound card serve as the audio data-acquisition mechanism.

Once the desired activities in a control account are captured on videotape, the scene is digitized by connecting the camera (which serves as a video player) to the frame-grabber that is installed on the computer workstation and stored on the hard disk in a digital format. A number of standard visual data formats are available for storing digital image(s). A scene can be digitally captured and stored on the hard disk in one of two methods: a sequence of frames (video clip) or individual images (still pictures). Next, voice messages describing each control account are digitally captured using the microphone that is connected to the sound card along with an audio software package that creates digital audio files from voice signals.

After the digital voice- and image-acquisition processes are complete, the audio and visual data are stored in the relational database for processing and reporting. The Access relational database management system (DBMS) software package is used for implementing the prototype system. The system's tables described in Section 5 were created using the Access data-definition language that is based on the standard Structured Query Language (SQL). Figure 5 shows the system's architecture and schematically illustrates the overall process of capturing, storing, and reporting pictorial and audio information.

A mechanism for storing digital images and audio data in the database is needed. The Access DBMS supports two different storage mechanisms. In the first one, the digital audio or image data are physically embedded in the database record. This mechanism stores each piece of data twice on the hard disk. In the second mechanism, a link to the physical location of the digital audio or image data file is stored in the database. Thus less storage is needed. Therefore, the link mechanism is selected for storing digital audio and visual data in this prototype implementation.

6 PROCESSING AND REPRESENTING INFORMATION: EXAMPLE REPORTS

Processing and representing data in the prototype system are accomplished by using the report generator utility of the Access DBMS, which utilizes SQL for data manipulation. In this section two reports will be discussed: the *control account audio/visual information* and the *control account delay record*. Each report is implemented twice: one for producing on-screen multimedia representation of the needed information and one for producing a hard-copy report. On-screen report presentations are described first. Then the hard-copy version of each report is presented and discussed.

The *control account audio/visual information* report, shown in Fig. 4a, has five fields: the control account code (CACode), the date of the record (Date), the description of the control account (Description), a visual record in the video-clip format (Visual), and an audio message (Audio). Once the user invokes this report, it is displayed on the screen in the form shown in Fig. 6. (Note that the figure is printed from a bit-map screen-dump file.) To view the video clip in the Visual field, the user needs to double click on the displayed image to activate a video player utility that can play the video clip. The video player utility is shown in Fig. 6 as well. To listen to the audio message associated with this record, the user needs to double click on the microphone icon displayed in the Audio field, which will activate the audio player that plays the message. Note that each record is displayed in one screen. The scroll bars along the side and at the bottom are used to navigate through the various records in this report. A hard copy of this report may be printed using a second report design. The output of this report is in tabular format (Fig. 7). Note that instead of printing an image in the Visual field of this report, the field type (MediaClip) is displayed. Pictures may be printed in this report. However, they would be displayed as still pictures in the Visual field for each record. The

Control Account Information Table

Control-Account-Code	Description	Start	Finish
1000	Footing Excavation	3/10/95	3/17/95
1100	Footing Rebar	3/20/95	3/24/95
1210	Concrete Footing Pour	3/31/95	
2100	Backfill Compaction	3/31/95	

Control-Account-Visual/Audio-Information Table

Control-Account-Code	Date	Visual-Record	Audio-Record
1210	3/31/95	MediaClip	Soundo'LE
1210	4/5/95	MediaClip	Soundo'LE
2100	3/31/95	MediaClip	Soundo'LE
2100	4/5/95	MediaClip	Soundo'LE

Delay-Record Table

Control-Account-Code	Date	Delay-Type-Code	Status
1210	3/31/95	1	start
2100	3/31/95	2	start
2100	4/5/95	2	in-progress
1210	4/5/95	1	in-progress

Delay-Types Table

Delay-Type-Code	Description
1	differing site
2	interference
3	prior work
4	weather
5	others

Delay Histroy Table

Control-Account-Code	Delay-Type-Code	Total-Duration	Action	Visual-Record
1000	1	6	Soundo'LE	MediaClip
1100	1	5	Soundo'LE	MediaClip

Fig. 3. An extract of some tables in the delay management database.

still picture would be the first frame in the sequence of images stored as a video clip. Therefore, the MediaClip value in the Visual field was used instead of the printed image, since it gives a better indication of the field's data content. Similarly, a Soundo'LE value is displayed in the Audio field, indicating an audio data content.

The *control account delay record* report, shown in Fig. 8, has five fields: the control account code (CACode), the description of the control account (CADescription), the date of the record (Date), the status of the delay (Status), and the description of the type of delay (DelayTypeDescription). Once the user executes this report, it is displayed on the screen in the form shown in Fig. 8. (Note that the figure is printed from a bit-map screen-dump file.) A hard copy of this report also may be printed. It is similar to the on-screen display as shown in Fig. 9.

