Complete Package for Computer-Automated Bridge Inspection Process

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A complete package for the Automation of Bridge Inspection Process, developed by the University of Central Florida for the Florida Department of Transportation (FDOT), is presented. FDOT's Inspection Forms A, B, and C for fixed bridges only were described previously. Form A contains the Report Identification and a Condensed Inspection Report. Form B is a comprehensive List of Deficiencies. Form C contains the Evaluation of Previous Corrective Action. The recently developed complete package covers fixed, culvert, and movable bridges. In addition to the previously reported forms, the package also includes Form D, Recommendations for Corrective Actions, and an automated work order system to replace Form E, formerly entitled Methods and Quantities. The automated system comprises five commercially available software programs and 25 developed programs; divided into two components, these are referred to as the *field* and *office systems*. The field system is used to collect all field inspection data. The inspection routines are operated with the use of a notebook computer and pen-based acquisition programs. The office system is used to process field data and to produce a final inspection report established by the National Bridge Inspection Standard. The system requires a desktop computer, a scanner, and a video capture card. Any graphical data collected in the field inspection are processed by use of the video capture, scanning, and image editing techniques. Automatic work orders are generated from deficient bridge elements specified in the inspection reports. Since the completion of the project five FDOT districts have implemented the automated system. Consequently the time spent producing the final report was substantially reduced, and inspectors were able to devote more time to performing field structural inspector to help ensure the safety and welfare of the public.

As published previously (*1*) a computer-automated system was developed for the purpose of creating a cost-effective bridge inspection program for the Florida Department of Transportation (FDOT). This preliminary system was developed for fixed bridges only, which used FDOT Inspection Forms A, B, and C. The recently completed package includes fixed, culvert, and movable bridges, an additional Form D, and an automated work order system that replaces Form E, formerly entitled Methods and Quantities. The complete package consists of 25 developed programs and five commercially available software programs (see Figures 1, 6, 7, and 8). The system can offer considerable time savings for inspectors while they are performing office work. With this system bridge inspection reports are standardized and work orders are effectively scheduled by the personnel involved.

Bridge inspection procedures require field and office work; therefore, the computer-automated system is divided into two components, referred to as the *field* and *office systems*. The field system uses a notebook computer to run field acquisition pro-

grams, whereas the office system uses a desktop computer, a scanner, and a video capture card to process the field data and to produce the final inspection report. Office programs were developed to work in conjunction with commercially available software to process field data and work orders. Field data such as video pictures and sketches can be digitized through a video capture card and scanner and can be printed in the inspection reports. The field and office bridge inspection procedures performed with the automated system and the results from a trial implementation by several district inspectors are discussed in the following sections.

FIELD INSPECTION PROCEDURES

Field inspections performed with the developed automated system are thorough, accurate, and efficiently stored. The previous (old) bridge inspection report is downloaded to the field notebook computer (GRiDPAD) before the inspection routine is performed. Old inspection data are available for comparison and input if desired. The field system gives the inspector the opportunity to perform an inspection of a culvert, fixed, or movable bridge. The inspection routines are initiated with the use of a bat file and a program named M.BAT and FIELD.EXE (Figure 1). M.BAT checks for the field computer configuration and then loads FIELD.EXE, which displays three choices on the notebook computer. The choices are C, F, or M. The acquisition programs for culvert, fixed, or movable structures are invoked by tapping the corresponding letter on the computer screen. The inspection routines developed for each of these inspections collects the data that will be used to generate
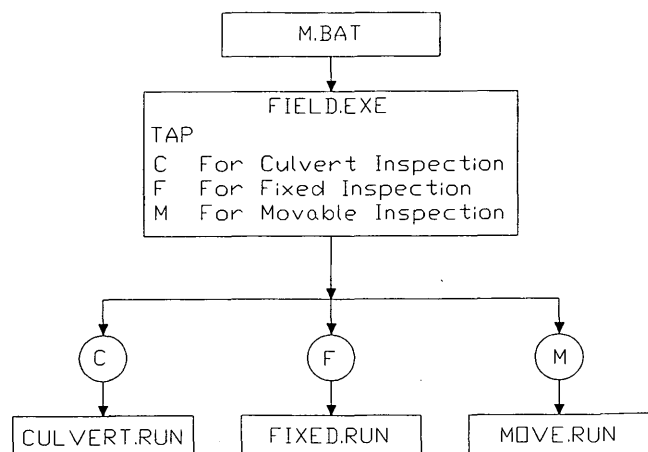

FIGURE 1 Flow chart of field system programs.

