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Automated Mapping System Implementation

Placing the system into the production environment provides an effective method for collection, storage and retrieval of large volumes of map data, and offers the engineer flexibility for manipulation of the map data heretofore unavailable.

Introduction

THE TEXAS Highway Department began using aerial photography for preliminary engineering planning surveys around 1930 with most of the photographs being obtained from the U. S. Department of Agriculture. Sophistication of photogrammetric instruments enabled accurate engineering data to be extracted from the vast amount of information visible in the aerial photographs, and subsequent requests for this information

the existing Computer and Reproduction Sections to form the new Division of Automation in 1965, automated techniques were being utilized already in film processing, ground control, aerotriangulation and photogrammetric earthwork measurements.

Compilation of map sheets has always been predominantly a manual operation with the map being drawn on a stable-base manuscript by the stereoplotter operator, the penciled lines scribed by a draftsman and a

ABSTRACT: *Manual methods of photogrammetric map compilation and graphics for highway engineering are known to have objectionable limitations including the allocation of manpower resources and inflexibility of the maps for automated manipulation for data analysis. The Automated Mapping System as developed and implemented into the production environment of the Texas Highway Department offers the engineer new dimensions and concepts for graphics presentation and/or data manipulation heretofore unavailable from manually produced maps. Implementation of the Automated Mapping System was designed for modular conversion of existing individual stereoplotter units to permit progressive implementation minimizing the interruption of existing map schedule commitments.*

prompted the formation of the Photogrammetry Section within the Highway Design Division in 1957. The Department obtained its initial stereoplotter in early 1958.

Increasing acceptance of this highway engineering tool of photogrammetry prompted continued expansion of equipment and personnel. Highway engineers became increasingly more automation-oriented and consequently the Department's existing photogrammetric systems were enhanced to accommodate these demands. When the Photogrammetry Section was combined with

film positive reproduced from the base manuscript. Although this method of map compilation offers numerous advantages over field methods, many objectionable limitations should be eliminated or minimized.

Perhaps the most serious limitation to manually produced maps is in their inflexibility. The tremendous amount of detail that can be captured very accurately from an aerial photograph for a manually produced map is not available for any type of automated manipulation or analysis. Another limitation of manually produced maps is in the alloca-

tion of manpower resources. Photogrammetric map cartography requires considerable manpower and is usually in an environment of fluctuating workloads, thus affecting time schedules, sheet quality and certainly the overall economics of mapping. Therefore, a more flexible system for collecting, storing, retrieving and presenting map graphics was needed to improve planning, coordination and management of the information, emphasizing the use of the Department's existing photogrammetric equipment.

IMPLEMENTATION

The overall objective for implementing an Automated Mapping System into the production environment of the Texas Highway Department was to provide an effective method for collection, storage, manipulation and retrieval of large volumes of map data. Existing Automated Mapping systems were reviewed and evaluated and, although these systems yielded some suggestions for implementation of a Texas Highway Department system, they were dedicated to a different map production environment and made use of equipment not readily available to the Department.

The Department had already developed automated capabilities for processing the preliminary data necessary for map production as follows:

- The aerial film obtained using Wild RC-8 aerial cameras is processed by GAF Transflo automated processors.
- Photographic prints and diapositive plates are prepared using a LogEtronic Mark III printer.
- Primary ground control is obtained using various types of electronic distance measuring units with the traverse data processed and adjusted in the computer by specialized software programs.
- Supplemental mapping control is accomplished through aerotriangulation techniques for strip and block photography adjustments. The desired coordinate readouts for the required control points are obtained through computer programming dedicated to this purpose.
- Map sheet layout work is semi-automated through the use of digital readout equipment.

The next step in the development of an Automated Mapping System was to convert map compilation and drafting from the standard graphics imagery presentation to numerical imagery for computer processing and map data manipulation. This conversion would represent a significant departure from previous map-oriented information system approaches which have been primarily dedicated to yield limited types of data for specific operational applications.

EQUIPMENT

Inasmuch as the Texas Highway Department has 15 projection type stereoplotters in operation and five of these stereoplotters had already been converted for automation to yield Y-Z numerical values for terrain analysis (cross-sections for earthwork measurements), emphasis was directed toward modifying the remaining units for automated map compilation. Preliminary investigations using an existing stereoplotter with the Y-Z digital output modified to yield X-Y data demonstrated that numerical information could successfully be captured with this type equipment configuration.

The Automated Mapping System developed for implementation into the production environment of the Texas Highway Department was designed as a modular conversion of existing individual stereoplotter units to permit progressive implementation that could readily be adapted to a total automated system when desired. This conversion scheme minimized the interruption of existing schedule commitments and allowed ample time for operator familiarization and training.

Using the aforementioned modular conversion program the Department has modified six of ten map compilation stereoplotter units for automated map production with each unit containing an equipment configuration as shown in Figure 1. Figures 2 through 7 further detail the individual components of the digital and plotting equipment configurations.

SOFTWARE

The Texas Highway Department had made some progress in the development of computer programs for automating map graphics through in-house research. The objective of these earlier efforts had been to produce graphics in order to permit studying procedures for digitizing map data and to determine if the stereoplotter operators could successfully capture and identify the required data. Crude preliminary plots from this digitized data satisfactorily demonstrated that both of these requirements could be met.