7 LIMITATIONS AND LESSONS LEARNED

During the implementation phase of this project, a number of technology-related limitations and issues were encountered. First, the computing power of a 486-based computer is not efficient enough in handling the retrieval of pictorial and audio data from the database. Better retrieval speeds can be achieved, however, by using a more powerful microprocessor such as a Pentium or better. Second, memory demands are high. The computer workstation locks up when an image and an audio selection are being processed simultaneously. Sixteen megabytes of memory should be the minimum, with larger sizes highly recommended. Third, disk space for storage is an issue of great concern. Multimedia data and information require large storage volumes. Therefore, it was concluded that the best approach for dealing with such high

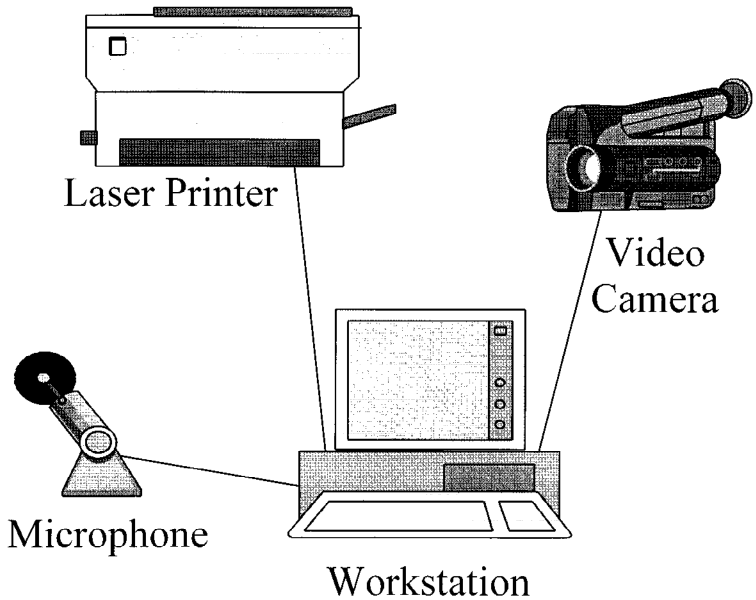

Fig. 4. Hardware components.

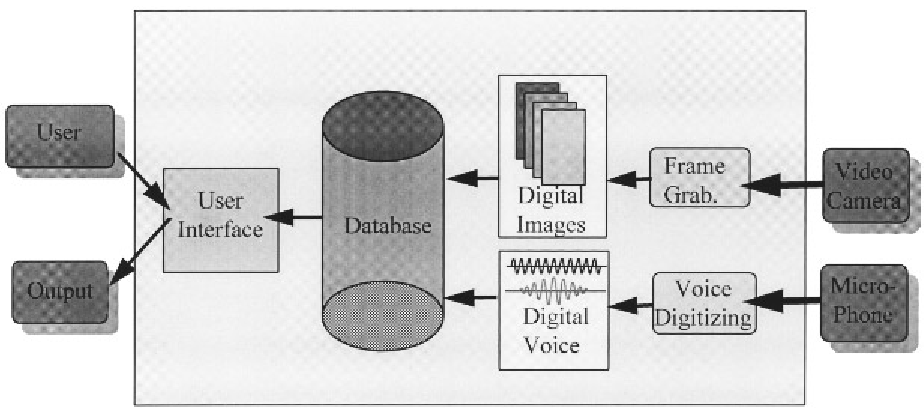

Fig. 5. System architecture.

storage demands is to install a read-write CD ROM drive on the computer workstation. A compact disk's cost is much lower than a hard disk, while its storage capacity is reasonably high. This should alleviate the problem of demand on the hard-disk space.

8 SUMMARY AND CONCLUSIONS

This paper addressed the issue of delay management in construction. The paper demonstrated that pictorial and audio data and information play key roles in the management of delays and potential claims situations. It described the implementation efforts in the development of a prototype automated multimedia system in support of delay management. Additionally, the paper discussed how such data and information should be acquired, stored, processed, and presented in an automated manner to improve the delay management process and enhance the quality of its data. The paper, therefore, strongly promotes the role of multimedia data in the construction environment by developing and testing the concept of automated acquisition and storage of pictorial and voice data. The following briefly describes the benefits from implementing the ideas presented in this paper.

- Instant pictorial data and verbal description capture provide fast, accurate visual and audio information about the progress on the site, particularly in delay situations. Thus performance can be evaluated on time and problem areas detected as they occur. This makes corrective actions effective.