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FDOT inspection reports on the office system. The field data are also used to produce work orders for bridge deficiencies cited as requiring service. FDOT uses inspection reports to fulfill the historical data requirements established by the National Bridge Inspection Standard. The report sections that are automated with the computer automated system are Forms A, B, C, and D. Form A comprises (a) a Cover Sheet (Report Identification) and (b) a Condensed Inspection Report (CIR). The Cover Sheet is used to identify geographical details such as bridge location and the beginning mile marker. The Cover Sheet also lists the bridge inspectors' names with their corresponding Certified Bridge Inspection numbers. The reviewing supervisor and confirming professional engineer with signatures are also assimilated in the Cover Sheet. The CIR lists every bridge element inspected along with a corresponding numerical condition rating (NCR). The NCR is a numerical value ranging from 0 to 9 for structural elements and from 0 to 4 for nonstructural elements. For the structural rating a 9 would represent the best value and a 0 would correlate to a failure condition. NCR definitions are given in Table 1. Form B is the Comprehensive List of Deficiencies, which identifies all deficient bridge elements ascertained during the bridge inspection. Graphical images of deficient elements may accompany Form B in media such as videos, photographs, or sketches. Form C is the Evaluation of Previously Recommended Corrective Actions. The purpose of Form C is to evaluate all elements that were previously reported as deficient and that required service during the last bridge inspection. The inspector specifies whether the corrective action has been performed satisfactorily or if continued service is required. Form D is entitled Recommendations for Corrective Actions, which denotes deficient bridge elements that require repair.

The field system uses a three-step data collection procedure. Step 1 collects data for Form A and Form B, while Steps 2 and 3 collect data for Forms C and D, respectively. The acquisition program provides flexibility while performing a field inspection. The field software was developed in Pen Pal Version 1.1 (2) and incorporated pen technology for use on the electronic notebook, yet desktop computer execution is possible. The programs are made up of a series of forms that contain their own independent source code. The forms take advantage of pen objects such as buttons, radio buttons, lists, fields, and text. Program execution is event driven, which means that a pen down, pen up, or drag with the notebook pen will trigger program logic execution. The source

code pertaining to each form works in conjunction with the global code. The global code contains initiation routines and other procedures that can be "called" by any form.

All inspection reports from culvert, fixed, and movable bridges are divided into components such as the Superstructure, Substructure, Deck, Mechanical, Paint Systems, and so on. Each component has a list of bridge elements that require inspection as specified in the Bridge Management Inventory System (BMIS). For example the Deck component would contain elements related to the decking and expansion joints. The forms used in Step 1 data collection are divided into the same bridge components that appear on the FDOT inspection report. These forms display the BMIS elements that correspond to the component of interest. Figure 2 shows the Superstructure form with its accompanying elements. During a new inspection old inspection data are available for review or as input. Old NCRs are displayed in a column adjacent to the new NCRs or the NCRs from the current inspection. A series of forms works with each bridge component to assist with entering data or viewing or editing comments. An asterisk issued with an NCR denotes that a comment on that particular element will appear in Form B. When an asterisk is denoted by the inspector the acquisition programs will invoke Pen Pal forms to collect Form B data. The inspector has the ability to jump to any component of the bridge at any time while in Step 1 data collection. After all BMIS elements have been addressed, Step 1 data collection will then verify that all elements have been evaluated and that for all elements for which an asterisk was issued there is a corresponding comment in Form B. When the verification process is complete, Step 2 (Form C) data collection begins.