This preliminary software package was dedicated to testing graphics output and allowed no data manipulation. Expansion of this software package has allowed the further testing of map plots and introduced new capabilities into the software package to permit edit, data storage and manipulation
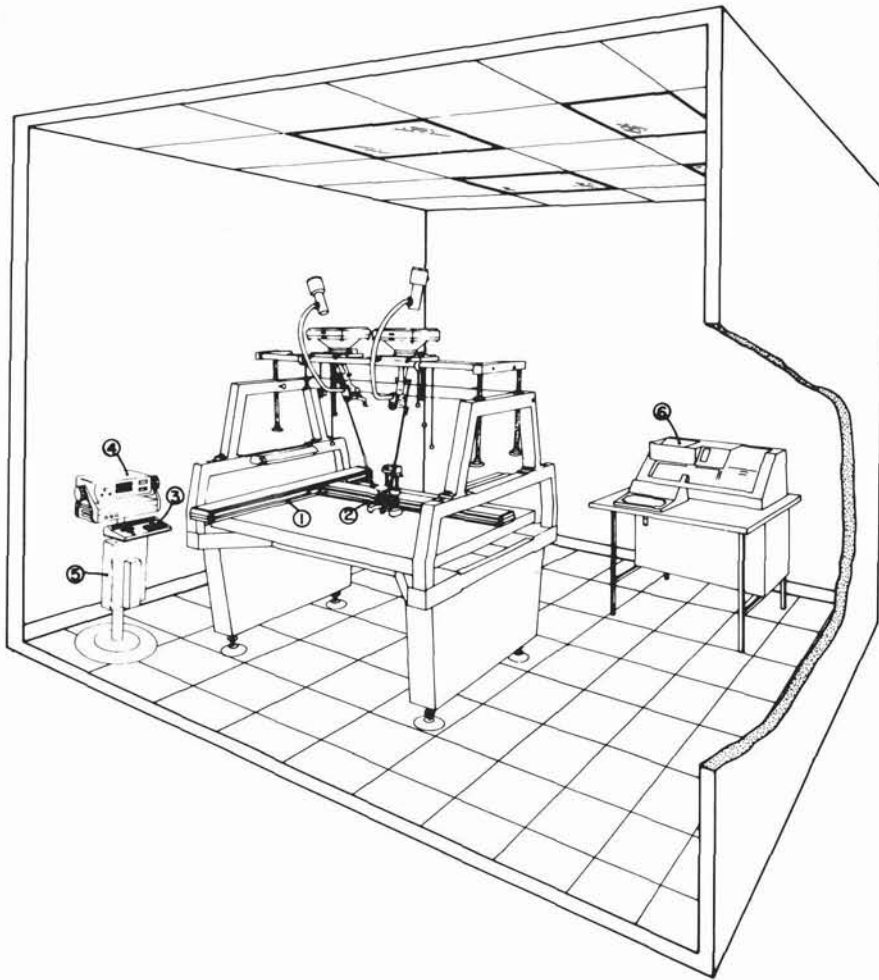
FIG. 1. Stereoplotter Unit Converted for Automated Data Collection. (1) X-Y Coordinate Arm Assembly. (2) Tracing able Recording Interface. (3) Remote Data Control Switch System. (4) Electronic Data Display. (5) Recording Interface. (6) IBM 029 Keypunch.

and also optimized the graphics generation computations.

This expanded Texas Automated Plotting System (TAPS) software package was designed and developed to perform the following functions:

■ *Edit and Special Routines.* The digitized data are initially subjected to an edit analysis for the detection of various stereoplotter operator input errors such as duplications, closure gaps, squaring techniques, insufficient data, improper coding & omissions. These errors are noted and corrected within the edit procedure. Also during the edit routine a coordinate transformation adjustment occurs wherein the X-Y machine coordinate values of the various map features are converted to project ground coordinates. Special sub-routines within the TAPS software package are designed to op-

timize selective line work computations and further reduce the computer time that is required to generate a plot tape. These subroutines include a procedure for computing vegetation boundaries, one for defining the double lines required for curbs and railroad tracks and one for simplifying computations required for locating simple and complex curves.

■ *Storage.* The project data-base file is constructed from the edited data and stored on a disk. The data file is readily accessible for manipulation such as the generation of a plot tape for obtaining a graphic presentation of map features.

■ *Manipulation.* The project data base collected by translating photographic imagery to a series of numerics, edited and optimized by the computer software programming and stored on a disk file is readily available to yield a variety of engineering
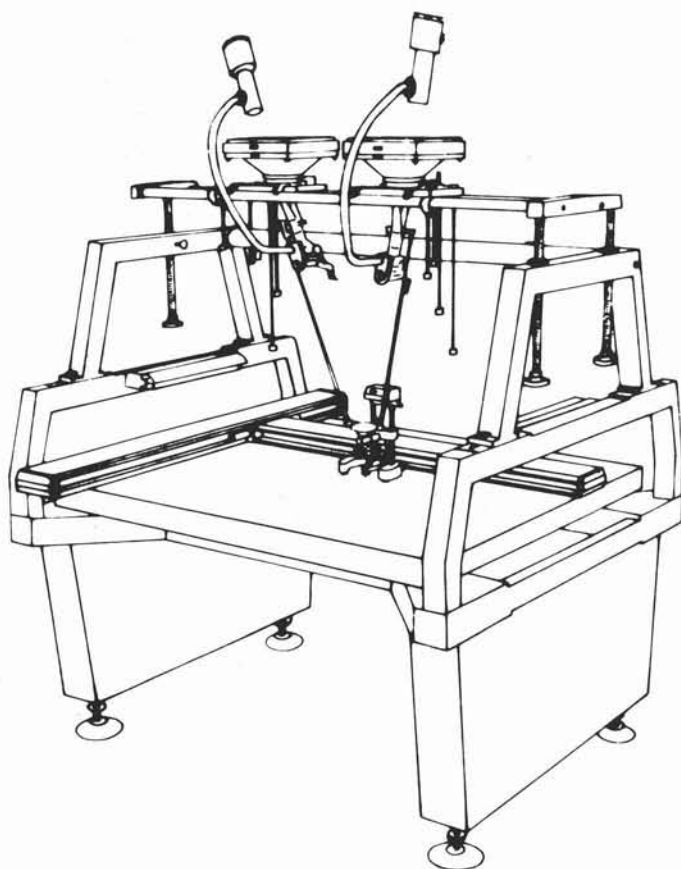
FIG. 2.   Standard Projection-type stereoplotter with X-Y Coordinate
Arm Assembly. The X-Y coordinate arm assembly is designed for
high accuracy positioning anywhere on the stereoplotter drawing
surface to 0.001 inch per foot of arm length. The arms have rack and
pinion activated non-contacting rotary optical encoders. The stereo-
plotter tracing table is attached to the X axis arm. The dimensions of
the arms are customized to utilize the maximum amount of drawing
surface afforded by each stereoplotter and each arm is equipped with
fine adjustment motion for precise positioning.