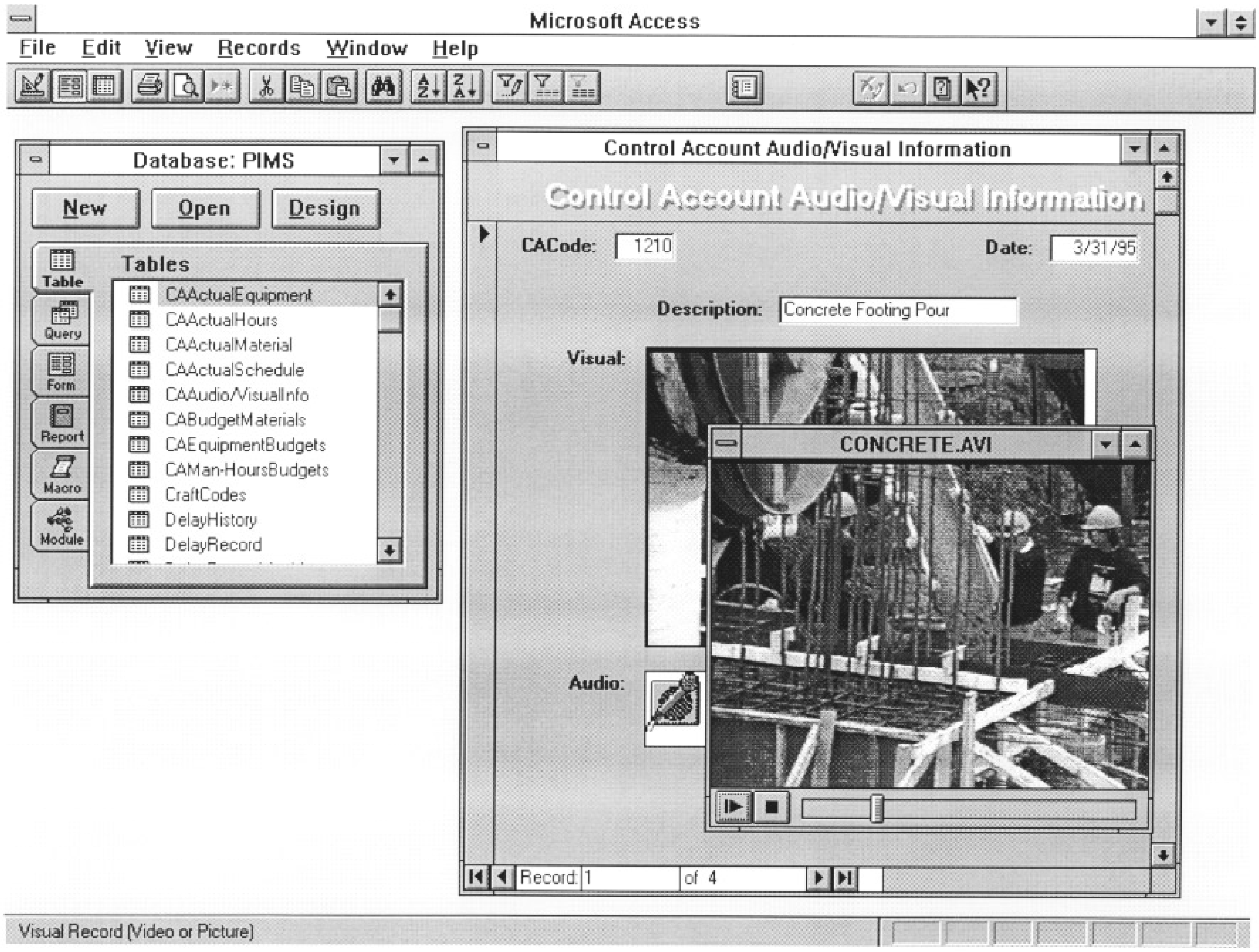

Fig. 6. An extract of the control account audio/visual information report (with the video player utility).

Control Account Audio/Visual Information Report

CACode	CA Description	Date	Visual	Audio
1210	Concrete Footing Pour	3/31/95	MediaClip	Soundo'LE
2100	Backfill Compaction	3/31/95	MediaClip	Soundo'LE
1210	Concrete Footing Pour	4/5/95	MediaClip	Soundo'LE
2100	Backfill Compaction	4/5/95	MediaClip	Soundo'LE

Fig. 7. An extract of the control audio/visual information report.

- Pictorial and audio data are stored in a centralized database and thus are available to all levels of management.
- Permanent, reliable data storage is achieved by storing pictures and audio messages in their digital format on such magnetic media as tapes, disks, or CDs.
- Integration of the multimedia data with project control functions provides a powerful and effective management control system.
- Construction productivity is improved by visually and conceptually identifying procedures and methods that could be performed more effectively and more efficiently.

