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DESIGN OF A MAP UPDATE CAPABILITY FOR ENGINEER TOPOGRAPHIC UNIT--ETC(U)
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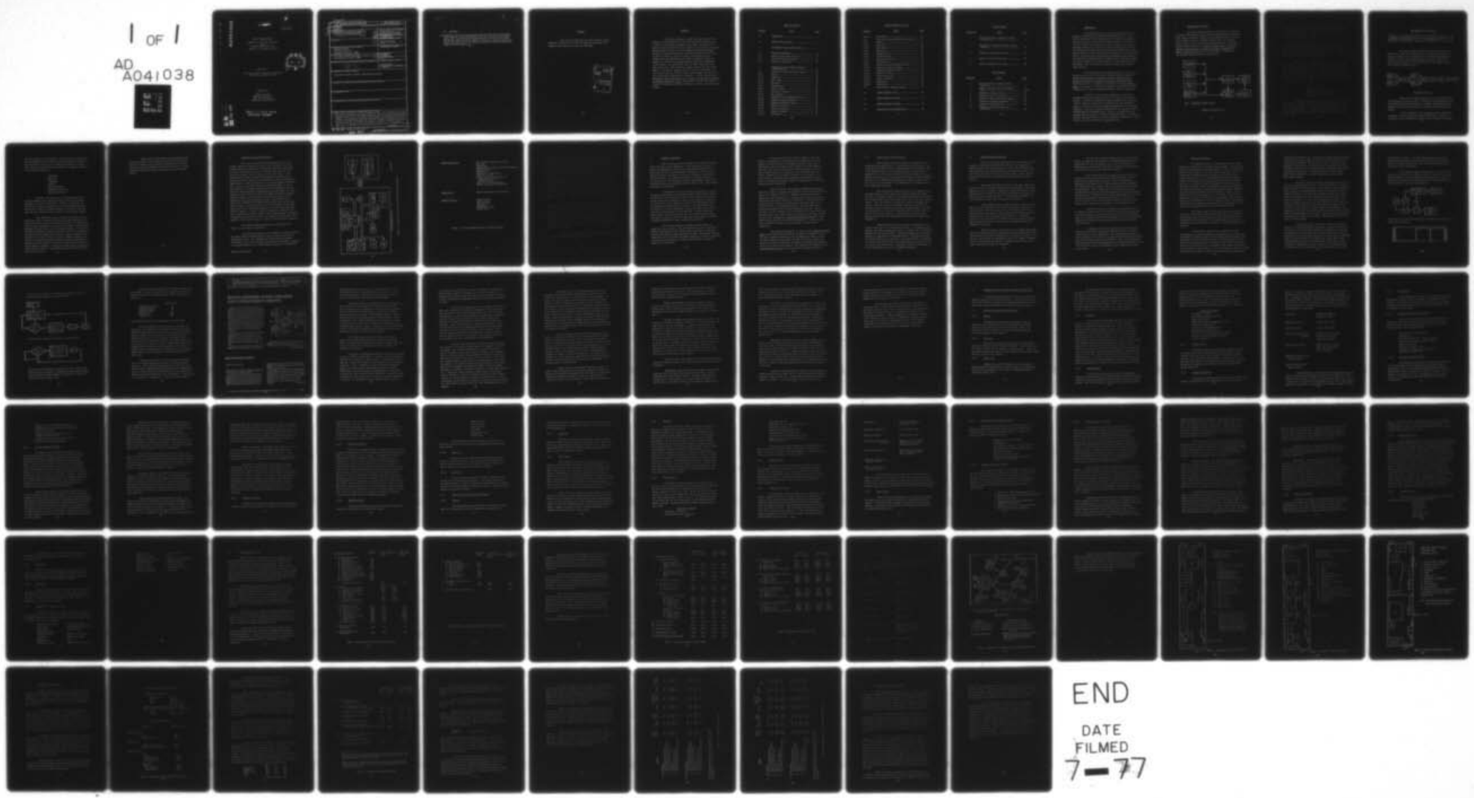

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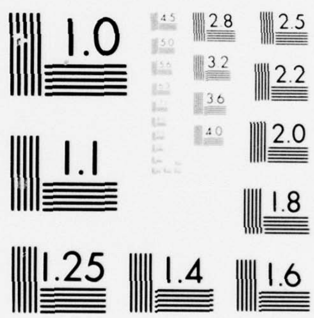
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26 May 1977
53-0200-0001

Final Technical Report

DESIGN OF A MAP UPDATE CAPABILITY FOR ENGINEER TOPOGRAPHIC UNITS

(Contract No. DAAG53-76-C-0176)

Submitted to

U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

Submitted by

Raytheon Company
Autometric Operation
400 Army Navy Drive
Arlington, Virginia 22202

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This report contains the final conceptual design of two systems for the compilation of Field Army map updates using all types of tactical reconnaissance imagery as data input. Both systems are capable of producing Class B output accuracy, and incorporate innovative design features to improve ease of operation and system throughput. One system is designed to perform a monoscopic solution where the map is used as a source of control to form a terrain model that is combined with the appropriate sensor model to transform image

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coordinates into their correct ground positions with relief displacement errors removed. The second system uses the mono solution for mono input imagery and a full analytical mapping solution for stereo input imagery. The systems' design evolution, theory of operations, technical characteristics, estimated costs, field deployed van layout, and cost effectiveness comparisons are presented.

FOREWARD

This document constitutes the Final Technical Report, DESIGN OF A MAP UPDATE CAPABILITY FOR ENGINEER TOPOGRAPHIC UNITS (Contract Data Requirements List Line Item 0005).

ABSTRACT

This report contains the final conceptual design of two systems for the compilation of Field Army map updates using all types of tactical reconnaissance imagery as data input. Both systems are capable of producing Class B output accuracy, and incorporate innovative design features to improve ease of operation and system throughput. One system is designed to perform a monoscopic solution where the map is used as a source of control to form a terrain model that is combined with the appropriate sensor model to transform image coordinates into their correct ground positions with relief displacement errors removed. The second system uses the mono solution for mono input imagery and a full analytical mapping solution for stereo input imagery. The systems' design evolution, theory of operations, technical characteristics, estimated costs, field deployed van layout, and cost effectiveness comparisons are presented. A prior interim report, Preliminary Concept Formulation Plan - Design of a Map Update Capability for Engineer Topographic Units, 10 March 1977, contains the results of a series of analyses and trade-off studies that led to the final systems' design.

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1. INTRODUCTION

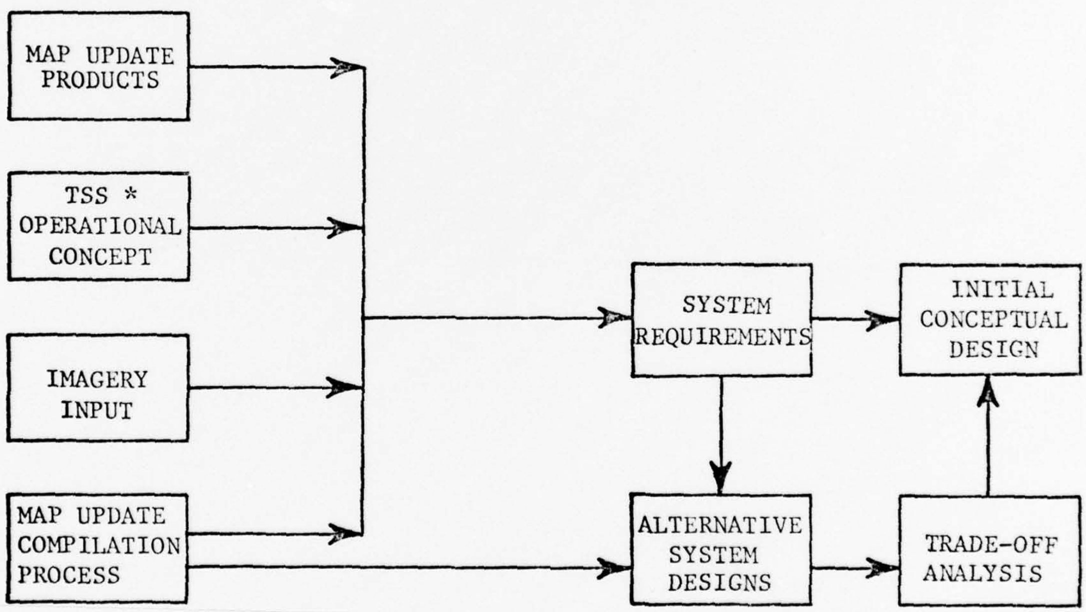
This report presents the final conceptual design of two systems for optimizing the Field Army map update capability. Both systems incorporate various design features to optimize the map update task and are capable of treating all types of expected sensor input to obtain Class B map accuracy. One system is designed to work with monoscopic imagery only, and will use an orthorectification technique for compilation, in which points from the map are used to form a mathematical model to correct digitized image points for relief displacement errors. The second system is designed to accommodate both monoscopic or stereoscopic imagery and will be capable of full analytical mapping with stereo imagery. Both systems have as a major option an offline orthoprinter that will be used to generate rectified and orthophoto image products.

The alternative systems described here were selected for further design by ETL after review of Raytheon Company/Autometric's Interim Technical Report, Preliminary Concept Formulation Plan - Design of a Map Update Capability for Engineer Topographic Units, dated 10 March 1977. The material contained in this Final Technical Report is intended to be sufficiently complete and detailed to permit consideration of future prototype development, test and evaluation.

Section 2. of this report summarizes the study scope, technical approach and results that led to the final system designs. Section 3. presents the alternative system configurations and options. Section 4. discusses the theory of operations for each alternative system. Section 5. gives the technical characteristics of all system components. Section 6. presents summary tables that contain estimated developmental and production costs. Section 7. portrays the field deployed mobile van layout. Section 8. contains results of a trade-off analysis incorporating system cost and performance comparisons. Section 9. presents the study conclusions and recommendations.

2. SYSTEM DESIGN EVOLUTION

The system designs presented in this report resulted from a detailed investigation into the design requirements for a Field Army quick response map update capability that could deal with all types of aerial imagery as input. A complete description of the technical effort leading to the initial system conceptual design is contained in Raytheon Company/Autometric's Interim Technical Report, Preliminary Concept Formulation Plan - Design of a Map Update Capability for Engineer Topographic Units, dated 10 March 1977. A schematic of the technical approach followed is shown below.



*TSS - Topographic Support System

Concept Formulation Plan

As shown, the requirements for an advanced map update capability were derived from a survey and analysis of the expected input data, output products, and alternative compilation processes and techniques, all placed in a frame of reference of the current Field Army map update operational concept (TSS).

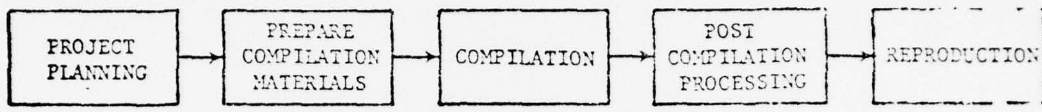
The primary design constraints stemmed from the nature of the Field Army map update environment, i.e., the variety of sensor input: vertical and oblique frame photography, panoramic photography, SLAR, TIR, and other unconventional electro-optical sensor imagery, in mono or stereo form; plus the requirement for a rapid turnaround capability in the production of finished products.

Additionally, it was decided that any advanced map update system should incorporate a capability to provide Class B map accuracy, even if this level of quality would not always be necessary. Also, it was concluded that a provision for vertical update, i.e., contours, elevations, or height measurements, would be desirable. Based upon the design guidelines and criteria from the requirements analysis, the primary basis for evaluating alternative system's suitability consisted of assessing the following attributes:

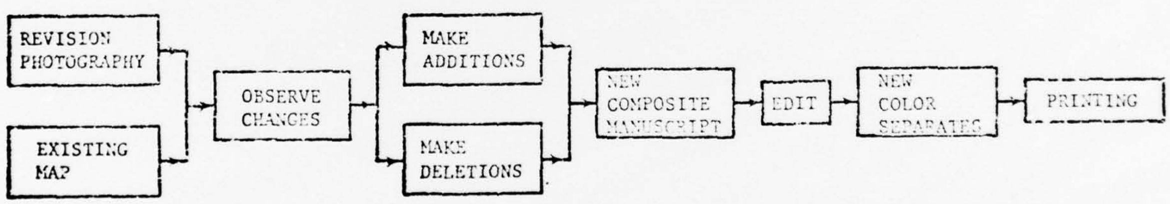
Sensor Capability
Speed and Ease of Compilation
Operator Skill Level Requirement
Product Accuracy and Content

The basic steps in the map update compilation process are shown below to highlight the areas that can be treated by system design or modification to obtain improvements in compilation efficiency, timeliness, or production cost. An optimum system must affect improvement in more than one functional area if significant performance benefits are to result.

Map Update Process Components



Also shown is another diagram of the map update process. The important point to be observed here is that the basic compilation problem is composed of the following tasks: matching the imagery and the map to detect updates; delineation of the feature updates into the correct map format; and final presentation of the updated features in a finished cartographic form.