management and planning functions. Man-
ipulative capabilities include total
graphics, selective graphics yielding land
use information and classification levels,
variable scale formats for transportation
route analyses, perimeter and area compu-
tations and environmental resources for
corridor access studies.

The software functions heretofore outlined
are dedicated to the conversion of map data to
a computer format for the manipulation of the
desired output as shown in Figure 8. Addi-
tional software techniques will be designed
and developed as the user needs are iden-
tified.

COMPARISON OF MAPPING PROCEDURES

The production requirements of a mapping
project to be prepared using the Automated

Mapping System are very similar to the re-
quirements of a project using manual photo-
grammetric procedures with respect to
ground control, aerial photography and aero-
triangulation. Beyond the aerotriangulation
step, however, the procedures required to
complete the map differ considerably and a
brief description of the two methods is out-
lined as follows:

MANUSCRIPT PREPARATION

Manual. Map compilation using manual
techniques requires the preparation of a map
manuscript on a stable-base scribecoat mate-
rial. All the ground control points and sup-
plemental control points obtained by aero-
triangulation are plotted on the manuscript
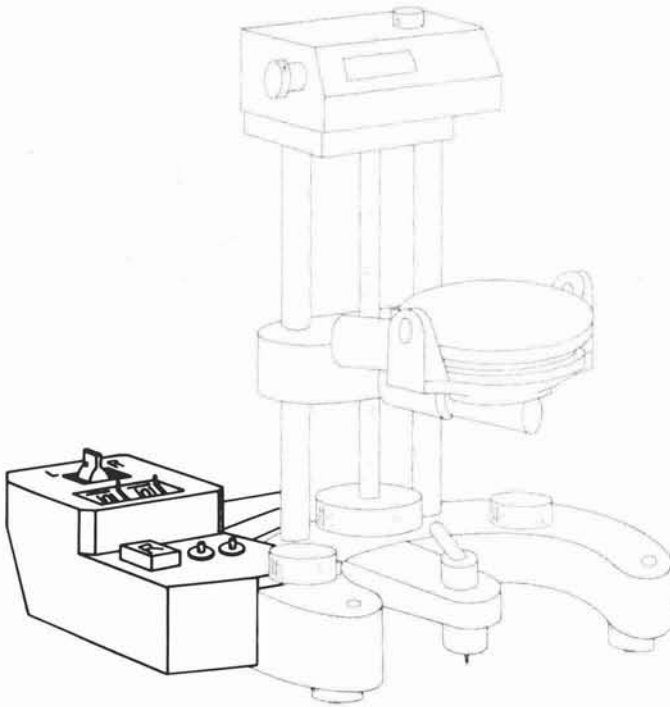and oriented to a coordinate grid system.

FIG. 3. Stereoplotter Tracing Table Recording Interface is a mechanical attachment to the X axis coordinate arm and contains two 0-9 manual data switches; one three-position switch; and the record, the final record and clear buttons. The two 0-9 manual data switches are used to enter the identification codes of the features being digitized. This enables the data to be entered for manipulation through routine software programs. The three positional switch allows the operator to enter the direction the stereo model will be tied to the adjacent stereomodel and the features that will be included in the tie. The record button enters each set of X-Y coordinate data for the feature being digitized; and depression of the final record button enters the final X-Y coordinates for the feature and releases the card.

Sheet lengths and widths are also noted on the base manuscript.

Automated. With automated techniques the stereoplotter operator is furnished a film positive sheet with the stereomodel's principal points plotted on it. This base sheet is furnished to permit "rough" scaling. The actual precision scaling is done in the computer using software routines similar to those used in the aerotriangulation solution.

MAP COMPILATION

Manual. After the projected photographic control points are adjusted to fit the control points as plotted on the map manuscript, the stereomodel is ready for compilation. This procedure is accomplished by optically transferring the photographic imagery to the map manuscript using the stereoplotter tracing table. This line work is then intensified by the operator.