No doubt, automating the acquisition, storage, and representation of multimedia information is evolving as a key issue in the design of future construction information systems.

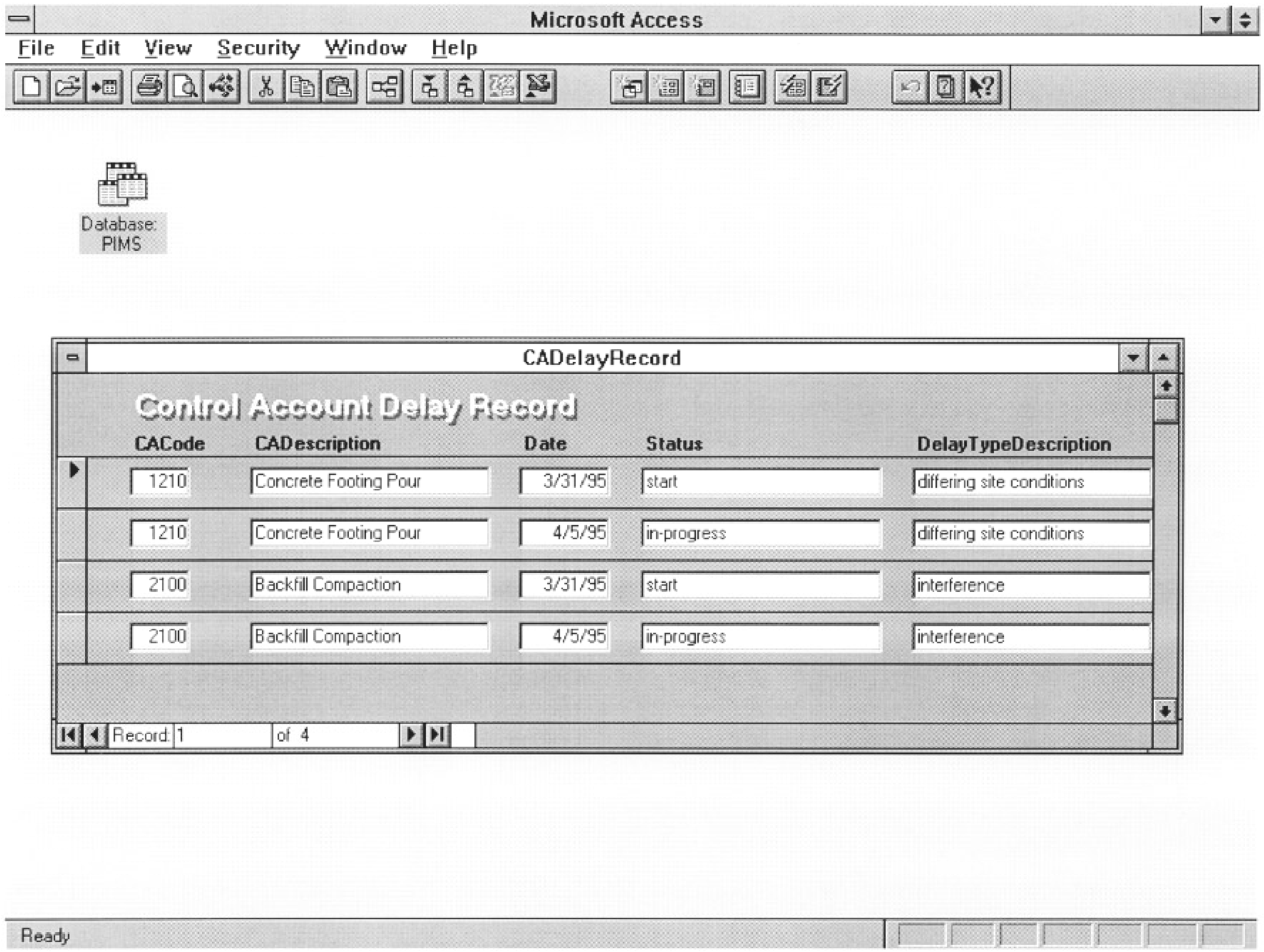

Fig. 8. An extract of the control account delay record report.

Control Account Delay Record Report

CACode	CA Description	Date	Status	Delay Description
1210	Concrete Footing Pour	3/31/95	start	differing site conditions
1210	Concrete Footing Pour	4/5/95	in-progress	differing site conditions
2100	Backfill Compaction	3/31/95	start	interference
2100	Backfill Compaction	4/5/95	in-progress	interference

Fig. 9. An extract of the control account delay record report.

Therefore, multimedia information should play an important role in future project management and control.

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