Step 2 data collection sequentially displays the previously recommended corrective actions and then allows the inspector to specify whether the service performed is adequate or inadequate. Two buttons are used in Form C to process a standard response, such as "Recommended corrective actions have been satisfactorily completed." If the BMIS element still requires service, a button titled "ADD TO FORM D" provides the ability to add this item to the current Form D (Recommendations for Corrective Actions) by tapping the button with the pen. An illustration of the form used to process Step 2 data collection is given in Figure 3. After all of the previously recommended corrective actions have been evaluated, Step 3 (Form D) data collection is initiated.

TABLE 1 NCR Definitions by Category

STRUCTURAL		NON-STRUCTURAL	
NCR	Description	NCR	Description
N	Not Applicable	N	Not Applicable
9	Excellent Condition	4	Good Condition
8	Very Good Condition	3	Fair Condition
7	Good Condition	2	Marginal Condition
6	Satisfactory Condition	1	Poor Condition
5	Fair Condition	–	Not Defined
4	Poor Condition	–	Not Defined
3	Serious Condition	–	Not Defined
2	Critical Condition	–	Not Defined
1	"Imminent" Failure Condition	–	Not Defined
0	Failed Condition	–	Not Defined

SUPERSTRUCTURE COMPONENTS			
BMIS NO.	**ELEMENT TITLE**	**NEW NCR**	**OLD NCR**
G12.00	SUPERSTRUCTURE OVERALL	⊔⊔⊔	⊔⊔⊔
G12.01	BEAMS/STRINGERS/GIRDERS	⊔⊔⊔	⊔⊔⊔
G12.02	FLOOR BEAMS	⊔⊔⊔	⊔⊔⊔
G12.03	MAIN GIRDERS	⊔⊔⊔	⊔⊔⊔
G12.04	SWAY BRACING	⊔⊔⊔	⊔⊔⊔
G12.05	LATERAL BRACING	⊔⊔⊔	⊔⊔⊔
G12.06	UPPER CHORD	⊔⊔⊔	⊔⊔⊔
G12.07	LOWER CHORD	⊔⊔⊔	⊔⊔⊔
G12.08	VERTICALS	⊔⊔⊔	⊔⊔⊔
G12.09	PORTALS	⊔⊔⊔	⊔⊔⊔
G12.10	MISCELLANEOUS MEMBERS	⊔⊔⊔	⊔⊔⊔
G12.11	COUNTERWEIGHT	⊔⊔⊔	⊔⊔⊔

DECK
SUBSTRUCTURE
MECHANICAL
ELECTRICAL
GENERAL
PAINT SYSTEM
CONTINUE INSPECTION

END INSPECTION   VIEW COMMENTS   EDIT GRAPHICAL DATA

FIGURE 2 Example form Superstructure used in Step 1 data collection.

Step 3 data collection processes the BMIS elements denoted as deficient in Form B. Forms are used to display each deficient element sequentially, and the inspector is given the choice of recommending or not recommending corrective action or viewing the new comment to reassess the deficiency. Figures 4 and 5 illustrate the forms used in Step 3 data collection. If the inspector selects "YES" to recommend corrective actions, the element is displayed in the form shown in Figure 5. The inspector then assigns an activity code from a specific list pertaining to the BMIS element and then estimates the number of units, such as square feet or pounds of steel. After all deficient elements have been processed, the acquisition program closes all corresponding data files, the fields are reinitiated, and the inspector is given the opportunity to quit or perform another bridge inspection.

The data obtained by the field data acquisition programs are stored as files in the notebook computer until the inspector returns to the office. Office procedures will then be performed on the desktop computer and its peripherals.