Automated. The stereomodel is "roughly" scaled to fit the control points plotted on the film positive base sheet. The project request number and model numbers (constant data) are set for entry onto the punch cards using the remote data switch system described in Figure 4. This constant data information is automatically entered at the beginning of each card when the initial X-Y coordinate values for that card are recorded. The model is now ready for "compilation." Initially the operator will digitize the model principal points and control points to establish the scale factor which is determined from interaction with the Department's aerotriangulation adjustment program. The operator then proceeds to transfer the photographic imagery into a numerical "manuscript" using feature codes. The recorded X-Y coordinate positions are machine values that will be converted to project coordinates in the com-
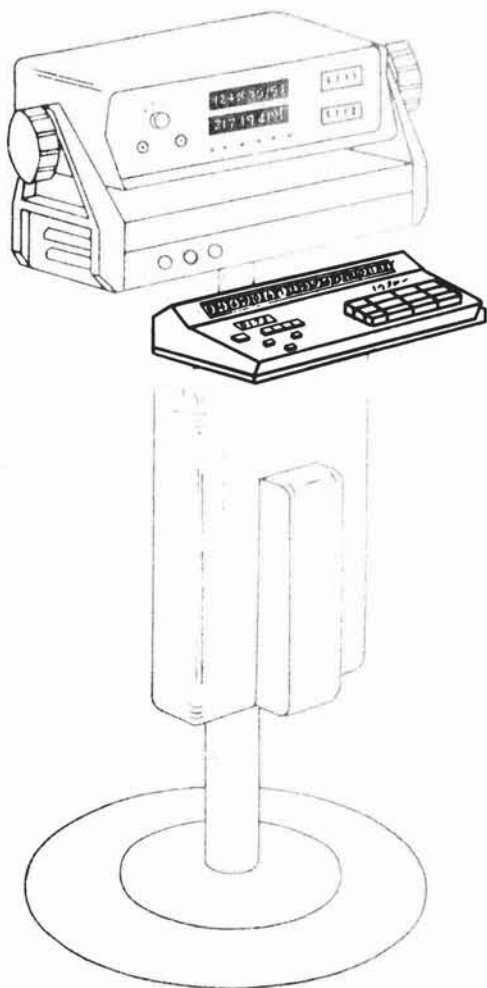
FIG. 4.   The remote data control console consists of 17 manual switches for entering constant and variable data. The constant data includes such information as accounting information, model identification and sheet numbers. Variable data could include any code identifier that would permit later accessing of the computer stored data. The constant data setting remains the same throughout the model digitizing operation and is automatically added to each punch card.

FIG. 5.   The data display console receives X-Y positional data as measured by the floating mark of the stereoplotter tracing table and transmitted from the coordinate assembly arm. The display unit consists of two axis displays with each axis having five numerical digits, a floating decimal indicator, plus and minus signs, and X or Y indicators. The five digits of each axis are displayed by bi-directional Light Emitting Diode accumulative counters. Each decade of both the X and Y display permits random presetting to any desired number. The console allows complete variable scale selection which is independent in eaxh axis. The scale factors are selectable for each axis through five thumb-wheel switches. In addition to X-Y coordinate recording, the console is capable of computing the area of any dimensional shape and registering the resultant area in the Y axis display.

puter during the edit routine. The sequence of feature digitizing is determined by operator convenience and imagery transfer efficiencies. Approximately the same amount of time is required to digitize the stereomodel data as is required to draw the imagery uing manual techniques.

By using the various feature codes to enter the planimetric features, later automated manipulation and data analyses are possible. Upon completion of digitizing all planimetric information visible on the aerial photo-
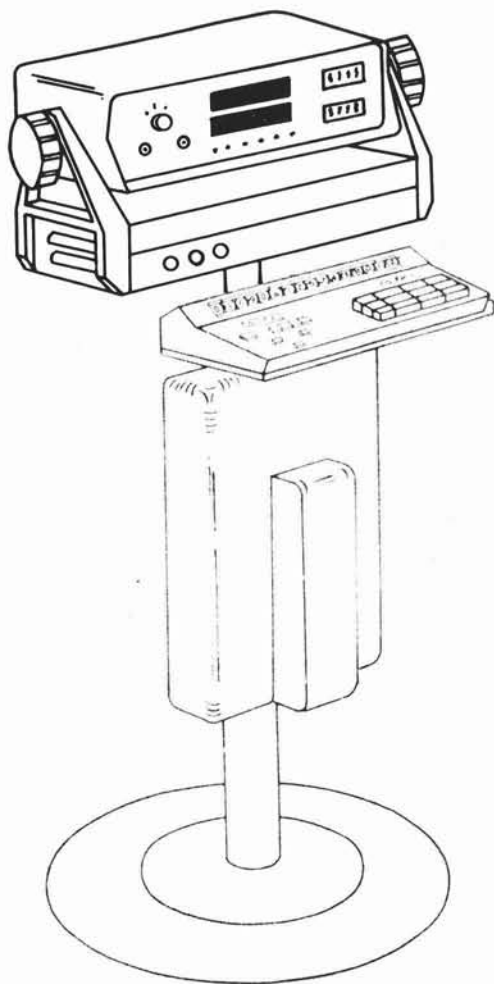
graphs, the model tie data are entered using the remote data switch system thus insuring a smooth adjustment between adjacent models.
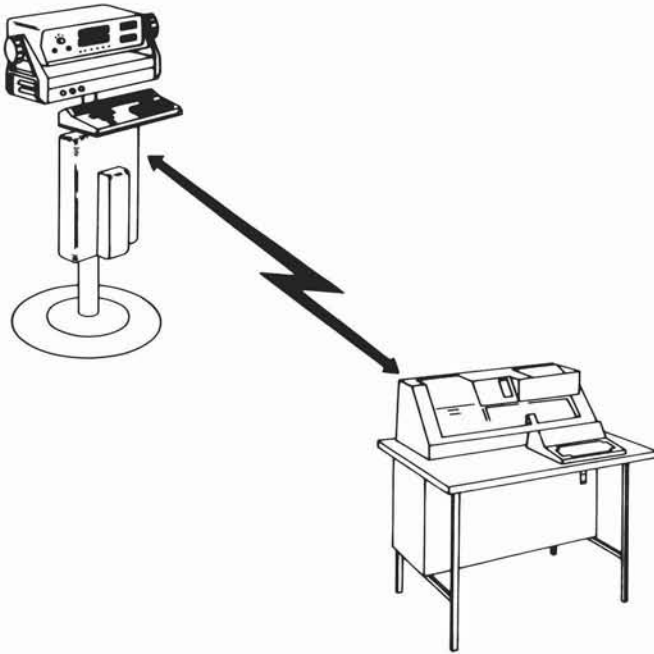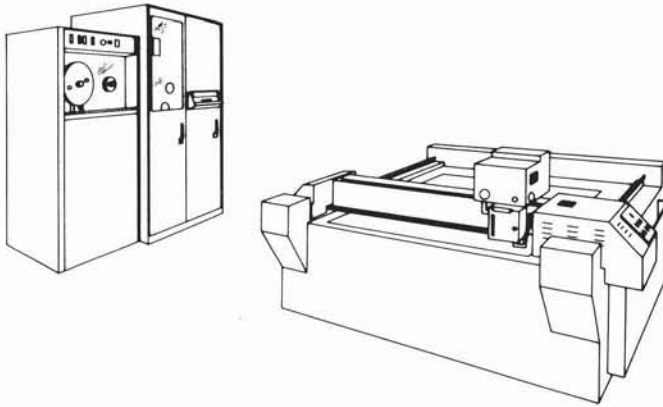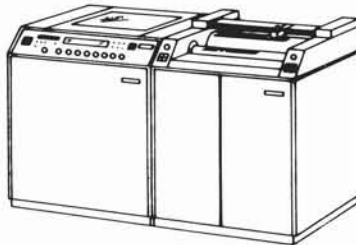
FIG. 6.   The recording interface and IBM 029 Keypunch provide the
means for data collection in the desired card format. A patch panel is
included with the recording interface to permit card format modifica-
tions.