Map Revision Process

These two flow diagrams portray the basic design objectives of any advanced map update system: tailoring all compilation phases so that efficiency and good throughput is obtained, and insuring that all fundamental compilation functions are facilitated through the system design.

To test alternative system configurations and compilation techniques, a trade-off analysis was performed using a scenario of a map update task to establish and compare system efficiency, throughput, cost effectiveness, and capabilities. Fifteen different compilation system configurations were tested; various techniques for compilation were investigated, so that in all, ninety-three separate processes were evaluated. System trade-offs consisted of a parametric analysis of the following attributes:

System Cost
Labor Cost
Throughput
Accuracy
Sensor Capability
Compilation Efficiency
Operator Skill Level

From the trade-off analysis it was concluded that no existing equipment could universally satisfy Field Army map update performance criteria or requirements. However, it was shown that there were techniques and equipment that could be adopted and incorporated into a single compilation instrument to provide a rapid and cost effective solution to major portions of the map update problem.

This instrument, named the Analytical Map Update System, would incorporate the desirable features of an analytical plotter to provide full sensor capability and product accuracy. A viewing system having the basic capabilities of a stereo zoom transfer scope would be provided that would permit easy may and image matching. It would have an additional feature of computer controlled optics to allow automatic adjustment so that viewing with all types of imagery throughout compilation would be easy and not require time consuming operator intervention. An interactive graphics capability would be incorporated to permit both on-line viewing of compilation results and easy data edit and cartographic finishing. A variety of software would be provided to permit different methods of compilation, compatible with the different forms of imagery input.

After review by ETL, Raytheon Company/Autometric was directed to conduct a final design effort that would incorporate most of the features of the original conceptual design into two systems with various component options and alternatives. The two systems and associated variants are presented in the following section.

3. ALTERNATIVE SYSTEM CONFIGURATIONS

After the review of Raytheon Company/Autometric's preliminary conceptual design, ETL directed that two systems, each with a common option, be subjected to a final, more detailed design effort. One system is designed to accept mono imagery only, while the other system is designed to process either stereo or mono imagery. Both systems have an option of an offline orthoprinter that will permit production of plane rectified or differentially rectified (orthophotos) image products. Figure 1 presents the two system's hardware configuration. As seen, both systems share many common components, with the main difference in hardware being that the system designed to process only mono input needs only one digitizing photo stage, while the system designed to process both mono and stereo imagery includes two digitizing photo stages. (The mono system's photo stage also has a lower measurement resolution requirement than the stereo system's photo stages, and a slightly less complex optical system with the servo photo optics option.) Also shown in Figure 1 are the various alternatives and options for the viewing optics, data entry device and interactive graphics subsystem. In order to depict a standalone production system, a contact photo printer, process camera, film processors, platemaker, lithographic press and ozalid copier are included in each system. This equipment is not shown in Figure 1. Table 1 lists all system components.

The primary difference between the two systems is reflected in their modes of compilation.

The mono system will use a new technique to produce accurate map update products from mono imagery that are corrected for relief displacement errors. The technique, now called pseudo-orthographic rectification (or by some, orthorectification with pseudo-DTM*), combines the defining equation of the sensor imaging process with a mathematical

*Digital Terrain Model

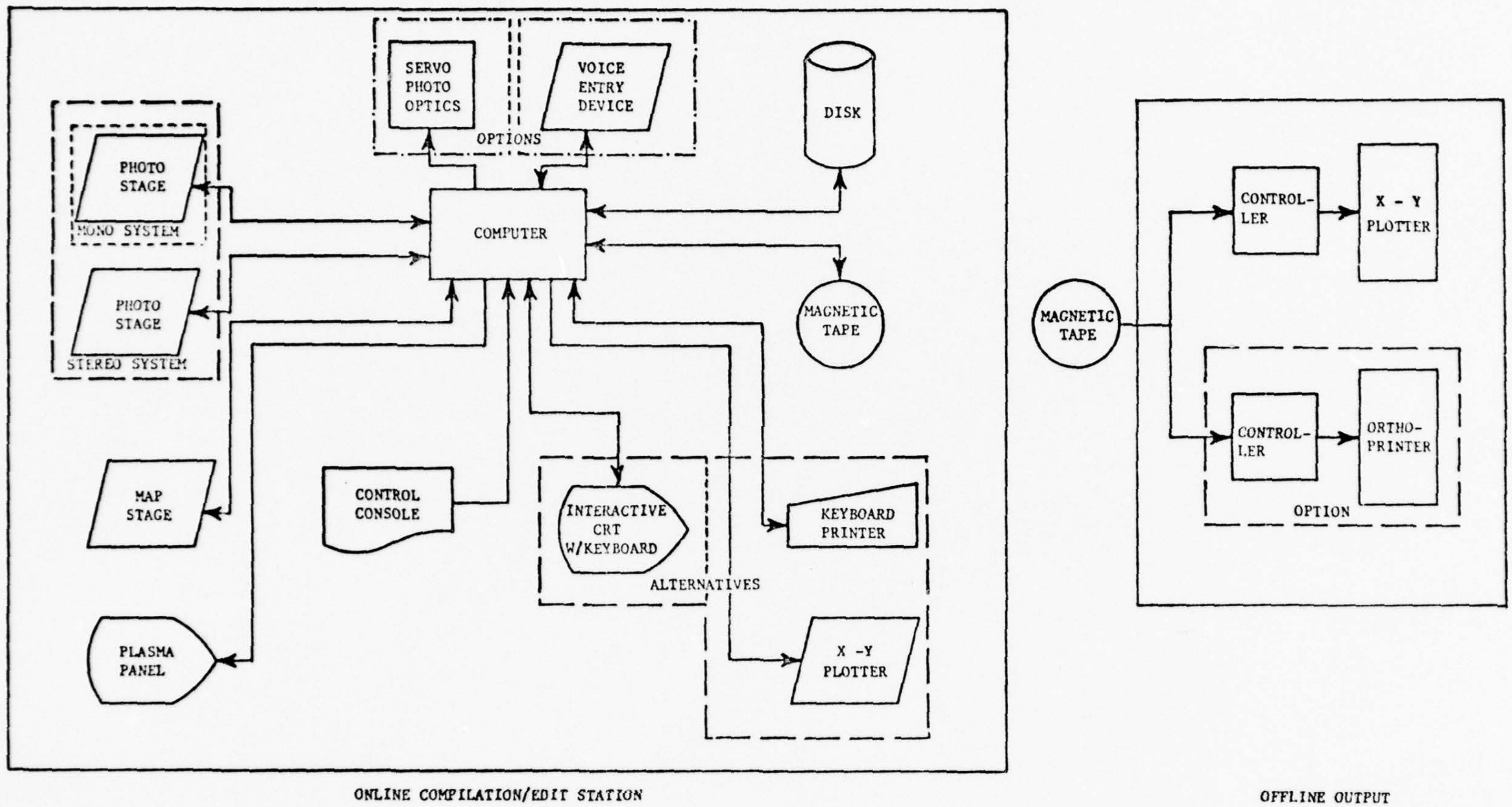


Figure 1 - Advanced Map Update Compilation System Configuration

Compilation Station:	Photo Stages (Mono System (1) Only) Map Stage Plasma Panel Viewing Optics (Computer Controlled Option) Control Console Minicomputer Disk Unit or Bubble Memory Magnetic Tape Unit Interactive CRT with Keyboard, or Keyboard/Printer and Small X-Y Plotter Voice Entry Device (Optional) Offline X-Y Plotter and Controller
System Option:	Offline Orthoprinter and Controller
Support Equipment:	Contact Printer Process Camera Film Processor Platemaker Lithographic Press Ozalid Copier

Table 1 - List of Advanced Map Update System Components

representation of the terrain to allow the determination of the correct position of image points on the ground with relief displacement effects removed. (The correction for relief displacement is obtained by constructing a model from point coordinates (X,Y,Z) derived from the map and conjugate tie points measured on the imagery.) The operator can use check points to assess the accuracy of the solution and can employ an interactive procedure to change or increase the map control so that the desired result is obtained. Class B accuracy has been demonstrated with the pseudo-ortho technique. A simple case of orthorectification is where terrain elevation is held constant. This method may be used in areas of very low relief, or when time versus accuracy is of paramount concern. The pseudo-ortho technique can also be used to produce image products where the terrain model coordinates would be reformatted into the profile scan format needed to drive an offline orthoprinter. Orthophotos and plane rectifications could be so produced.

The stereo system will have all of the capabilities of the mono system when mono imagery is input, plus additional capabilities and compilation techniques for stereo input. The stereo system will permit topographic compilation with stereo imagery, i.e. contours, spot elevations and height measurements will be possible. With stereo imagery, full analytical mapping will be possible using photogrammetric models with map or survey points as control. Production of orthophotos can be accomplished through a pseudo-ortho technique for mono input or through conventional profiling with stereo imagery to construct a DTM to drive the offline orthoprinter.

A discussion of the purpose and role of each of the system's components is presented in the following section.

4. THEORY OF OPERATIONS

Both the mono and stereo versions of the advanced map update system will have similar capabilities. Both systems will be able to produce cartographically finished line and symbol manuscripts ready for final color separation and lithographic reproduction. If the offline orthoprinter option is adopted, rectified or orthophoto image products will be possible. Both systems will accept film or paper positives at original scale, thus minimizing imagery preprocessing. Control can be either derived from existing survey data, APPS, or as is most commonly envisioned; the map itself.

As described in the prior section of this report, the mono map update system will use an orthorectification technique for compilation, that will use points from the map to form a model of the terrain so that image relief displacement errors can be corrected. A variant of the orthorectification technique is plane rectification, where terrain is represented as having constant elevation. The latter method does not correct for relief displacement, and would be used only in areas of low relief or when accuracy is not important. The mono system will employ special software to reformat the terrain model into the proper scan format to drive the offline orthoprinter if that option is adopted, to produce orthophotos or plane rectified image products.

The orthorectification technique has been shown to be capable of Class B accuracy. The model representing the terrain can be prepared independently of the feature update compilation or performed as part of the feature update compilation process. The operator will use check points and the interactive graphics subsystem to check if sufficient accuracy has been obtained, or if more control points are needed to refine the terrain model.

The stereo system will be able to employ the same procedures as described for the mono system for production of line map updates, rectified imagery, or orthophotos from mono input imagery. Additionally, the stereo system will be capable of a full analytical solution, using the map, survey data, or APPS as sources for control. This technique provides for correction of relief displacement and allows a standard level of product accuracy to be maintained. With stereo imagery, orthophotos will be produced by profiling the stereo model in a conventional manner to produce a terrain model to drive the optional offline orthoprinter.

Both the mono and stereo systems compilation for graphic output will produce an edited, cartographically formatted, plotter tape to drive to the offline X-Y plotter. Composite single color overprint manuscripts, color separations, or in some cases, direct plots on overlays or map stock will be produced on the plotter. Final cartographic touchup and edit, halftone screening, names and legend layout, etc., may be performed in a conventional manner. The most common final reproduction method will be through lithographic printing. However, the latter is time consuming, and an alternative for a quick turnaround, moderate volume issue (color copier), is discussed in the final section of this report. (Section 9. - Conclusions and Recommendations.) Other graphic output media can be wash-on, photographic, or diazo depending upon the specific timeliness, product quality, or issue volume requirement.

The following paragraphs are taken from the Interim Technical Report and are presented to detail the rationale and purpose of each of the major components proposed for the two advanced map update systems. The system discussion is presented in terms of the stereo system, but except for a very few differences in hardware, components and component roles are the same for both systems. The reader who is familiar with the Interim Technical Report may wish to skip the following discussion.

4.1 General System Characteristics

The following discussion outlines, in concept form, the requirements and capabilities of a system which we have chosen to call an Analytical Map Update System. This equipment will incorporate many of the desirable features of an analytical plotter, along with the capabilities of a stereo zoom transfer scope, and additional features designed to provide ease of operation and interactive graphic capability. While many of the components and subsystems of AMUS are state-of-the-art, there is no requirement for any improvement in the state-of-the-art to implement the system.

From the previous studies conducted, it is concluded that the AMUS should be able to handle mono or stereo photographic inputs from frame or panoramic cameras and in addition should be able to handle side looking radar records and perhaps scanner type inputs from infrared sensors. This wide diversity of input data, with the attendant wide range of scales and relative distortions, leads very quickly to the conclusion that an analytical plotter type instrument will be necessary if the operation is to be able to rapidly produce revisions. This is not to say that AMUS requires the extremely high accuracy normally associated with first order analytical plotters used for original map compilation.

Additional requirements can easily be formulated for the viewing system based on the input photo products. For compilation from panoramic and oblique photography, there is a requirement for anamorphic magnification and image rotation. Matching of image scale to map scale generates a requirement for zoom magnification. Simultaneous viewing of the photo model and the map sheet to be updated places a requirement to optically introduce the map into the photo optical system, much like the stereo zoom transfer scope. Additional features and requirements will be discussed in detail in the following paragraphs.