EVALUATION OF PREVIOUS CORRECTIVE ACTION

PREVIOUS CORRECTIVE ACTION:

EVALUATE CORRECTIVE ACTION: (No Corrective Action Taken)
                                (Satisfactorily Completed)

NEXT   ADD TO FORM D

FIGURE 3 Example form used in Step 2 data collection.

```
┌─────────────────────────────────────────────────────────────┐
│  ┌─────────────────────────────────────────────────────────┐ │
│  │      BRIDGE MAINTENANCE REPAIR AND REHABILITATION         │ │
│  └─────────────────────────────────────────────────────────┘ │
│  ┌─────────────────────────────────────────────────────────┐ │
│  │                                                           │ │
│  │    YOU INCLUDED THE FOLLOWING ELEMENT IN THE COMPREHENSIVE│ │
│  │    REPORT OF DEFICIENCIES:                                │ │
│  │                                                           │ │
│  │    ┌─────────────────────────────────────────────────┐   │ │
│  │    │                                                 │   │ │
│  │    └─────────────────────────────────────────────────┘   │ │
│  │                                                           │ │
│  │    DO YOU WISH TO RECOMMEND IT FOR CORRECTIVE ACTION ?    │ │
│  │                                                           │ │
│  │           ( YES )    ( NO )                               │ │
│  │              ( VIEW COMMENT )                             │ │
│  │                                                           │ │
│  └─────────────────────────────────────────────────────────┘ │
└─────────────────────────────────────────────────────────────┘
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FIGURE 4   Example form used to denote service required in Step 3 data collection.

OFFICE REPORT PROCEDURES

The office procedures are performed from a desktop computer with the office system. The programs in the office system were developed with Microsoft BASIC Version 7.0 (*3*), Jetform's JFDESIGN (*4*) for form design, and FILLERG (*5*) for form editing and printing of inspection forms. The three main functions of the office system are to (a) upload, download, edit, and print inspection reports, (b) process graphical (image) data such as photographs and video, and (c) process work orders from bridge inspection data. There is also a menu system to control the execution in each function. The three menu names are FDOT Main Menu, Image Editing Menu, and Work Order Processing Menu. The FDOT Main Menu is the main control program from which the other menus are accessed. System control is always passed back to the FDOT Main Menu.

FDOT Main Menu

All office functions are performed or accessed from the FDOT Main Menu. Figure 6 displays the flow chart for the FDOT Main Menu.

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┌─────────────────────────────────────────────────────────────┐
│  ELEMENT: ┌───────────────────────────────────────────────┐ │
│           └───────────────────────────────────────────────┘ │
│  CODE   UNIT                        ACTIVITY                 │
│  ┌──────────────────────────────────────────────────────┐   │
│  │                                                      │   │
│  │                                                      │   │
│  └──────────────────────────────────────────────────────┘   │
│  ┌──────────────────────────────────────────────────────┐   │
│  │FUNCTION CODE:                                        │   │
│  │                                                      │   │
│  │      NUMBER OF UNITS REQUIRED: L_____J             │   │
│  │   ○ STATE FORCES    ○ CONTRACT   ○ HEAVY BRIDGE CREW │   │
│  │REPAIR DESCRIPTION:                                   │   │
│  │  ─────────────────────────────────────────────      │   │
│  │  ─────────────────────────────────────────────      │   │
│  │  ─────────────────────────────────────────────      │   │
│  │  ─────────────────────────────────────────────      │   │
│  │  ─────────────────────────────────────────────      │   │
│  └──────────────────────────────────────────────────────┘   │
│     ( DELETE )   ( OOPS )   ( NEXT )   ( VIEW COMMENT )       │
└─────────────────────────────────────────────────────────────┘
```