Gerber Model 32 Precision Flat Bed Plotter

CalComp 1136 Drum Plotter
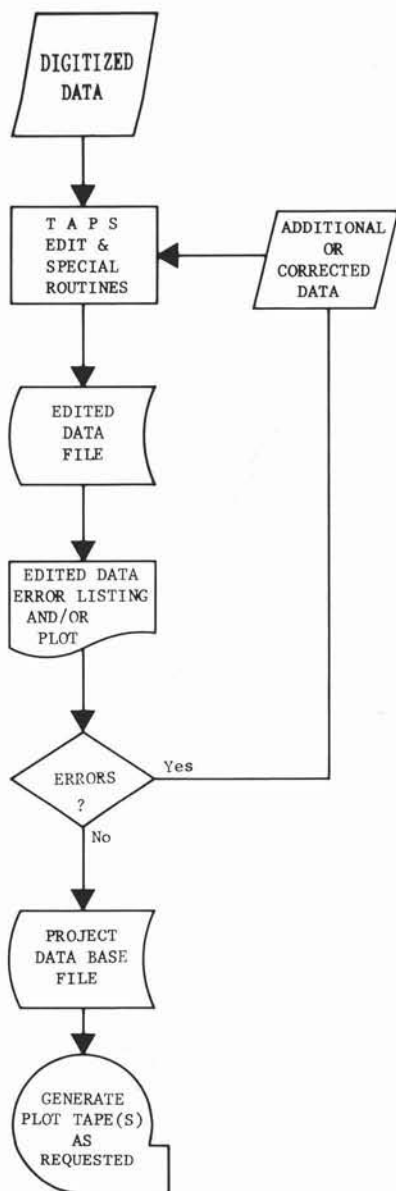FIG. 7.   Digital Plotters Used For Graphic Presentations.

FIG. 8.   Texas Automated Plotting System (TAPS) Software.

EDIT

Manual. The completed map manuscript is edited to check for omissions and obvious blunders by the stereo operator using aerial photographs identical to the diapositive plates used in the stereoplotter. This edit check is accomplished while the stereomodel remains set up in the machine. Corrections are made during this initial orientation to minimize reset expenses.

Automated. With the present equipment configuration, the digitized data which have been collected on punch cards are processed through the Automated Map System software on one of the Department's two IBM 370 computers, wherein certain edit processes take place as described previously under "Software." During this edit run, blunders are detected and adjusted, machine X-Y coordinates are converted to project X-Y coordinates and a plot tape is generated. The plot tape is then loaded onto the Department's CalComp 1136 drum plotter to produce an edit plot. This edit map from the CalComp 1136 plotter is drawn approximately 50 times faster than the map information can be digitized by the stereo operator. Minor discrepancies may be corrected on the edit sheet if no additional plots will be required or deferred for correction on the final sheet. Some major discrepancies require correcting the card data and building a new plot tape with an additional computer run.

GRAPHICS

Manual. The map manuscript as drawn and edited by the stereoplotter operator is given to the Cartography Section for further processing. This section completes the manuscript by scribing the stereo operator's line work. The scribed manuscript is then copied by standard reproduction techniques to obtain a film positive. This scribing technique offers some flexibility as exemplified by the fact that a film positive of the planimetric data can be obtained prior to scribing the elevation data for the composite map. The scribed manuscript is retained for future reference to the project.

Automated. If no significant errors are present, the plot tape generated for use in the edit procedure is also used to generate the final graphics on a CalComp 1136 drum plotter or a precision flatbed plotter. (The Department does not own a flatbed plotter at the present time. These plots are obtained through a Service Center.) Frequently the final graphics output is obtained directly from the CalComp 1136 drum plotter as many engineering applications do not require the precision line work and superior accuracies available from a flatbed plotter. If the CalComp 1136 is to be used for the final output, the plot is immediately photographically reproduced onto a film positive to minimize scale deficiencies due to paper instability.