4.2 Optical-Mechanical Subsystem

For stereo coverage, AMUS should have two independent photo carriages. Each stage should have both back and front lighting for viewing transparencies or opaque prints. A 10" x 10" illuminated area will satisfy all frame camera requirements and panoramic formats up to $\pm 45^{\circ}$ sweep angles with up to six inch focal length. Larger panoramic formats and strip formats from SLR and IR can be handled by separate set-ups.

Each stage should have a full 10" x 10" travel without interference in order to handle varying overlap photography. Each stage should have an X, Y measurement capability over the full range of travel. Stage measurement accuracy in the order of $\pm$ 0.0005" will suffice for over 90% of the expected input data. If only planimetric updates are to be performed, a lower order of accuracy would suffice.

A stage should also be provided to mount the map sheet and permit it to be translated in such a way as to maintain alignment with the photo model. For most cases, a 10" x 10" range of travel would suffice, since seldom would the photo model cover an area greater than that shown on a 10" x 10" section of the map sheet. A positional accuracy of the stage travel of $\pm$ 0.005" would exceed the map accuracy specification by at least a factor of four and should be relatively inexpensive to achieve.

Visual feedback to the operator of the changes being digitized in the photo model can be supplied by placing a plasma panel beneath the map sheet and having the computer plot the points on the panel. In this way, the operator can continuously check on the degree of completeness of the new data being entered. In addition, this feature can be used to give him an online edit capability.

The size of the required plasma panel need be only large enough to contain the area imaged by a typical photogrammetric model, namely about nine by five inches or less. This is fortunate, as plasma panels in sizes larger than ten by ten inches are non-standard items and thus are costly and difficult to obtain.

The viewing system for the photographic model must have several features in order to match the model to the map for the expected range of image types and scales. These features include independent zoom magnification, image rotation, anamorphic magnification, and anamorphic rotation in each of the optical trains viewing the photographs. The map image must be introduced into one of the optical trains by means of beam splitting optics after the distortions producing optics. This part of the optical system should have a range of fixed magnifications selectable by the operator at set-up time. All of the above features are currently available in the stereo zoom transfer scope and thus do not represent any developmental risk.

For AMUS all the photo viewing system adjustments should be encoded and servo driven by the computer once the operator has made the initial set-up, so that the operator does not have to continually make time consuming adjustments during compilation. This will obviously represent some modification and development but is well within the state-of-the-art.

A measuring mark will be required for each photo stage, both for initial set-up in measuring fiducial marks, etc., and as a floating mark in stereo compilation. This mark should be placed as near as possible to the plane of the photo so that shifts in the optical axis of the viewing system do not introduce errors in the measurement. There should be several interchangeable sets of marks of different sizes for the different scales of photography and the magnifications that will be used.

4.3 Computation Subsystem

The computation system of the AMUS provides the logical thread for tying all of the hardware systems together. The system must provide several functions to the AMUS concept. First, it must provide overall logical control of the entire map revision process, at least through those portions which are performed on the AMUS. Second, it must allow for the set up of the photogrammetric model, which includes the orientation of the map sheet and the picking of control, and also the orientation of the photographs for both interior and exterior orientation. Third, it must provide a means for digitizing the updates (both additions and deletions) and saving this information with identifying information for later plotting. Fourth, it must provide a means for the operator to see the updates which have been performed, so that he can keep track of his progress. Last, it must provide an edit capability so that the operator can edit the digitized information after compilation to insure that the cartographic symbols which have been generated will plot in an acceptable manner.

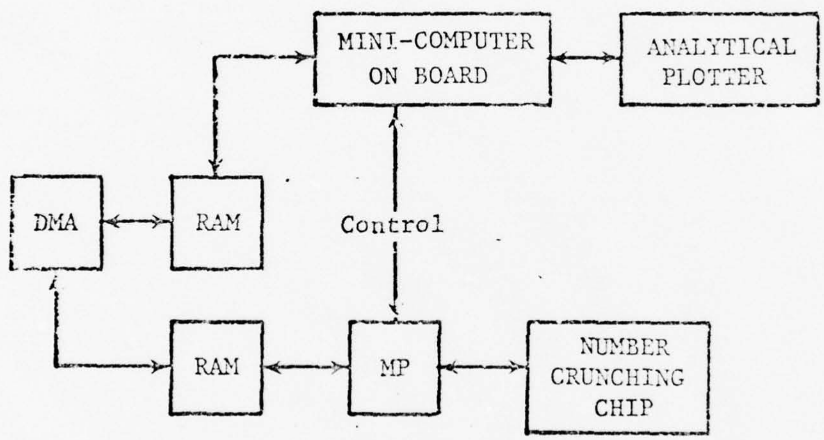
The logical control of the entire process can easily be accomplished by a rather modest computer capability, but some form of data terminal, such as a CRT display or printer, must be available for communication with the operator. Also, some input device, such as a keyboard, must be available for the operator to input information to the computer.

The preliminary operations for compilation, whether the model is on an analytical plotter, a digitizing table, or whatever, are designed to orient the photo or stereo model to the map sheet. This procedure is not time critical, because it is performed only once per model. The derived parameters are stored for future reference, and the process of recording the data is initialized. The computer requirements for this phase are rather simple. Any of the available computer-on-a-board series produced by DEC, Data General, Hewlett/Packard and others would suffice for this application. Floating point hardware should be included to facilitate the large amount of floating point arithmetic to be performed in this operation. The required code for this function would probably be less than 32K - 16 bit words, although possibly more would be needed to cover all of the various options. RAM memory needed would certainly not exceed 32K. A scratch disk would be needed, which could be well satisfied by a typical floppy disk of approximately 800 kilobyte capacity.

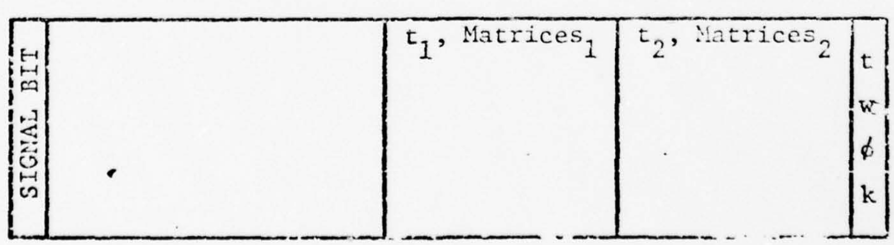
The area in which the computer speed becomes critical is in the area of actual plotter control. In this application, the computer must be capable of providing updates to the photo carriage positions at such a rate that the motion appears smooth to the operator under any realistic slew rate. For frame camera systems, and for side looking radar, this problem is not very demanding of computer speed, and the typical minicomputer on a board with floating point processor would handle the problem very well. The major difficulty arises in the case of dynamic camera systems, in which the orientation matrix must be changed as the position of the point changes on the photograph. The computation of the rotation matrix involves many trigonometric functions, which take considerable time to compute. Therefore, some facility must be incorporated to allow these updates to the orientation matrix to be made in a timely fashion.

The simplest manner in which to handle the orientation matrix is to store an orientation matrix for a certain time, and then to also store a time derivative matrix for interpolation. Obviously, the matrices used to determine the orientation matrix must be updated frequently, as the linear approximation for a system such as a panoramic camera is valid over only a very small range of scan angle values. It would probably be possible to accomplish this update with a single processor, by triggering the updated outputs to the photograph stages at certain clock times, and using the intervals in between to update the orientation matrices. The advent of microprocessors allows a simpler and more elegant solution formulation, however, and relieves much of the logical problem associated with simultaneous updating of two systems in the same computer.

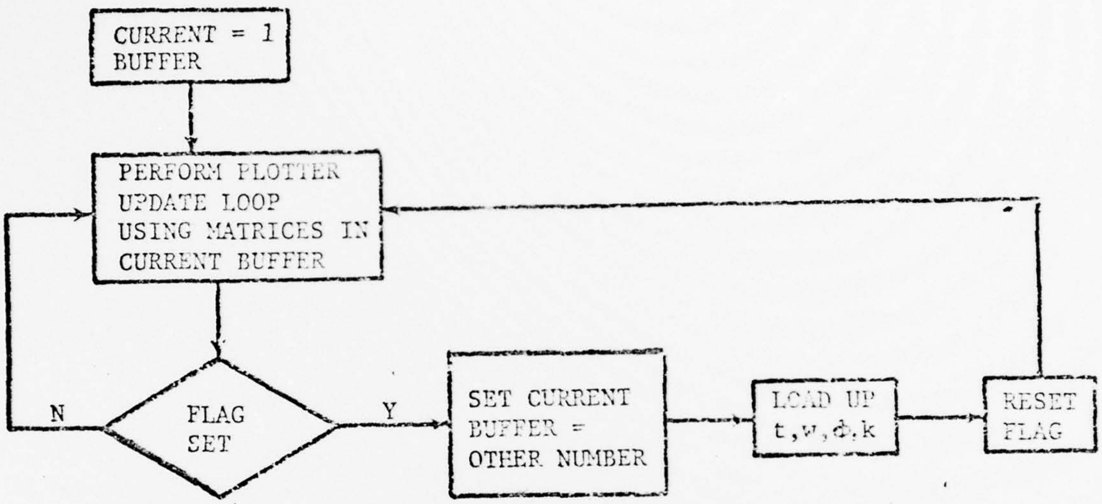
The recommended computer architecture is presented below. One will note that complete parallel processing capability is provided. The microprocessor, with its associated computational chip, is concerned with computing the orientation matrices, without regard to the type of sensor, or any other considerations.



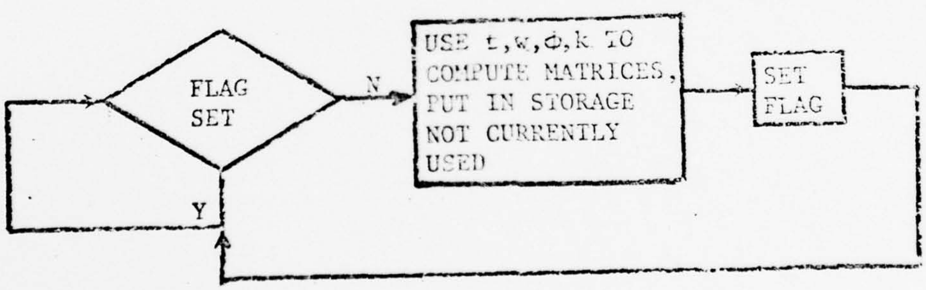
The storage in the RAM is detailed below, insofar as it is relevant to the present discussion.



The flow for the portion of the minicomputer program associated with attitude determination is presented below.



The flow of the microprocessor program is detailed below.



The next item which must be discussed is the rate at which these updates can be accomplished. The panoramic camera system provides the more difficult update problem, and this will be used to determine the expected update times.

First, the problem of updating the orientation matrix will be attacked. It will be assumed that the computational chip will perform operations at the following rates (which reflect state-of-the art):

	microseconds
floating add (32 bit)	8
floating subtract	12
floating multiply	38
floating divide	41
square root	184
trig function	700

The following page shows the announcement of one such chip.

For the evaluation of the two matrices and their time derivatives, the computation will consume approximately 20 milli-seconds, including a factor of two for safety and to cover logical operations which are not considered in the operation counts. To determine whether this rate is adequate, one should consider a three inch focal length panoramic camera, and a maximum slew rate on the stage of two inches per second. Thus, between updates, the maximum distance travelled on the film would be .04 inches. The maximum change in scan angle over .04 inches would be .75 degrees, which should certainly be subject to linear interpolation with small error.

One should notice that the above computation represents the rate at which the matrix can "chase" the carriage during a fast slew. In the precise pointing process, the need for inter-polation will be largely relieved, because the matrix updates will occur so rapidly that there will almost never be any appreciable distance over which interpolation must be performed. In particular, if the carriage is stationary for a period of time, the matrix

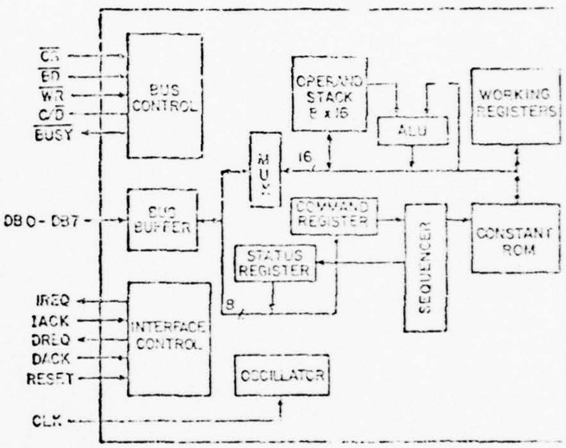
Speedy arithmetic circuit unburdens busy microprocessor systems

Taking much of the calculation load off a μP-based system can accelerate processor speed. Up to now, however, all of the available calculator circuits haven't been fast enough to unburden the μP. Advanced Micro Devices plans to change that with its Am9511 arithmetic-processor unit.