FIGURE 5   Example form used to assign corrective actions in Step 3 data collection.
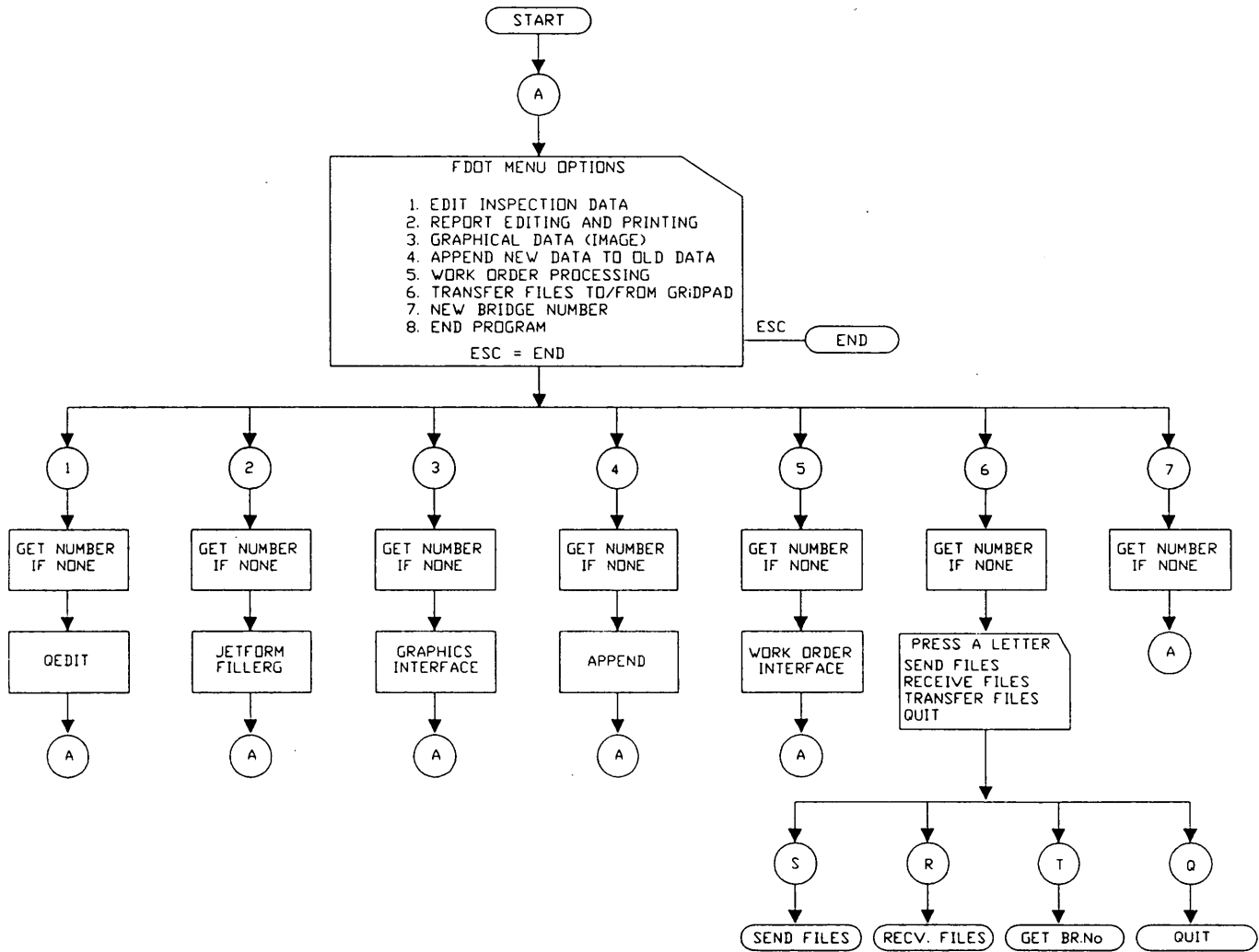
FIGURE 6 Flow chart for FDOT Main Menu.

Data Transfer

Option 6 of the FDOT Main Menu is used to perform data transfers. Data transfers consist of downloading the previous (old) inspection reports to the field notebook computer or uploading new inspection reports to the desktop office computer from the field computer. Field data are stored in a series of delimited files that must be recompiled into Jetform files for processing of the inspection report. The conversion of the delimited files to Jetform files and Jetform files back to delimited files takes place during the transfer and is accomplished with the use of two programs that were developed. The programs that were developed provide the ability to combine multistructure inspections into one standard report. Multistructure inspections occur when a bridge comprises a fixed and a movable span. If these spans are inspected concurrently they must be assimilated into one standard report. The bridge number is used to designate which files are to be transferred.