Engineering map graphics requiring superior accuracies and line quality are obtained on a precision Gerber 1232 flatbed plotting system with an optical exposure head. The optical head offers excellent line quality and line weights and also has the abil-
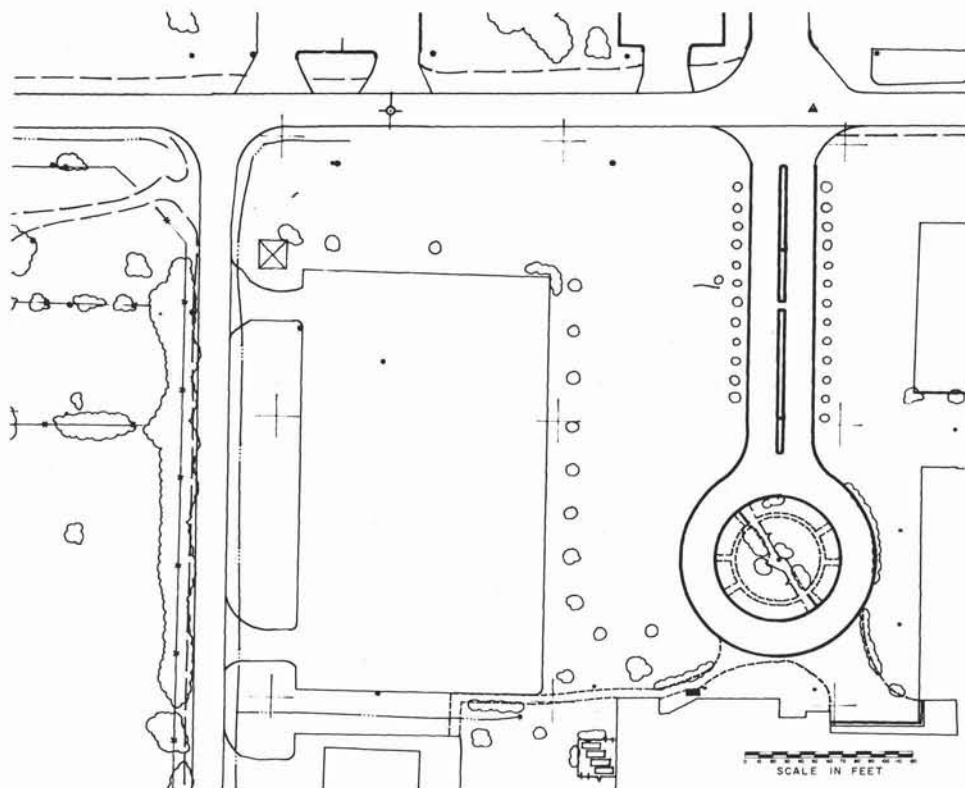
FIG. 9.   100 feet-per-inch Plot, Plotted on CalComp 1136 Drum Plotter.

ity to "flash" symbols for various planimetric features such as manholes, poles and guard posts. Graphics obtained from the flatbed plotter are drawn directly on a film positive.

Graphics from either plotter can be obtained at various scales and line weights.

Figure 9 is a typical output from a CalComp 1136 drum plotter; Figure 10 from a Gerber 32 flatbed plotter.

APPLICATIONS OF AUTOMATED MAPPING

Implementation of this Automated Mapping System offers the engineer new dimensions and concepts for graphic presentations and/or data manipulation heretofore unavailable in manually produced maps. Through digitizing methodology and sophisticated computer software routines, the imagery extracted from the aerial photography is deposited into a "data bank" (project file) for use in multi-disciplinary engineering management applications. Examples of how this data may be manipulated and presented are as follows:

Total Map Graphics. The engineer can obtain a photogrammetric map containing all planimetric and topographic features extracted from the aerial photograph similar to maps heretofore

obtained using manual photogrammetric techniques.

Selective Map Graphics. Differential levels of management information can be extracted from the "data bank" project file. These selective graphics might include separate maps showing only the transportation networks, recreation areas, buildings, utilities or any other classification of land use or combinations of classifications.

Selective Area Graphics. Specific areas can be extracted from the project file and plotted without requiring a plot of the entire area. This "windowing" feature will be very useful to the traffic engineer for extracting selective interchanges for signalization studies and design, and to the safety engineer for accident site evaluations.

Additions and Deletions. The project file can be accessed to update land use applications as new subdivisions, parks, transportation routes or industrial changes occur.

Differential Scales. The system offers the engineer the flexibility of selecting the scale of the graphic presentations within the accuracies as dictated by the photographic scale at the point of data entry. Several areas from the same project file can be obtained at varying scales.