The 9511 connects either to a μP bus or via a DMA interface to the μPs memory and can do floating or fixed-point arithmetic, trig functions, inverse trig functions, square roots, logarithms and exponentials. An 11-kbit ROM on the chip does calculations by using Chebyshev polynomials.

The NMOS circuit can perform 32-bit floating-point additions in 8 μs, subtraction in 12 μs, multiplications in 38 μs, divisions in 41 μs, rooting in 184 μs, trig operations in a minimum 550 μs and inverse trig operations in a minimum 900 μs—all based on a 4-MHz clock rate.

Two versions of the 9511 are available: a 2-MHz unit called the 9511 and a 4-MHz model,



the 9511-4. Thus, typical execution time for an 32-bit floating-point multiply operation is either 76 or 38 μs—both much faster than an

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MICROPROCESSOR DESIGN

(continued from page 43)

8080 software subroutine, which requires 3 to 4 ms to perform a similar function.

All transfers, including operand, result, status and command information, take place over an 8-bit bidirectional data bus. Transfers to and from the 9511 can be handled by the associated processor using conventional programmed I/O, or by a direct-memory-access controller. Upon completion of each command, the arithmetic chip generates an interrupt request to signal data are ready for the processor.

Two supplies, +5-V and +12-V, are required. A 24-pin DIP houses the circuit, and operation is specified for a 0-to-70-C range. Initial sample prices for the 9511 are expected to start at $100, and units will be available around July, 1977. *Advanced Micro Devices, 901 Thompson Pl., Sunnyvale, CA 94086. Elliott Sopkin (408) 732-2400.*

CIRCLE NO. 503

computation will catch up so that it is being computed at the stage position, and no interpolating will be done at all. Thus, the process represents a convergent interaction process in the case of a moving stage which then becomes stationary.

The second problem is the updating of the table positions, given the matrices as computed by the parallel microprocessor. For the panoramic camera equations, it is found that these updates can be performed by the minicomputer on a chip with a floating point arithmetic unit in under 4 milliseconds, assuming a considerable safety factor for system overhead and communication. Thus, 250 updates to the carriage position per second should be capable of being generated, which will certainly exceed the requirement of seemingly smooth carriage motion. Actually, the overhead of writing the data to the disk, accepting header information, and other overhead functions will slow this loop time somewhat.

It is seen that the problem of driving an analytical plotter using a fully dynamic model for the sensor is possible without very much sophistication in the computer hardware, and that even a relatively modest computer will suffice to perform all functions on the system.

The process of digitizing the updates takes place concurrently with the plotter control process. Actually, the only modification required is the ability to transfer points to a mass storage device upon some command, which could be a foot switch, or time or distance increments. Also, a capability to input some header information denoting the type of feature being digitized must be included. Perhaps some of the voice encoding mechanisms which are currently on the market could be used for this application, to avoid the operator having to raise his head from the eyepiece to enter something on a keyboard. The information which is digitized will be output to mass storage, which would take the form of a floppy or cartridge disk, having adequate capacity (6 megabits or so should be adequate). To obtain maximum ruggedness and reliability in the Field Army environment, it might be desirable to substitute solid state bubble memory chips for the disk.

In order that the operator can see the updates which he has made, some display must be provided to superimpose these updates onto a map sheet, which is in turn superimposed into the field of view of the instrument. A very attractive means of accomplishing this display would be a plasma panel located under the map sheet, which would illuminate the added features which could then be seen through the map sheet. Thus, both the map sheet and the changes would be visible in the field of view of the instrument through the same optics which are used to view the map sheet by itself. These indicated updates would be merely lines and dots, and would not be expected as cartographic symbols, because the resolution of the average plasma panel is not adequate for this representation at 1/50,000 scale.

The final function would be the online editing of the updates produced. This function would require the capability to display the updates, with the proper symbolization, in order to determine whether the proper updates had been made. Checking of the positional accuracy would have already been accomplished during the compilation process by superimposing the updates onto the map sheet as the updates were compiled; however, there would be no symbolization at this phase. The addition of the symbolization would allow houses to be moved away from roads to accommodate the exaggerated width of the road symbol, buildings to be squared, contours to be modified to cross roads correctly, etc.. This online editing capability would require no additional computer facilities, except for a graphics display unit, the software to drive it, and the software to generate the proper symbols. All of this software could probably be contained in between 32 and 64K sixteen bit words of ROM, and could be used in a 32K working RAM memory on the computer.

A desirable feature of the AMUS software would be the capability to determine whether every portion of the model area had at some time been covered by the field of view of the instrument. Of course, the computer cannot ascertain whether the operator actually looked at the area in question in an attempt to detect changes, but the computer can certainly determine that certain areas could not have been examined. These areas could be displayed on the graphics terminal at the conclusion of compilation, and the operator could ask the computor to drive to these areas so that he could examine them. In this manner, complete examination of the model area could be insured, based only upon the integrity of the individual operator. This procedure would insure that changes were not inadvertently missed in compilation, and would have a negligible impact on the cost and complexity of either the hardware or software.

Recent developments in the field of voice pattern recognition have permitted the development of systems which will recognize normal speech patterns and present these to a computer in standard format. In particular, one such system, which sells for under $15,000 per unit, will permit the storage of up to 220 utterances of up to two seconds duration. The system interfaces with a standard computer through an ASCII line, provided that the computer is programmed to recognize the syntax of the signal transmitted. An option which is available is a voice synthesizer which will allow the input message to be spoken back as interpreted by the machine for verification of the receipt and proper identification.

A device such as this would be ideal for the entry of feature type information into the map update digitizing process, and presents no appreciable development risk. The machine is trained for each potential operator by having the operator input the entire vocabulary to form a reference library. After this initial training session, the proper library is called up when the operator enters his identification number into the unit. From that point on, all input can be by voice, unless there are certain functions which are desired to be reserved as keyboard entries.

Further visual feedback can also be supplied to the operator of the current feature type by providing a small alpha-numeric display which could be optically multiplexed into the corner of the map display field of view or simply displayed on a corner of the plasma panel.

The data recording system should consist of two parts. The first part is a disk for temporary storage of the revision data prior to final editing, and the second part is a magnetic tape recorder for generation of a plot tape to drive a plotter. The disk system could easily be satisfied by a 6.4 megabit disk with a 500,000 bit per second transfer rate, which is a standard commercially available floppy disk. Such a disk would accommodate point coordinates for over 100,000 points. At the rate of three points per second, this would represent ten hours or so digitizing. That should certainly be adequate for any map update operation. Three points per second would create an output rate of approximately 150 bits per second, so the transfer rate is certainly adequate for the acceptance of data, probably without even the requirement for double buffering of output buffers.

The entire disk can be emptied in 13 seconds, so the transfer from disk to graphic display or from disk to magnetic tape should create no problems.

The magnetic tape unit could be any standard seven or nine track tape unit, with nine track being preferred because of its compatibility with byte oriented computers. Assuming a 1600 bpi phase encoded system, and a transfer rate to equal that of the disk, one would find that a transport speed of 45 ips should be adequate, with lower speeds suitable if some decrease in write speed could be tolerated. Lowering the write speed to 25 ips would add only 12 seconds to the time to completely empty the disk, and would pay off in greater tape deck reliability and lower tape wear.

The display to be used for data editing must be capable of displaying an area of the map sheet such that updates to be made on this area can be viewed at original scale, and also be capable of slewing and zooming over that area so that any particular portion of the compiled map information can be viewed at a scale which is enlarged enough to allow the operator to edit the information effectively. Assuming that 1/50,000 scale maps are being updated, a zoom ratio of approximately five to one should suffice to allow the detailed editing to be accomplished. The average photogrammetric model will probably cover less than a nine by five inch area, so a 24 inch screen would allow a rather large area of the model to be viewed simultaneously even at rather high magnification.

The display must include either a cursor or light pen as a means to identify points or objects on the screen for editing purposes, and must include a keyboard for input of instructions to the computer. This keyboard could be the same one which is used for other interactive communication with the computer. However, the display should be of the refresh type rather than the storage type, in order to allow the addition and deletion of features without erasing and regenerating the entire display. A refresh display also allows objects to be moved incrementally and then examined, rather than being moved the total distance required in one step.

Sufficient software should be available for the display to allow the generation of symbols for the various map features, including railroads, houses, roads, etc.. Swamp overlays and other such features should be available. It is realized that software for all of these feature generations may not presently exist, but this software must be obtained during the development of the AMUS as it is very desirable to display the updates in the same manner as the final map sheet would appear, with the exception of the colors.

The most practical primary output device for AMUS is a conventional X-Y coordinate plotter; and it should be capable of full map format plotting. Other types of output devices, while they may be considered for base plant use, are of doubtful suitability in the Field Army environment. Plotter technology from a standpoint of size, cost, reliability, operator skill, and flexibility of output product type is proven and should be acceptable for Field Army map update. Additionally, the plotter output can be used with little impact or change to currently used and familiar cartographic procedures.

5. ADVANCED MAP UPDATE SYSTEMS TECHNICAL CHARACTERISTICS

The technical characteristics of the mono and stereo map update systems will be presented separately. The areas where the two systems have different components or component requirements are in the photo stage, photo viewing optics and computing subsystem software.

5.1 Monoscopic Advanced Map Update System

5.1.1 General

The Monoscopic Advanced Map Update System shall be suitable for the compilation of class B topographic map products from monoscopic mapping and tactual reconnaissance imagery. The system may include a capability to produce rectified photographs or orthophotographs from mono imagery.

5.1.2 Input Data

The system shall accept film positive or paper positive imagery at original scale in widths to 9.5 inches. Frames that exceed 9.5 inches in length will be compiled in separate setups. Input data will include imagery from vertical frame, oblique frame, panoramic, SLAR, and other electro-optical sensors.

5.1.3 Photo Stage

A photo stage shall be provided as a secure mounting surface and digitizing platen for the input imagery. The stage shall be selectively illuminated, front or rear, to accommodate paper or film input imagery media.

The illumination source shall be of variable intensity, controlled by the operator, and shall not cause thermal distortion of the imagery. Provision shall be made to hold the imagery flat against the stage and fixed in place throughout compilation. The stage shall be at least 10 x 10 inches and shall be capable of 10 inch travel along each axis. The stage shall be encoded to have a measurement capability of .001" resolution and .005" accuracy (1σ). Stage motion will be directed by the operator. A larger sized photo stage will be acceptable.

5.1.4 Map Stage

The map stage shall be capable of accepting a full-sized map sheet, in paper, film, or scribe coat form without cutting or otherwise destroying the original input copy. The viewable area of the map during any single compilation setup shall be 10 x 10 inches. Positioning of the map sheet between compilations shall be readily accomplished. The map shall be capable of 10 inch travel in both axis and shall be servo driven by the computer to maintain alignment with the photo stage. The map stage shall be encoded to have a measurement capability of .002" resolution and .005" accuracy. The map stage shall be illuminated so that the operator can select on, off, or flicker modes. A plasma panel will be incorporated into the viewable area of the map stage to provide an online display of compilation data registered to the map. The panel shall have a resolution of at least 60 dots per inch. Brightness of the panel shall be sufficient so that displayed information is readily visible to the operator. The panel shall be approximately 8 x 8 inches to no greater than 10 x 10 inches.

5.1.5 Viewing Optics

An optical system that permits correct, superimposed viewing of both the input imagery and the source map shall be provided. The optical system shall permit binocular viewing of the input imagery and map. (Left eye and right eye: map and photo.) The photo viewing optics may be encoded and servo driven by the computer subsystem so that once setup, the operator will not need to readjust the optics during compilation. The map viewing optics shall have fixed magnifications of 0.75, 1, and 2. A dot reticle that can be interposed into the map viewing optics of 500 $\pm$ 100 micrometers shall be provided. Specifications for the photo viewing optics are given below.

Photo Viewing Optics

Zoom Range 4:1 Minimum

Fixed Magnifications 0.6 and 2.3

Image Rotation 360°

Anamorphic Magnification Range 1:1 to 2:1

Anamorphic Rotation $\pm 90^{\circ}$

Field of View 190mm/magnification

Interchangeable Dot Reticles of

30, 100, 300 and 1,000 micrometers ($\pm$ 10%)

Opaque, luminous or projected reticles

will be acceptable.

5.1.6 Control Console

The control console shall permit the operator to operate all compilation station subsystems and to monitor operating status. Controls will include on/off power switches, illumination intensity controls, status indicators, photo and map stage motion controls, and digitizing mode controls. The control console may include a means for the operator to input operations codes or feature identifications during compilation.

5.1.7 Interactive Graphics

An interactive graphics subsystem will be provided to allow operator communication with the computer and serve as a final edit station. The graphics subsystem shall display the compilation data in symbolized form with sufficient resolution to permit a cartographic edit. The display shall be a large size, high resolution, refresh CRT, or a small format X-Y plotter. The CRT display brightness shall be at least 100 foot lamberts spot brightness. A full ASCII A/N keyboard shall be provided with at least 16 function keys. Recommended display specifications are given below.