Text Editing, Inspection Report Form Filling, and Printing

The FDOT Main Menu provides two options for editing data. Option 1, "Edit Inspection Data," in the Main Menu is QEdit

(6). When this option is selected the raw data used in the inspection report are displayed as ASCII text and can be edited. This option provides a quick method for modifying inspection data and should only be used by inspectors with text editor experience. Option 2 of the Main Menu is "Report Editing and Printing." This option provides a full-screen what you see is what you get (WYSIWYG) environment, using Jetform's FILLERG application. The selected bridge's inspection report is displayed exactly as it will be printed. From Option 1 the inspector can edit and print the final inspection report.

Image Editing Menu

The Image Editing Menu is used to coordinate the use of the developed programs with the commercial programs to perform functions such as digitizing, annotating, and printing images of deficient bridge elements. Two DOS batch programs are used along with the menu that was developed in Microsoft BASIC 7.0. Figure 7 presents the flow chart for the Image Editing Menu. This menu is accessed from and returns control back to the FDOT Main Menu.
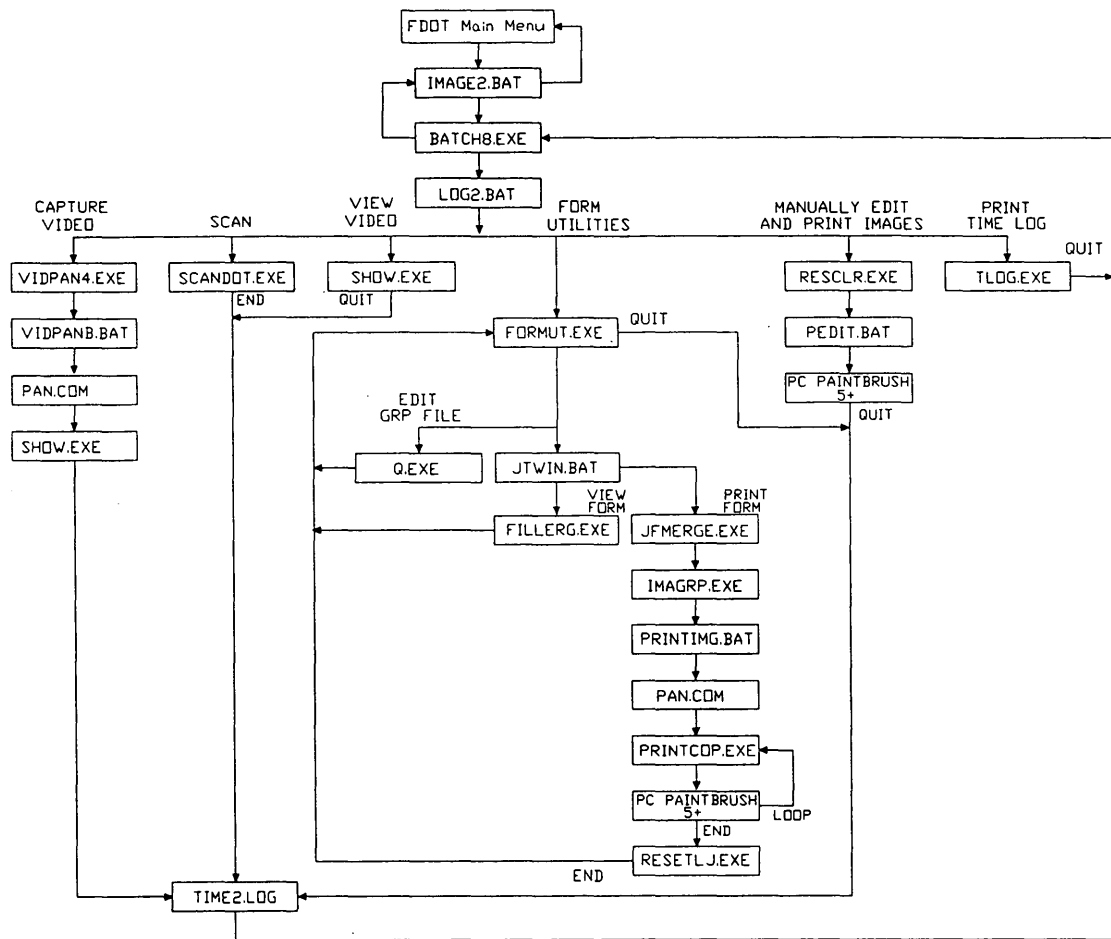
FIGURE 7 Flow chart for Image Editing Menu.