Data Analysis. The engineer will be able to analyze environmental and economic problems
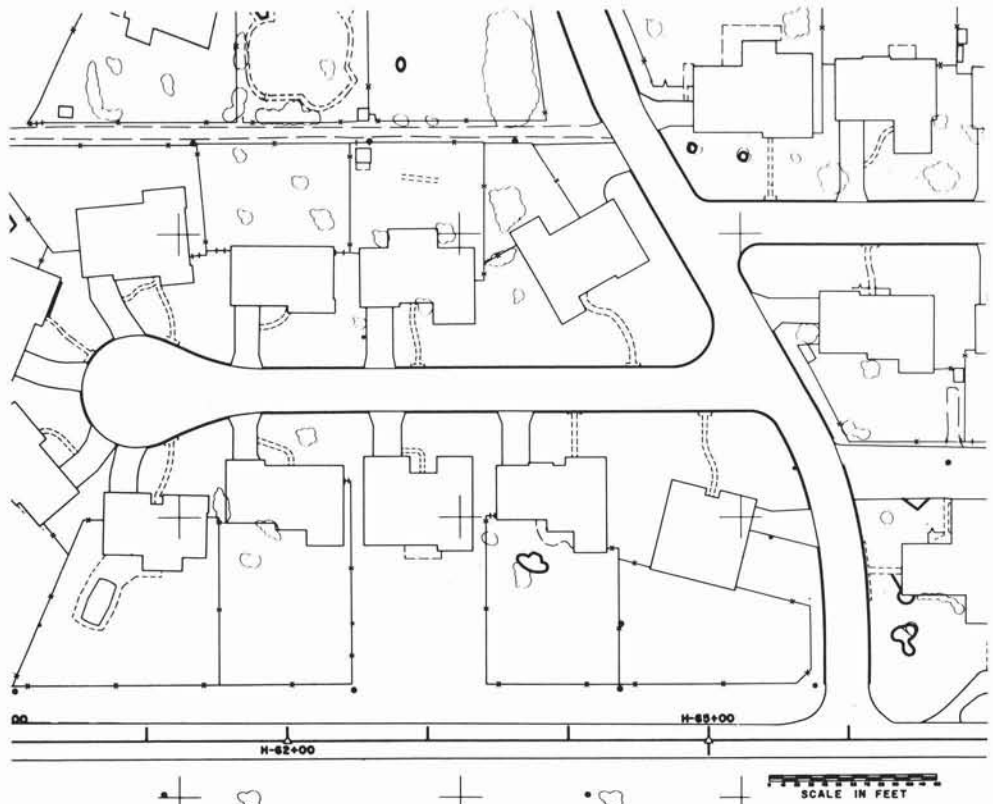
Fig. 10.   100 feet-per-inch Plot, Plotted on Gerber Model 32 Precision Flat Bed Plotter.

through combining the selective areas and feature uses. This would display a certain area, the type of improvements and transportation routes available.

These are only a few examples of how the stored data can be manipulated. The implementation of this system opens the possibility of developing capabilities that will permit engineers and managers (1) to obtain information heretofore unavailable or in an undesirable form and, (2) to make decisions based on this information.

CONCLUSIONS

Implementation of the Automated Mapping System into the production environment of the Texas Highway Department provides an effective method for collection, storage and retrieval of large volumes of map data, and offers the engineer flexibility for automated manipulation of the map data heretofore unavailable.

The cost involved in obtaining map data using automated methodology is comparable to the cost of maps produced using manual techniques. The added expenses of equipment depreciation for the digitizing accessories, computer time, editing and precision

plotting are offset by the substantial reduction in the number of man hours required to complete the job manually.

Attempting to compare the economics of an Automated Mapping System to conventional mapping techniques is similar to comparing photogrammetric mapping to conventional field mapping. Appraisal values for the advanced methods depend on the resourcefulness of the user in performing the variety of manipulative processes available.

Graphics produced by automated manipulation of map data offer new concepts and dimensions for presentation. These plots can be obtained at different scales, line weights and line types in a time frame much faster than an identical map manuscript can be scribed using standard cartographic techniques. This time comparison ranges from 10 times faster using a precision flatbed plotter with the optical exposure head to 50 times faster for edit plotting on the CalComp 1136 drum plotter.

The limited amount of manual drating used with automated graphics permits personnel previously restricted to drafting duties the opportunity to be trained and assigned to other production areas in the Photogram-
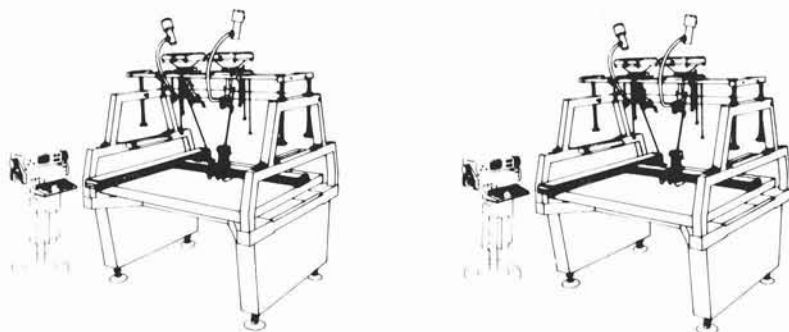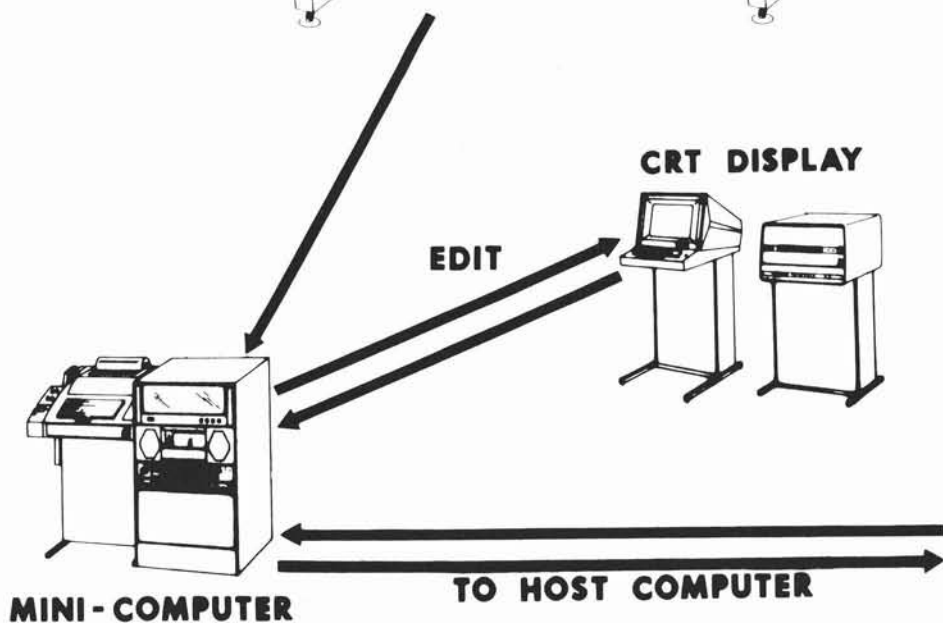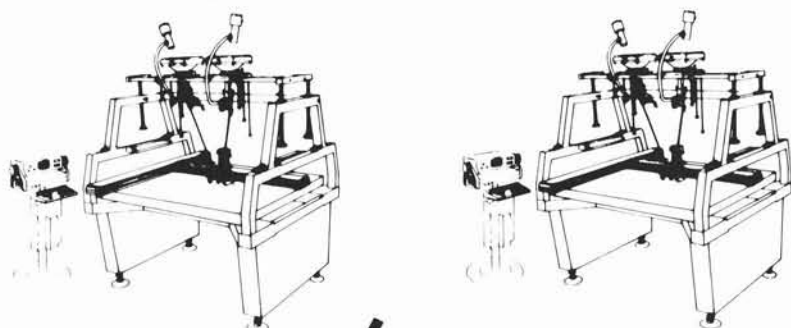
FIG. 11. Automated Station.