Screen Size:	At Least 19" Diagonal, Rectangular Format.
Addressable Locations:	At least 2048 x 2048
Display Locations:	At least 1024 x 1024
Character Generator-Stroke or Matrix:	Display at least 64 ASCII characters and special cartographic symbols.
Line Generator-Vector:	Blink, solid line, dashed line, and dot; variable size and spacing.

Independent Intensity and Contrast Control

Cursor or Light Pen for Interactive Edit

As an alternative to the interactive CRT graphic system, a small online X-Y plotter may be provided for data edit and output plots. This plotter shall be capable of plotting a 10x10 inch area with an accuracy of at least .01". The plotter shall accommodate drafting film or paper media. A desirable feature would be a capability for automatic multicolor plotting.

5.1.8 Data Terminal

If the interactive CRT graphics is not adopted, a full ASCII A/N keyboard and printer shall be provided for communication with the computer. The printer shall be capable of printing at least 64 ASCII characters, 80 characters per line, with a writing speed of 30 char/sec on standard width paper forms.

5.1.9 Automatic Speech Recognition Device

A voice data entry device may be provided to permit the operator to input feature identification codes during compilation without having to interrupt photo and map viewing. The voice entry device shall have the following features:

Vocabulary of at least 50 words

Training Mode

Data Editing Capability - "Erase", "Cancel"

Voice response or alternative A/N display

Audible Reject Alarm

Recognition Accuracy > 98%

Accommodate background noise from normal office levels to 60-70 dB.

5.1.10 *Computing Subsystem Hardware*

The computational subsystem will provide logical control for the compilation process including setup, picking of control, orientation, storage of map coordinates and digitized features with identification codes, transformation of digitized values to map coordinates, and performance of edit and symbolization of the digital features. The computational subsystem hardware shall consist of the following:

1 Minicomputer with floating point hardware

1 Microprocessor chip with added calculator chip

1 32K bit RAM with DMA

1 Floppy disk with 6.4 M bit capacity or equivalent bubble memory

1 Magnetic Tape Unit (9 track, dual density)

6 32K 16 bit ROM or Disk equivalent

5.1.11 Computing Subsystem Software

The computing system software will consist of the following related software modules: Process Control Module; Photogrammetric Resection Module; Compilation Module; Pseudo-Digital Terrain Model, Generation Module; Orthoprinter Module; and Edit Module. The entire software present on the system shall operate in such a manner so as to constitute a complete system, with minimum operator intervention beyond the responses to questions asked by the software. All software shall be written in such a manner so as to be easily modified by a programmer of reasonable experience. Code shall be liberally commented, and shall be written in a high level language such as ANSI FORTRAN IV whenever possible. Full documentation to include both operations manuals and a detailed discussion of the program modules and program flows shall be prepared.

Process Control Module: The process control module shall provide all logical guidance for the proper execution of the software sequences which are necessary for the execution of the map update process. This module will carry on an interactive communication with the operator and will call the various other modules in the required order to perform the sequence of operations desired by the operator. All questions to the operator shall be stated in simple English, with responses kept to a simple Yes/No in as many cases as possible. Selection of an item from a menu is permissible, but the memorization of mnemonic words or phrases is to be avoided.

Photogrammetric Resection Module: The photogrammetric resection module shall provide for the recovery of the taking parameters for the following sensors: Frame photography (both intralens and focal plane shutter); Side looking radar (slant range presentation), Panoramic photography (film motion IMC only) and; thermal infrared scanner imagery. The model shall be sufficiently accurate so as to allow the compilation of updates to at least 1/50,000 Class B accuracy, provided an adequate terrain model is available. The module will perform a pseudo-orthographic rectification with a terrain model, and will produce plane rectified output if relief is held constant.

All operator communication with the program will be performed in the interactive mode, with the program prompting the operator for his answers. Diagnostic information will be provided by the program to allow the operator to determine the quality of his solution, so that he can determine whether to proceed based upon the results of that solution, or whether the solution should be redone.

Compilation Module: The compilation module shall provide control for the update compilation process. It shall provide the following services: Interact with the operator to control the logical flow of the operations; plot the updates on a plasma panel underlying the map sheet, so that the operator can see those updates which have been made; drive the map stage to keep it aligned with the area of the model currently being viewed; and provide for the deletion of updates made incorrectly.

Pseudo-Digital Terrain Model Generation Module: This module will control the measurement of points and the generation of a digital terrain model from inputs of map coordinates and heights for points located on the map area of interest. The program shall interact with the operator, so that detailed operator instructions will be unnecessary. At the conclusion of the digital terrain model generation, the program shall ask the operator to measure check points. The program shall then interpolate within the derived digital terrain model for the height of the terrain at these check points, and compare this value with the value entered by the operator. Should the discrepancy be greater than the operator feels that he can operate, or greater than some preset constant in the program, the program shall require that the operator measure more points until the conditions can be satisfied.

Orthoprinter Module: This module shall transform the results of the pseudo-digital terrain model generation module unto a scan profile format suitable for driving the offline orthoprinter. This module will also transform the plane rectification results into a scan profile format with constant elevation to drive the orthophoto printer.

Edit Module: The edit module shall provide an online capability for the creation of directly plottable line and symbol manuscript from the map update terminal. It shall provide output to the interactive graphics terminal of the feature updates, in cartographic symbolization, so that the operator can modify the compiled changes to insure that the final product will be legible to the eventual user. All communication with the operator will be interactive, with the operator having to input only binary answers to questions in most instances. The edit module, upon completion, shall generate a tape to drive the offline X-Y plotter which generates the final output manuscript.

5.1.12 Offline X-Y Plotter

The offline X-Y plotter will produce paper, drafting film, or scribe coat camera ready manuscripts suitable for final color separation finishing. The plotter shall be capable of a plot area of approximately 24 x 30 inches. Required resolution and accuracy is .001" and .005" respectively. Maximum plotting speed shall be at least 10 ips. A controller shall be provided that accepts 9 track 1600 bpi or 800 bpi magnetic tape. The plotting head shall accommodate ink or scribing heads of variable widths. A desirable option would be a photo head with interchangeable symbol wheels.

5.1.13 Offline Orthoprinter

The offline orthoprinter shall be suitable for the production of plane and differentially rectified image products from frame, panoramic, SLAR and electro-optical scanner imagery. The orthoprinter shall be a projection type where illuminated elements of the input photo are transformed by a zoom lens and a dove prism to allow continuous image element rotation and magnification change to correct for sensor and terrain image distortions. The basic zoom magnification shall be approximately .4 - 2X. Image rotation shall be at least ±1 radian. The input format shall be at least 9.5 x 9.5 inches with an output format of at least 19 x 19 inches. Slit masks of variable sizes shall be provided. Limiting resolution for high contrast targets shall be at least 40 l/mm. The orthoprinter shall have a maximum scanning speed of at least 10 mm/sec. A controller shall be provided that will except 9 track, 800 or 1600 bpi NRZI or phase encoded magnetic tape. A data terminal or control console shall be provided as a communication device. Lighttight input and output photo carriers or drums shall be provided so that printer operations can be conducted under normal room lighting conditions.

5.1.14 Support Equipment

The advanced map update system shall include the following equipment for photographic and reproduction support.

Contact Printer

Process Camera

Film Processors

Platemaker

Lithographic Press

Ozalid Copier

The equipment of the above categories now selected for inclusion in the TSS is satisfactory for inclusion in the advanced map update system.

5.1.15 Maintenance

Maintenance manuals and full documentation shall be provided for all system components. All components and assemblies that require routine maintenance or parts replacement shall be designed so that no special operator skills or training is required.

5.1.16 Environment

All system components shall be capable of operating within the TSS mobile van controlled environment. In a non-operating status all equipment shall be capable of storage and transit within the climatic categories and transport modes envisioned for the TSS. Suitable shipping/storage cases shall be provided.

5.2 Stereoscopic Advanced Map Update System

5.2.1 General

The Stereoscopic Advanced Map Update System shall be suitable for the compilation of Class B topographic map products from monoscopic or stereoscopic mapping and tactical reconnaissance imagery. The system may include a capability to produce rectified photographs or orthophotographs.

5.2.2 Input Data

The system shall accept film positive or paper positive imagery at original scale in widths to 9.5 inches. Frames that exceed 9.5 inches in length will be compiled in separate setups. Input data will include imagery from vertical frame, oblique frame, panoramic, SLAR, and other electro-optical sensors.

5.2.3 Photo Stages

Two independent stages shall be provided as a secure mounting surface and digitizing platen for the input imagery. Each stage shall be selectively illuminated, front or rear, depending upon input imagery media. The illumination source shall be of variable intensity, controlled by the operator, and shall not cause thermal distortion of the imagery. Provision shall be made to hold the imagery flat against the stage and fixed in place throughout compilation. Each photo stage will be 10 x 10 inches and shall be capable of 10 inch travel along each axis. Each stage shall be encoded to have a measurement capability of .0001" resolution and .0005" accuracy (1σ).

Stage motion will be directed by the operator and interfaced to the computer to allow independent movement of each stage, as during setup; or simultaneously driven with one stage computer-slaved to the one under operator control, so as to maintain the photogrammetric model. If the system orthophoto option is selected, the photo stages shall be capable of automatic one-axis scanning and opposite axis stepping with operator selected speed control.

5.2.4 Map Stage

The map stage shall be capable of accepting a full-sized map sheet, in paper, film, or scribe coat form without cutting or otherwise destroying the original input copy. The viewable area of the map during any single compilation setup shall be 10 x 10 inches. Positioning of the map sheet between compilations shall be readily accomplished. The map shall be capable of 10 inch travel in both axis and shall be servo driven by the computer to maintain alignment with the photo model. The map stage shall be encoded to have a measurement capability of .002" resolution and .005" accuracy. The map stage shall be illuminated so that the operator can select on, off, or flicker modes. A plasma panel will be incorporated into the viewable area of the map stage to provide an online display of compilation data registered to the map. The panel shall be at least 9 x 5 inches, and shall have a resolution of at least 60 dots per inch. A larger size plasma panel no greater than 10 x 10 inches would be desirable. The panel shall have sufficient brightness so that displayed information is readily visible to the operator.

5.2.5 Viewing Optics

An optical system that permits correct, superimposed viewing of both the input imagery and the source map shall be provided. The photo viewing optics may be encoded and servo driven by the computer subsystem so that once setup, the operator will not need to readjust the optics during compilation. The map viewing optics shall have fixed magnifications of 0.75, 1, and 2. A dot reticle that can be interposed into the map viewing optics of 500 $\pm$ 100 micrometers shall be provided. Specifications for the photo viewing optics are given below.

Photo Viewing Optics

Zoom Range 4:1 Minimum

Fixed Magnifications 0.6 and 2.3

Image Rotation 360°

Anamorphic Magnification Range 1:1 to 2:1

Anamorphic Rotation $\pm 90^{\circ}$

Field of View 190mm/magnification

Interchangeable Dot Reticles of

30, 100, 300 and 1,000 micrometers ($\pm$10%)

Opaque, luminous or projected reticles will be acceptable.

The optical system shall incorporate an optical switch so that the operator can view the imagery in steroscopic or monoscopic modes. (In stereo, left eye: left photo; right eye: right photo, map. In mono, left eye and right eye: map and photo.)

5.2.6 Control Console

The control console shall permit the operator to operate all compilation station subsystems and to monitor operating status. Controls will include on/off power switches, illumination intensity controls, status indicators, photo and map stage motion controls, and digitizing mode controls. The control console may include a means for the operator to input operations codes or feature identifications during compilation.

5.2.7 Interactive Graphics

An interactive graphics subsystem will be provided to allow operator communication with the computer and serve as a final edit station. The graphics subsystem shall display the compilation data in symbolized form with sufficient resolution to permit a cartographic edit. The display shall be a large size, high resolution, refresh CRT, or a small format X-Y plotter. The CRT display brightness shall be at least 100 foot lamberts spot brightness. A full ASCII A/N keyboard shall be provided with at least 16 function keys. Recommended display specifications are given below.

Screen Size:	At Least 19" Diagonal, Rectangular Format
Addressable Locations:	At least 2048 x 2048
Display Locations:	At least 1024 x 1024
Character Generator-Stroke or Matrix:	Display at least 64 ASCII characters and special cartographic symbols
Line Generator-Vector:	Blink, solid line, dashed line, and dot; variable size and spacing
Independent Intensity and Contrast Control	
Cursor or Light Pen for Interactive Edit	

As an alternative to the interactive CRT graphic system an online X-Y plotter may be provided for data edit and output plots. This plotter shall be capable of plotting a 10x10 inch area with an accuracy of at least .01". The plotter shall accommodate drafting film or paper media. A desirable feature would be a capability for automatic multicolor plotting.

5.2.8 Data Terminal

If the interactive CRT graphics is not adopted, a full ASCII A/N keyboard and printer shall be provided for communication with the computer. The printer shall be capable of printing at least 64 ASCII characters, 80 characters per line, with a writing speed of 30 char/sec on standard width paper forms.