Capturing and Converting Video Images

Images recorded on video are captured and converted to a digital format with automated software that controls the capture process and a Jovian Super VIA Video Input Adapter. The captured images are stored as .PCX files with 640-by-480 color resolution. These images can be manipulated, displayed, and printed with the inspection report from the Image Editing Menu.

Scanning Photos and Sketches

The scanning process is automated with the developed program called ScanDOT. ScanDOT reads graphical text stored with the inspection files and sequentially displays descriptions for each image to be scanned. The inspector places the corresponding picture or sketch on the scanner and then invokes the scan by pressing the "S" key.

Video Data Base of Structures

The images stored in the desktop computer can be displayed on a VGA monitor by using SHOW.EXE, which is a utility program

provided with the Jovian Super VIA Adapter. When the Video Data Base of Structures option is selected from the Image Editing Menu, the inspector can view all captured images for a specified bridge.

Image Form Utilities

The Image Form Utilities selection in the Image Editing Menu provides the ability to edit and print graphical images and annotative text. The first option in the utilities menu is "View Image Forms," which allows viewing of image forms as they will actually be printed with FILLERG. The second option, "Edit Image Data," facilitates the editing of the graphical text that pertains to the images (annotation). The third option, "Print Image Forms," prints out the images with text on the designated forms.

Manually Editing and Printing Images

The Manually Editing and Printing Images option automatically loads Zsoft's PC Paintbrush Plus (7), which is used to manually edit and print photographs, sketches, and video images. The program has many sophisticated image enhancement functions, if required, and is easy to use.

Work Order Processing Menu

During the development of the system it became increasingly more important to incorporate an automated work order system. FDOT officials mandated the development of a computer-automated work order system following a tragic incident that apparently involved a deficient element that was discovered during bridge inspection but that was not communicated effectively to maintenance personnel. In response to this mandate the Work Order Processing Menu was developed.

The Work Order Processing Menu is accessed by the FDOT Main Menu. When the inspector completes all work order tasks program control is returned to the FDOT Main Menu. The Work Order Menu was written in Microsoft BASIC 7.0. The functions available on the menu are Generate Work Orders, Edit and Print Work Orders, Desktop to Mainframe Format, Mainframe to Desktop Format, Select a Different Bridge, and Exit. Deficient elements requiring corrective actions are quickly communicated to maintenance personnel by using this system. Once the work orders are uploaded to the mainframe they are distributed to the proper maintenance personnel via computer communications in a timely manner, and prompt responses are mandated. Therefore management is assisted with scheduling the time of delivery of resources and tracking supplies. Efficient communication is essential in work order processing to prevent time delays for service. These delays can cause tragic incidents because of unrepaired bridge elements. Figure 8 presents the flow chart for the Work Order Processing Menu.

Generate Work Orders

Generate Work Orders is used to create a work order for every deficient element requiring corrective action. Inspection reports provide the initial input for creating work orders. The key work order fields used for processing are set to a default value if the input does not exist in the inspection report.

Editing and Printing Work Orders

When work order generation is complete, the Edit/Print Work Orders option of the Work Order Processing Menu is used for editing, printing, or both. Selection of this option invokes Jetform's FILLERG, which fills the work order forms with the generated data and provides editing and printing capabilities.