metry operations. The flexibility of personnel allocation is especially beneficial in Texas where photogrammetry is in an environment of fluctuating workloads primarily influenced by seasonal ground cover conditions.

Although the use of automated graphics has substantially reduced the number of draft-

ing personnel heretofore required and permitted reallocation of manpower resources, conversion to an Automated Mapping System also has necessarily upgraded and expanded the responsibilities of all personnel involved. In addition to the limited manual cartographic drafting duties which will always be necessary, personnel assigned to the drafting
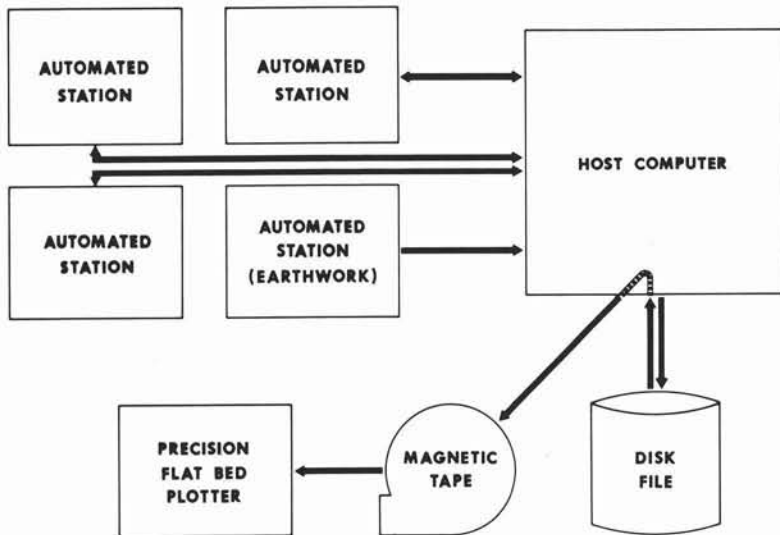
FIG. 12.   Total Automated Information Management System.

section must assume additional respon-
sibilities in editing and quality control. This
will require the draftsman to be thoroughly
familiar with digitizing techniques, auto-
mated plotter operation and the overall proj-
ect requirements. Digitizing methodology
requires the stereoplotter operator to acquire
the added skills of a photo interpreter, or
image analyst, for accurately entering the
correct identification code for each feature.
Useful manipulation of the data for presenta-
tion of selective graphics or statistical
analyses is totally dependent on this digital
input.

RECOMMENDATIONS

The modular conversion program for mod-
ifying individual stereoplotter units for au-
tomated mapping has worked very well with
little interruption to the Department's exist-
ing schedule commitments. With the host
IBM 370 computer readily accessible in the
same building, card handling from each in-
dependent stereoplotter unit offers no seri-
ous production problems; however, use of
the keypunch collection system limits rapid
editing capabilities, consequently reducing
the potential efficiency of the system.

To overcome edit deficiencies and op-
timize the overall system, it is the
Department's intent to replace the individual
keypunch data collectors with multiple au-
tomated stations. The automated stations
would permit the use of all existing digital

hardware with the exception of the keypunch
interface which would necessarily be re-
placed with a computer interface. Each au-
tomated station could consist of three to five
stereoplotter units with digitizing acces-
sories, a cathode ray tube (CRT) display with a
hard copy unit and a minicomputer as shown
in Figure 11.

This equipment configuration will permit
each stereoplotter operator interaction be-
tween the digitizer, mini-computer and the
CRT display. In congested areas hard copies of
the digitized data can be obtained by the
operator for editing purposes. This will avoid
extended use of the display tube by any one
operator. The edited data will be transmitted
by the stereo operator to the host IBM 370
computer for final processing, disk storage
and further manipulation as required. The
use of several automated stations with small-
er mini-computers is preferable over having
a total system with one larger computer in
order to minimize production delays caused
by the inevitable down time of electronic
equipment. Figure 12 represents the pro-
posed multiple automated stations which will
utilize the host IBM 370 computer, disk files,
magnetic tapes and a precision flatbed plotter
for graphics.

The Texas Highway Department is pres-
ently preparing specifications to purchase or
lease a precision flatbed plotter for use in
conjunction with the CalComp 1136 drum
plotter purchased by the Department several
months ago.