5.2.9 Automatic Speech Recognition Device

A voice data entry device may be provided to permit the operator to input feature identification codes during compilation without having to interrupt photo and map viewing. The voice entry device shall have the following features:

Vocabulary of at least 50 words
Training Mode
Data Editing Capability - "Erase", "Cancel"
Voice response or alternative A/N display
Audible Reject Alarm
Recognition Accuracy > 98%
Accommodate background noise from normal office levels to 60-70 dB

5.2.10 Computing Subsystem Hardware

The computational subsystem will provide logical control for the compilation process including setup, picking of control, interior and exterior orientation, storage of digitized features with identifications codes, transformation of digitized values to map coordinates, and performance of edit and symbolization of the digitized features. The computational subsystem hardware shall consist of the following:

1 Minicomputer with floating point hardware
1 Microprocessor chip with added calculator chip
1 32K bit RAM with DMA
1 Floppy disk with 6.4 M bit capacity or equivalent bubble memory
1 Magnetic Tape Unit (9 track, dual density)
6 32K 16 bit ROM or Disk equivalent

5.2.11 Computing Subsystem Software

The computing system software will consist of the following related software modules: Process Control Module; Photogrammetric Resection Module; Compilation Module; Pseudo-Digital Terrain Model Generation Module; Orthoprinter Module; and Edit Module. The entire software present on the system shall operate in such a manner so as to constitute a complete system, with minimum operator intervention beyond the responses to questions asked by the software. All software shall be written in such a manner so as to be easily modified by a programmer of reasonable experience. Code shall be liberally commented, and shall be written in a high level language such as ANSI FORTRAN IV whenever possible. Full documentation to include both operations manuals and a detailed discussion of the program modules and program flows shall be prepared.

Process Control Module: The process control module shall provide all logical guidance for the proper execution of the software sequences which are necessary for the execution of the map update process. This module will carry on an interactive communication with the operator and will call the various other modules in the required order to perform the sequence of operations desired by the operator. All questions to the operator shall be stated in simple English, with responses kept to a simple Yes/No in as many cases as possible. Selection of an item from a menu is permissible, but the memorization of mnemonic words or phrases is to be avoided.

Photogrammetric Resection Module: The photogrammetric resection module shall provide for the recovery of the taking parameters for the following sensors: Frame photography (both intralens and focal plane shutter); Side looking radar (slant range presentation); panoramic photography (film motion IMC only) and; thermal infrared scanner imagery. The module shall be sufficiently accurate so as to allow the compilation of updates to at least 1/50,000 Class B accuracy, provided adequate control is available. Control will, in most cases, be scaled from existing map sheets, but may be available in coordinate form. The module must operate in both stereo and monoscopic modes. With stereo imagery, this module will produce a full analytical solution with relief displacement correction. With mono imagery, the module will perform an orthorectification solution, using the results of the pseudo-DTM generation module.

All operator communication with the program will be performed in the interactive mode, with the program prompting the operator for his answers. Diagnostic information will be provided by the program to allow the operator to determine the quality of his solution, so that he can determine whether to proceed based upon the results of that solution, or whether the solution should be redone.

Compilation Module: The compilation module shall provide control for the update compilation process. It shall provide the following services: Interact with the operator to control the logical flow of the operations; continually clear parallax in the photogrammetric model by commands to the photo carriage servo mechanism; plot the updates on a plasma panel underlying the map sheet so that the operator can see those updates which have been made; drive the map stage to keep it aligned with the area of the model currently being viewed; and provide for the deletion of updates made incorrectly. The compilation module must operate in either the monoscopic or stereoscopic modes.

Pseudo-Digital Terrain Model Generation Module: This module will control the measurement of points and the generation of a digital terrain model from inputs of map coordinates and heights for points located on the map area of interest. The program shall interact with the operator, so that detailed operator instructions will be unnecessary. At the conclusion of the digital terrain model generation, the program shall ask the operator to measure check points. The program shall then interpolate within the derived digital terrain model for the height of the terrain at these check points, and compare this value with the value entered by the operator. Should the discrepancy be greater than the operator feels that he can operate, or greater than some preset constant in the program, the program shall require that the operator measure more points until the conditions can be satisfied.

Orthoprinter Module: This module shall transform the results of the plane rectifications, pseudo-digital terrain generation, and terrain profiling compilation methods to produce a tape to drive the offline orthoprinter.

Edit Module: The edit module shall provide an online capability for the creation of directly plottable line and symbol manuscript from the map update terminal. It shall provide output to the interactive graphics terminal of the feature updates, in cartographic symbolization, so that the operator can modify the compiled changes to insure that the final product will be legible to the eventual user. All communication with the operator will be interactive, with the operator having to input only binary answers to questions in most instances. The edit module, upon completion, shall generate a tape to drive the offline X-Y plotter which generates the final output manuscript.

5.2.12 Offline X-Y Plotter

The offline X-Y plotter will produce paper, drafting film, or scribe coat camera ready manuscripts suitable for final color separation finishing. The plotter shall be capable of a plot area of approximately 24 x 30 inches. Required resolution and accuracy is .001" and .005" respectively. Maximum plotting speed shall be at least

10 ips. A controller shall be provided that accepts 9 track 1600 bpi or 800 bpi magnetic tape. The plotting head shall accommodate ink or scribing heads of variable widths. A desirable option would be a photo head with interchangeable symbol wheels.

5.2.13 Offline Orthoprinter

The offline orthoprinter shall be suitable for the production of plane and differentially rectified image products from frame, panoramic, SLAR and electro-optical scanner imagery. The orthoprinter shall be a projection type where illuminated elements of the input photo are transformed by a zoom lens and a dove prism to allow continuous image element rotation and magnification change to correct for sensor and terrain image distortions. The basic zoom magnification shall be approximately .4-2x. Image rotation shall be at least $\pm$ 1 radian. The input format shall be at least 9.5 x 9.5 inches with an output format of at least 19 x 19 inches. Slit masks of variable sizes shall be provided. Limiting resolution for high contrast targets shall be at least 40 l/mm. The orthoprinter shall have a maximum scanning speed of at least 10 mm/sec. A controller shall be provided that will except 9 track, 800 or 1600 bpi NRZI or phase encoded magnetic tape. A data terminal or control console shall be provided as a communication device. Lighttight input and output photo carriers or drums shall be provided so that printer operation can be conducted under normal room lighting conditions.

5.2.14 Support Equipment

The advanced map update system shall include the following equipment for photographic and reproduction support.

Contact Printer
Process Camera
Film Processors
Platemaker
Lithographic Press
Ozalid Copier

The equipment of the above categories now selected for inclusion in the TSS is satisfactory for inclusion in the advanced map update system.

5.2.15 Maintenance

Maintenance manuals and full documentation shall be provided for all system components. All components and assemblies that require routine maintenance or parts replacement shall be designed so that no special operator skills or training is required.

5.2.16 Environment

All system components shall be capable of operating within the TSS mobile van controlled environment. In a non-operating status all equipment shall be capable of storage and transit within the climatic categories and transport modes envisioned for the TSS. Suitable shipping/storage cases shall be provided.

5.3 Representative Component Vendors

Representative sources for major components or subassemblies of the advanced map update systems are listed below. Excluded is all of the support equipment and those subassemblies that are engineering design items rather than purchased components.

Voice Recognition Device	-	Threshold Technology, Inc.
Plasma Panel	-	Science Applications, Inc.
Viewing Optics	-	Bausch and Lomb
Map and Photo Stage Linear Encoders	-	Dynamic Research, Inc.
Minicomputer	-	ROLM, Inc.; Norden
Microprocessor	-	Intel
Computational Chip	-	Advanced Micro Devices, Inc.

Bubble Memory	-	Texas Instruments
Magnetic Tape Unit	-	Univac
CRT Interactive Graphics	-	Sanders; M&S Computing Corp.
Small X-Y Plotter	-	Textronix; Others
Keyboard Printer	-	ROLM, Inc; Norden
Offline X-Y Plotter	-	H. Dell Foster (11/75)
Offline Orthoprinter	-	Wild (OR-1)

6. SYSTEM COMPONENT COSTS

Table 2 presents estimated costs for the development and unit production of both system's subsystem components, based on the technical characteristics presented in the preceeding section. To reflect more accurately total procurement costs, full system hardware and software documentation costs and design and fabrication costs of compilation station shipping/storage cases have been included. Costs of hardware acceptance testing, personnel training, and provision of maintenance spare parts have been omitted, since they all will require further detailed definition, outside of the scope of this design study.

All costs are based upon current year price levels and do not include any dollar inflation or price reduction factors. Costs for the compilation subsystem's hardware reflect purchase of military hardened components which results in a significantly higher total as compared to a system using commercial quality components. (As an example, excluding the system software, the compilation subsystem developmental cost is about 50% greater than the cost using commercial parts.)

Costs for parts were obtained from manufacturer's brochures and parts catalogs, from budgetary quotes from discussions with sales representatives, and from costs contained in TSS documents. Developmental and production engineering and fabrication costs reflect labor estimates prepared by Raytheon Company/Autometric.

Procurement costs for the offline X-Y plotter, orthoprinter, and support equipment are based on manufacturer's quotes and TSS planning documents. Since all of this equipment is now planned, or under consideration for inclusion in TSS, it is assumed that none or only minor developmental effort will be required for field deployment.

I. COMPILATION SUBSYSTEM	Material ($000)	Deveoplmental Engr. & Fabrication ($000)		Production Fabrication ($000)
A. Computational Hardware				
1. Minicomputer	15.0			
2. Microprocessor	1.0			
3. Computational Chip	0.7			
4. RAM Memory	3.0			
5. Disk or Bubble Memory	15.0			
6. Tape Unit & Controller	28.5			
7. Power Supplies, Cables Connectors, Racks, etc.	8.0			
8. Voice Recognition Device	16.0			
9. Interactive CRT w/Keyboard	40.0			
10. Keyboard/Printer	10.0			
11. X-Y Plotter	15.0			
Subsystem Integration		135.0		12.0
B. Software		(Mono)	(Stereo)	
1. Process Control Module		22.5	25.0	
2. Photogrammetric Module		35.0	40.0	
3. Compilation Module		50.0	55.0	
4. Pseudo-Digital Terrain Model Module		GFE	GFE	
5. Edit Module		30.0	30.0	
6. Orthoprinter Module		35.0	35.0	
7. Software Documentation		80.0	90.0	
C. Compilation Station				
1. Mono Photo Stage	13.5	26.0		6.0
2. Stereo Photo Stages	27.0	52.0		12.0
3. Map Stage	13.5	26.0		6.0
4. Mono Optical System	10.0	17.5		5.0
w/Servo Optics	19.0	34.5		11.0
5. Stereo Optical System	10.0	35.0		10.0
w/Servo Optics	22.0	57.5		18.0
6. Plasma Panel	30.0	3.0		1.0
7. Control Console	10.0	16.0		4.0
D. Offline X-Y Plotter & Controller	45.0	15.0		5.0
E. Offline Orthoprinter & Controller	200.0	15.0		5.0

Table 2 - Advanced Map Update Systems Component Costs

	Material ($000)	Developmental Engr. & Fabrication ($000)	Production Fabrication ($000)
F. Support Equipment			
1. Process Camera	16.0		
2. Camera Film Processor	20.0		
3. Contact Printer	27.5		
4. Contact Printer Film Processor	15.0		
5. Platemaker	4.5		
6. Lithographic Press	37.0		
7. Ozalid Copier	1.0		
G. Storage/Shipping Containers			
1. Mono	7.5	8.1	7.5
2. Stereo	9.0	9.6	9.0
H. System Hardware Documentation		100.0	10.0

Table 2 (cont'd) - Advanced Map Update System Component Costs

The costs for the storage/shipping containers are for the compilation station only, for the reasons given in the preceeding paragraph. It is assumed that the containers themselves will be standard Army issue, GFE. Costs reflect design, purchase, and fabrication of the container interior for the compilation station's subsystems.

The system hardware documentation costs includes preparation of detailed compilation subsystem design, maintenance, and operation manuals. It is assumed that comparable documentation will be available in TSS or from vendors for the offline and support equipment. Equivalent documentation for system software is included in the software costs estimate.

Table 3 presents development and production cost estimates for mono and stereo systems with the various system options and alternatives. The compilation subsystem subtotals should be noted, since they reflect the actual unit procurement price. The support equipment and offline equipment can support multiple compilation stations and very likely will only be required in one unit-per field deployed system.

Table 4 presents total system costs for each of the two system's alternative configurations.