Desktop to Mainframe Format

While on the desktop computer work orders are in a special Jetform data format that uses specific field identifiers. This data arrangement conflicts with the mainframe input processing requirements, which necessitate the use of ASCII files with field delimiters. The Desktop to Mainframe Format selection is used to compile work order data into a format suitable for mainframe processing.

Mainframe to Desktop Format

After work orders have been processed on the mainframe, the Mainframe to Desktop Format option is used to extract information from the mainframe-delimited file and arrange it in the special Jetform data format. After the updated work orders are compiled into the Jetform format they can be edited and printed from the desktop computer exactly as performed after generating the work orders initially.
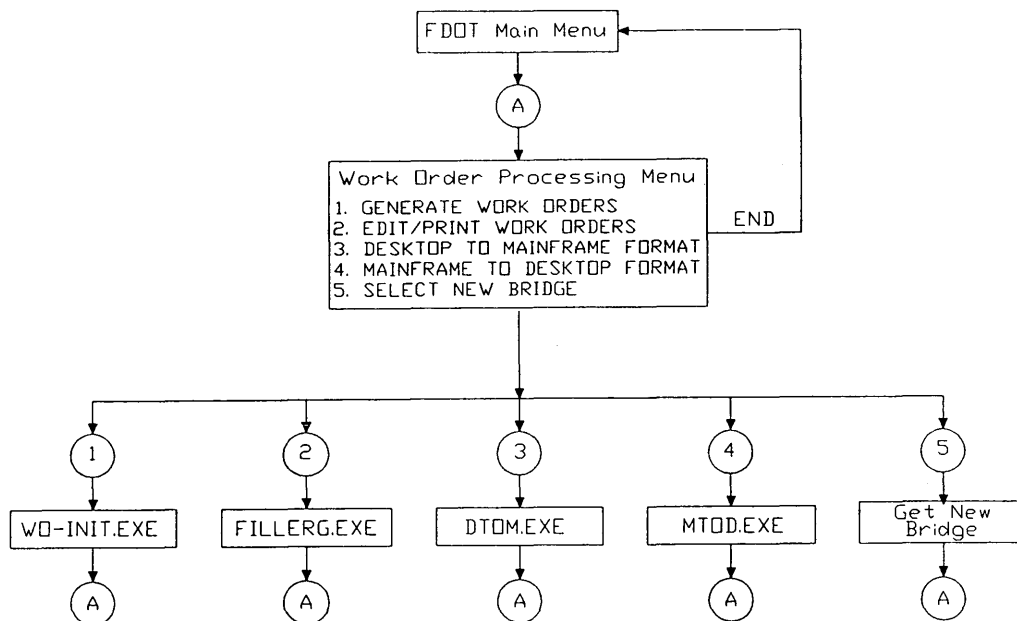

FIGURE 8   Flow chart for Work Order Processing Menu.

RESULTS AND CONCLUSIONS

The computer-automated bridge inspection process has been tested and implemented in several FDOT districts. The time spent on field procedures was not significantly different from that by the conventional method; however, a substantial reduction in the time required for office procedures was realized. A typical final inspection report can be produced in 10 to 30 min by the automated procedure. The conventional procedure required the inspectors to rewrite and rearrange field notes in a manner suitable for report compilation. The conventional method of producing a final report can take from 45 min to several weeks. The significant time savings realized by using the computer-automated system in the office enables inspectors to devote more time to performing field inspections to ensure the safety of every bridge component.

The benefits of using the computer-automated system include but are not limited to the following:

1. Thorough and accurate field inspections are performed.
2. Inspection reports are efficiently produced with a consistent format.
3. Inspection data are stored efficiently as computer disk files.
4. Deficient bridge elements requiring service are recorded, and the need for service is communicated to maintenance personnel in a timely manner.
5. Work order data are accessible on the FDOT's BMIS and Maintenance Management System.

6. Inspection reports can be transferred between offices electronically.

ACKNOWLEDGMENTS

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