	MONO SYSTEM Dev.	MONO SYSTEM Prod.	STEREO SYSTEM Dev.	STEREO SYSTEM Prod.
I. COMPILATION SUBSYSTEM				
A. Computational Hardware				
1. CRT Interactive Graphics Alternative	246.2	123.2	246.2	123.2
w/Voice Entry Device Option	262.2	139.2	262.2	139.2
2. X-Y Plotter Interactive Graphics Alternative	231.2	108.2	231.2	108.2
w/Voice Entry Device Option	247.2	124.2	247.2	124.2
B. Computational Software	252.5		275.0	
C. Compilation Station				
1. w/o Servo Optics	165.5	99.0	222.5	123.5
2. w/Servo Optics	191.5	114.0	257.0	143.5
D. Subtotals				
1. CRT Interactive Graphics Alternative	664.2	222.2	743.7	246.7
a) w/Voice Entry	680.2	238.2	759.7	262.7
b) w/Servo Optics	690.2	237.2	778.2	266.7
c) w/Voice Entry & Servo Optics	706.2	253.2	794.2	282.7
2. X-Y Plotter Interactive Graphics	649.2	207.2	728.7	231.7
a) w/Voice Entry	665.2	223.2	744.7	247.7
b) w/Servo Optics	675.2	222.2	763.2	251.7
c) w/Voice Entry & Servo Optics	691.2	238.2	779.2	267.2
II. OFFLINE X-Y PLOTTER	60.0	50.0	60.0	50.0
III. OFFLINE ORTHOPRINTER	215.0	205.0	215.0	205.0
IV. SUPPORT EQUIPMENT	120.5	120.5	120.5	120.5
V. STORAGE/SHIPPING CASES	15.6	15.0	18.6	18.0
VI. SYSTEM HARDWARE DOCUMENTATION	100.0	10.0	100.0	10.0

Table 3 - Comparative Subsystem Costs ($000)

	MONO SYSTEM Dev.	MONO SYSTEM Prod.	STEREO SYSTEM Dev.	STEREO SYSTEM Prod.
1. CRT Interactive Graphics Alternative	925.3	417.7	1007.8	445.2
a) w/Voice Entry	941.3	433.7	1023.8	461.2
b) w/Servo Optics	951.3	432.7	1042.3	465.2
c) w/Voice Entry & Servo Optics	967.3	448.7	1058.3	481.2
2. X-Y Plotter Interactive Graphics Alternative	910.3	402.7	992.8	430.2
a) w/Voice Entry	926.3	418.7	1008.8	446.2
b) w/Servo Optics	936.3	417.7	1027.3	450.2
c) w/Voice Entry & Servo Optics	952.3	433.7	1043.3	466.2
3. CRT Interactive Graphics Alternative w/Orthoprinter	1175.3	622.7	1257.8	650.2
a) w/Voice Entry	1191.3	638.7	1273.8	666.2
b) w/Servo Optics	1201.3	637.7	1292.3	670.2
c) w/Voice Entry & Servo Optics	1217.3	653.7	1308.3	686.2
4. X-Y Plotter Interactive Graphics Alternative w/Orthoprinter	1160.3	607.7	1242.8	635.2
a) w/Voice Entry	1176.3	623.7	1258.8	651.2
b) w/Servo Optics	1186.3	622.7	1277.3	665.2
c) w/Voice Entry & Servo Optics	1202.3	638.7	1293.3	671.2

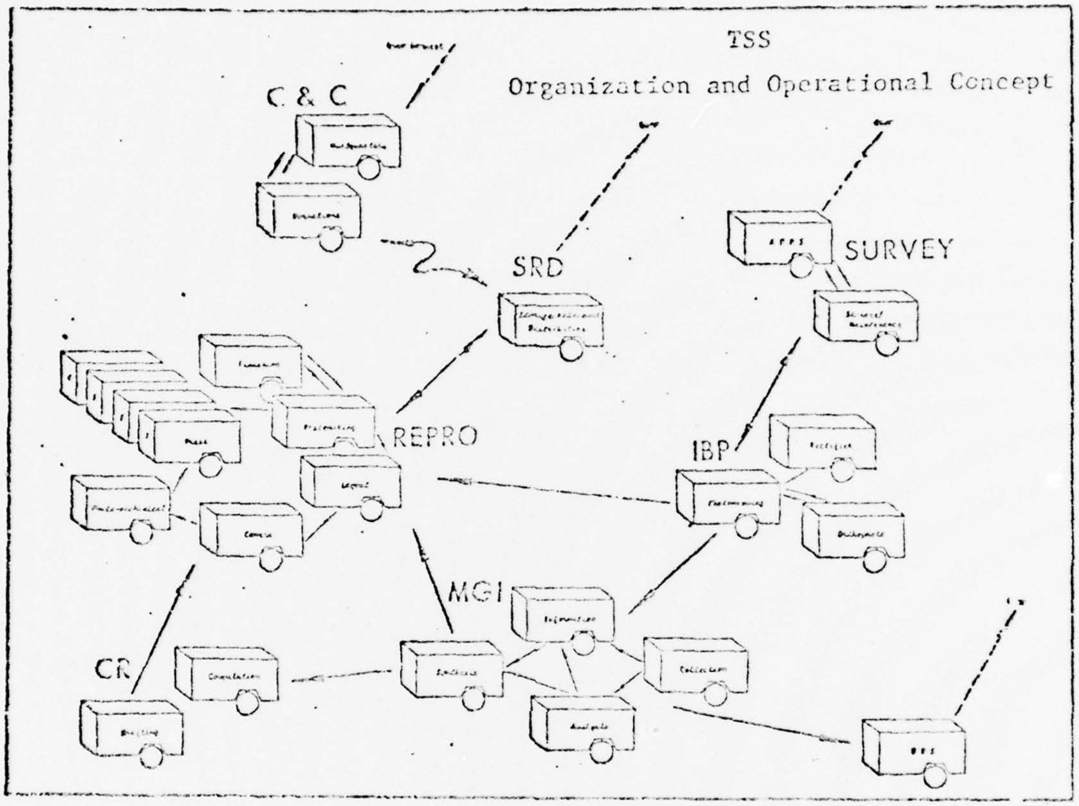
Table 4 - Comparative System Total Costs

7. FIELD DEPLOYED VAN LAYOUT

Figure 2 presents allocation of the advanced map update system equipment among the TSS subsystems. This is based upon the TSS organization plan provided to Raytheon Company/Autometric for this study. The basic organizational structure is shown below.

TSS Organizational Structure

Subsystem	Function
Command and Control (C&C)	Administration and management Process User Requests
Storage, Retrieval and Distribution (SRD)	Data Bank Storage Stock finished products
Reproduction (REPRO)	Reproduce TSS products and provide camera support to other subsystems
Cartographic Revision (CR)	Finishing of manuscripts Update Data Bank
Survey (SURVEY)	Surveying and point positioning
Image Base Products (IBP)	Photo processing, image transformations, and reproduction. Rectification, mosaicing, scaling, orthophotos, and stereo compilation
Military Geographic Information (MGI)	Terrain Analyses



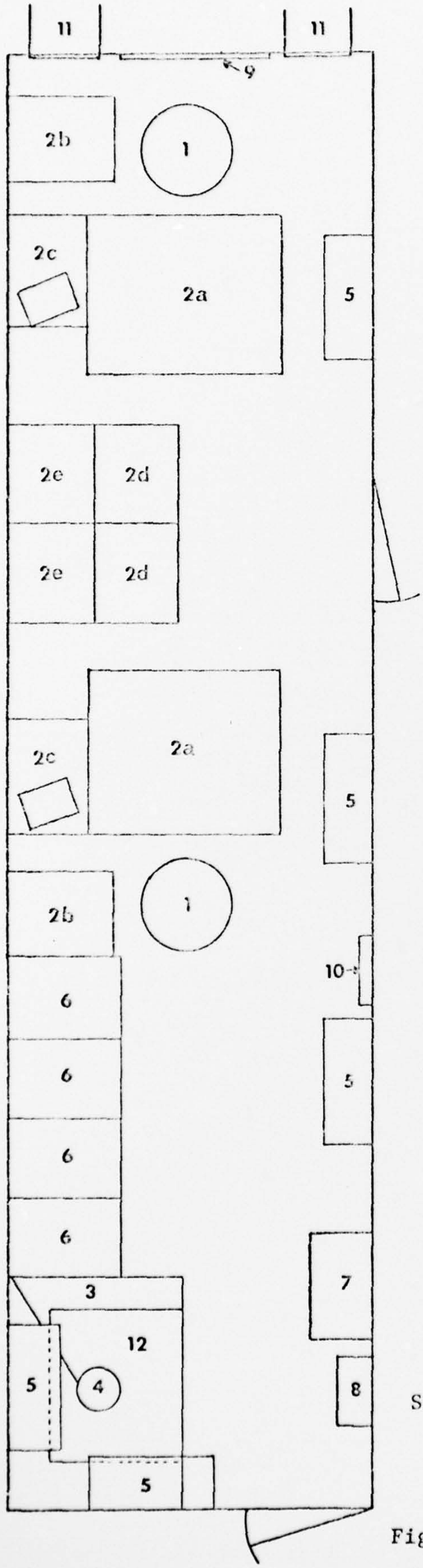
From: "A Systems Design Study for a Topographic Support System," January, 1976, page 8.

TSS Organization

Equipment	TSS Subsystem/Module
a. Compilation Subsystem	Cartographic Revision/Compilation
b. Offline X-Y Plotter	Cartographic Revision/Drafting
c. Offline Orthoprinter	Image Base Products/Orthophoto or Rectifier
d. Support Equipment	Reproduction/Camera, Photo mechanical Plate Processing, Press, and, Image Base Products/Orthophoto or Rectifier

Figure 2 - Allocation of Advanced Map Update System Components

Figures 3 through 5 portray van layouts for the compilation subsystem, offline X-Y plotter, and offline orthoprinter respectively. Plans are based upon a semitrailer mounted shelter 30' x 8' x 8' in size. This is the TSS shelter used in floor plans provided to Raytheon Company/Autometric for this study. The van layout plans are for illustration only and do not propose to indicate deletion of equipment now included in the TSS plan.



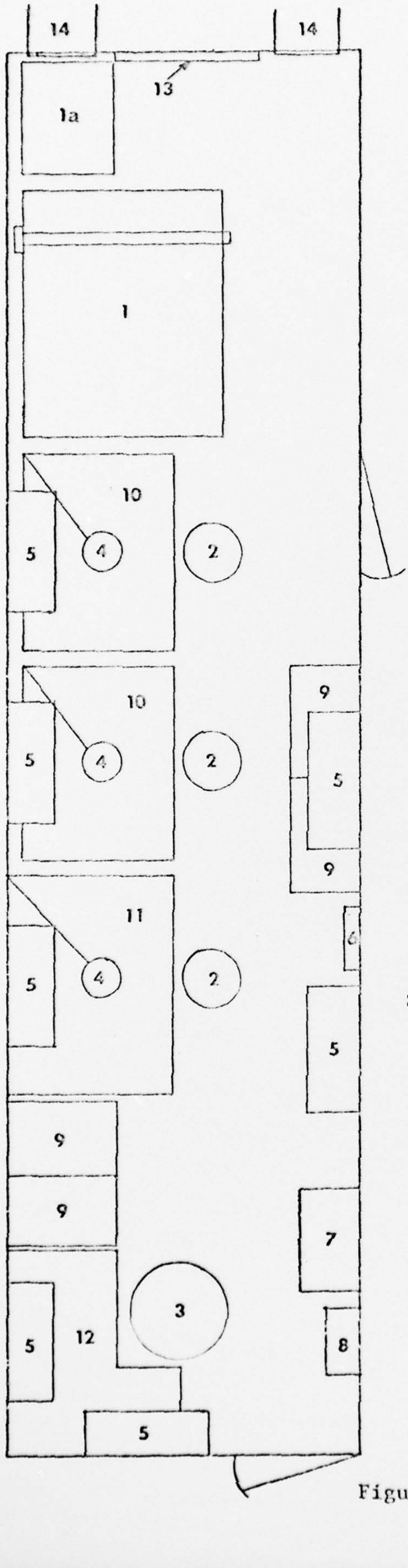
CARTOGRAPHIC REVISION SUBSECTION
COMPILATION MODULE
SEMITRAILER MOUNTED

1. Chair
2. Advanced Map Update Compilation Subsystem
   a. Compilation Station
   b. Interactive Graphics
   c. Voice Entry Device
   d. Magnetic Tape Unit
   e. Minicomputer/Disk Storage
3. Filing Cabinet, Map & Plan
4. Magnifier Lamp
5. Cabinet, Storage, Wall
6. Filing Cabinet, Legal Size
7. Humidifier, Dehumidifier
8. Panel Box
9. Tracing Board
10. Exhaust Fan
11. Air Conditioner
12. Light Table

Note: Shown is the stereo system's compilation station; the mono system's compilation station will have a smaller table size. However, the overall floor plan would probably not change too radically from that shown here.

Scale: 1" = 40"

Figure 3 - Compilation Subsystem Van Layout



CARTOGRAPHIC REVISION SUBSYSTEM MODULE

DRAFTING MODULE

SEMITRAILER MOUNTED

1. X - Y Plotter
1a. Plotter Controller
2. Stool
3. Chair
4. Magnifier Lamp
5. Cabinet, Storage, Wall
6. Exhaust Fan
7. Humidifier, Dehumidifier
8. Panel Box
9. Filing Cabinet, Legal Size
10. Table, Scribing, Tracing, Drafting
11. Filing Cabinet, Map and Plan
12. Composing Machine, Phototypesetter
13. Tracing Board
14. Air Conditioner

Scale: 1" = 40"

Figure 4 - Offline X -Y Plotter Van Layout

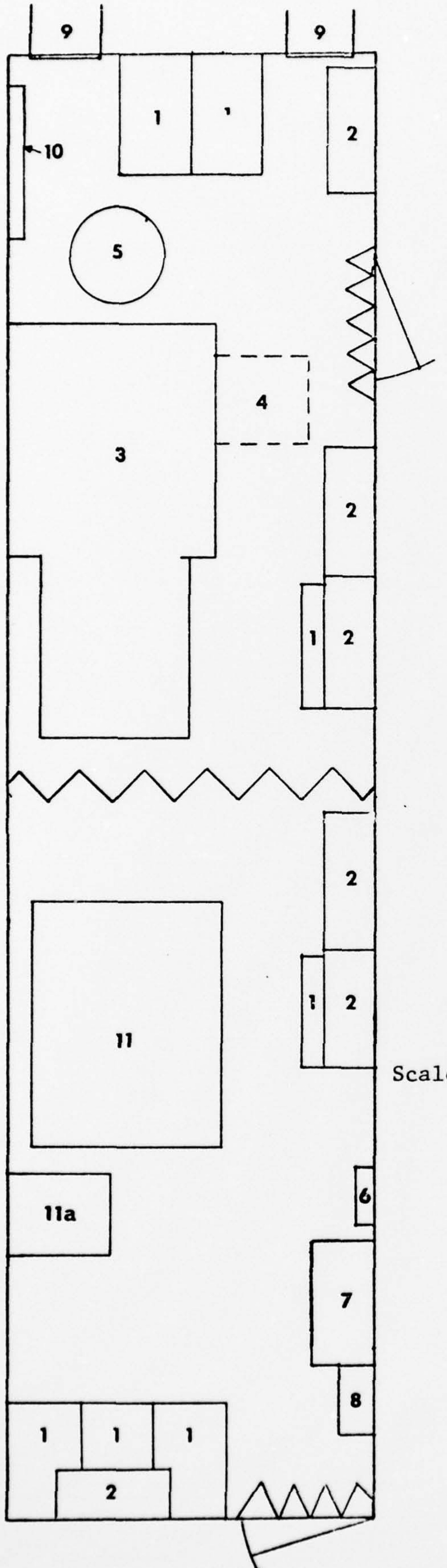


IMAGE BASE PRODUCTS SUBSYSTEM

ORTHOPHOTO MODULE

SEMITRAILER MOUNTED

1. Filing Cabinet, Legal Size
2. Cabinet, Storage, Wall
3. Ortho Projector
4. Pantograph
5. Chair
6. Exhaust Fan
7. Humidifier, Dehumidifier
8. Panel Box
9. Air Conditioner
10. Tracing Board
11. Offline Orthoprinter and Controller
11a. Orthoprinter Control Terminal

VVVV Curtain

Note: An alternative placement would be in the rectifier module

Scale: 1" = 40"

Figure 5 - Offline Orthoprinter Van Layout

8. SYSTEM TRADE-OFF ANALYSIS

In order to depict the various trade-offs in system cost, performance, and efficiency, an analysis of system throughput for a map update task was performed. The results of this analysis was then combined with cost considerations and normalized so that an overall assessment of each system and the various alternative system configurations could be presented.

The map update task selected to formulate compilation times was based on a complete revision of a 1:50,000 topographic map having a ground coverage of 620 km^2. The input photography was assumed to be vertical frame photography having a scale of 1:27,000. The map age was six years relative to the input photography. The final product was to be single color overprint of feature additions to a corrected original map manuscript (deletions made), reproduced on the lithographic press. Table 4 presents values for the map update scenario.

The compilation man hours and elapsed times were estimated by breaking the compilation processing into three phases and estimating the required time to complete each of the steps. The elapsed time is the total man hour time minus independent or overlapping processes. The first compilation time was for project planning, acquisition of working materials, imagery duplication and compilation preprocessing. This precompilation time was computed to be 3 and 4.5 hours, respectively, for the mono and stereo solutions.

The second phase consisted of compilation of the revision manuscripts and included setup, compilation, edit and plotting times. Totals for this phase ranged from 24 - 47.5 man hours depending upon the type of solution and system configuration.

Trade-Off Analyses Input Photography

Vertical Frame Photography

Focal Length	6"
Format	9" x 9"
Scale	1:27,000
Mode	60% Forward Lap
	20% Side Lap

2000 ft. elevation range in map area assumed.
Number of frames/map sheet (620 km^2, 1:50,000 map)

Mono	16
Stereo	38 (34 models)

Feature Update Volumes

Feature Type	Required Updates
Linear Features	
Number	351.9
Length (inches)	258.5
Point Feature	
Symbolized (Standard)	952.3
Symbolized (Non-Standard)	233.2
Area Features	
Water	
Number	49.10
Area (inches^2)	0.4
Length (inches)	7.96
Urban Tint	
Number	16.10
Area (inches^2)	4.28
Length (inches)	15.81

Table 5 - Trade-Off Analysis Map Update Scenario

The third and final phase included final edit and correction of the map manuscripts, names and border layout, final preparation of the color separation negatives, platemaking and press run. The man hour total for this phase was 12.5 hours.

Table 6 presents the results of the throughput analysis. The mono imagery case is based upon the pseudo-orthographic rectification solution while the stereo imagery case is based upon analytical stereo compilation. The mono solution requires greater time since the terrain model must be constructed in addition to feature update compilation. The additional time required for the mono case is somewhat ameliorated by a lower setup time for a single photo versus a stereo model, and the fewer number of mono frames as compared to the number of stereo models.

Also shown in Table 6 are the added compilation times that result from omitting the various system options and alternatives. The times shown, though based upon vertical frame photography, are representative of the compilation throughput for all the types of input imagery. Both systems have an equivalent capability for all sensor types, and each system's efficiency is relatively insensitive, by design, to different types of imagery.

The one exception to the equivalent sensor efficiency is associated with the servo optic option. Without this feature, compilation efficiency does vary with sensor type, and the servo optic option is more important with stereo imagery than with mono imagery. A weighting factor was used to change the compilation times based upon a postulated mix of imagery input as shown below, and a subjective assessment of the incremental efficiency to be lost without servo optics for each of the sensor types, also shown below.

	Input	Eff.	Σ
Vertical Frame	40%	-.2	.08
Panoramic	40%	-.5	.20
Oblique Frame	10%	-.5	.05
SLAR	10%	-.5	.05
Other	--		
		Lost Efficiency	.38

	Mono Imagery Man Hours	Mono Imagery Elapsed Time	Stereo Imagery Man Hours	Stereo Imagery Elapsed Time
I. Full Map Revision - Lithographic Output				
A. Full System Configuration (CRT, Voice Entry, Servo Optics)	48.5	42.0	42.5	35.0
B. System w/o Voice Entry Device	50.5	44.0	44.5	37.0
C. System w/o CRT Interactive Graphics	51.5	45.0	46.5	39.0
D. System w/o Servo Optics	52.5	46.0	48.5	41.0
E. Bare System Configuration (w/o CRT, Voice Entry, Servo Optics)	57.5	51.0	54.5	47.0
II. Image Products - Total Elapsed Time for One Frame/Model				
A. Orthorectification w/DTM[1]	2.4		2.6	
B. Orthorectification w/o DTM[2]	1.4		1.4	

[1]The mono case would use the pseudo-DTM generation technique transformed into a suitable scan profile format while the stereo case assumes conventional profiling of the stereo model.

[2]This case is a variation of orthorectification where ground elevation is held constant. Both the mono and stereo cases would use the same compilation procedure.

Table 6 - Comparison Throughput Comparison

Also shown in Table 6 is the time required to process a single image frame (limited to 10" x 10"),or equivalent stereo model, for plane rectified or orthophoto output, using either mono or stereo imagery.

To achieve a relative ranking of the two systems and their alternative configurations, labor and equipment costs were considered.

Equipment cost was computed by multiplying the system's hourly rental by the elapsed time. Hourly rental was based upon the normal business practice of capital equipment amortization. An eight year depreciation was assumed with full system utilization (365 day/year, 24 hours/day availability). Thus a system costing $100,000 would yield the hourly cost shown below.

$$\frac{\$100,000}{8\text{x}36\text{x}24} = \$1.43/\text{hour system cost.}$$

In the trade-off analysis, the system costs shown are for the total system production cost less the orthoprinter option. The latter is omitted since it is an option to both systems, and not necessary for the primary map update task. The orthoprinter option has an equivalent incremental cost effect on both systems, and thus would not change the comparative system ratings.

Labor cost was computed by multiplying the man hour total by an hourly rate reflecting required operator skill. It was assumed that both the mono and stereo systems would require the same level of operator skill, namely basic training in topographic mapping plus additional specialized training for the specific photogrammetric equipment and techniques. For the purpose of this analysis the operator's hourly rated used was $13.33/hour.

As mentioned, both systems are judged to be equal in terms of sensor and product capability. The one exception is that the stereo system can easily perform compilation of contours, spot heights, and height measurements, while the mono system cannot provide such information as easily or as reliably. For this reason, the mono system's total map update costs were increased by a factor of 0.05 to reflect this one difference between the two systems' capabilities.

A final system rating was formulated by normalizing all the alternative system results. This was accomplished by taking the lowest total map update cost and dividing it by each total update cost. The best candidate of the two systems and their alternatives would thus have a system rating of 1.0. A rating of 0.5 would indicate a relative cost effectiveness of 50%. Table 7 presents the results of the trade-off analysis.

Table 8 presents another comparison of relative costs and performance by showing the results of each column in Table 7 divided by the lowest value in each column. Also shown in Table 8 are column and row means for the two systems. The best performer in each category would have a value of 1.0. A rating of 1.5 would mean that in relative terms, the cost, man hours, etc. was 50% greater.

System	System Cost ($000)	Man Hours	Turn Around Time	Labor	Map Update Cost ($) System	Total*	System Ranking
I. MONO SYSTEM							
A. Full System Configuration (CRT, Voice Entry, Servo Optics)	448.7	48.5	42.0	646	269	963	.84
B. System w/o Voice Entry Device	432.7	50.5	44.0	673	272	995	.81
C. System w/o CRT Interactive Graphics	433.7	51.5	45.0	686	279	1016	.79
D. System w/o Servo Optics	433.7	52.5	46.0	700	285	1037	.78
E. Bare System Configuration (w/o CRT, Voice Entry, Servo Optics)	402.7	57.5	51.0	766	294	1116	.72
II. STEREO SYSTEM							
A. Full System Configuration (CRT, Voice Entry, Servo Optics)	481.2	42.5	35.0	566	241	807	1.00
B. System w/o Voice Entry Device	465.2	44.5	37.0	593	246	839	.96
C. System w/o CRT Interactive Graphics	466.2	46.5	39.0	620	260	880	.92
D. System w/o Servo Optics	461.2	48.5	41.0	646	270	916	.88
E. Bare System Configuration (w/o CRT, Voice Entry, Servo Optics)	430.2	54.5	47.0	726	289	1015	.80

*The mono system's total cost is increased by a factor of .05 to reflect its lower capability for vertical map update.

Table 7 - Trade-Off Analysis Results

System	System Cost ($000)	Man Hours	Turn Around Time	Labor	Map Update Cost ($) System	Total*	Mean
I. MONO SYSTEM							
A. Full System Configuration (CRT, Voice Entry, Servo Optics)	1.11	1.14	1.20	1.14	1.12	1.19	1.15
B. System w/o Voice Entry Device	1.07	1.19	1.26	1.19	1.13	1.23	1.18
C. System w/o CRT Interactive Graphics	1.08	1.21	1.28	1.21	1.16	1.26	1.20
D. System w/o Servo Optics	1.08	1.24	1.31	1.24	1.18	1.28	1.22
E. Bare System Configuration (w/o CRT, Voice Entry, Servo Optics)	1.00	1.35	1.46	1.35	1.22	1.38	1.29
Mean	1.07	1.23	1.30	1.23	1.16	1.27	
II. STEREO SYSTEM							
A. Full System Configuration (CRT, Voice Entry, Servo Optics)	1.19	1.00	1.00	1.00	1.00	1.00	1.03
B. System w/o Voice Entry Device	1.16	1.05	1.06	1.05	1.02	1.04	1.06
C. System w/o CRT Interactive Graphics	1.16	1.09	1.11	1.10	1.08	1.09	1.10
D. System w/o Servo Optics	1.14	1.14	1.17	1.14	1.12	1.14	1.14
E. Bare System Configuration (w/o CRT, Voice Entry, Servo Optics)	1.07	1.28	1.34	1.28	1.20	1.26	1.24
Mean	1.14	1.11	1.14	1.11	1.08	1.11	

*The mono system's total cost is increased by a factor of .05 to reflect its lower capability for vertical map update.

Table 8 - Comparison of Relative Costs and Performance

9. CONCLUSIONS AND RECOMMENDATIONS

The two designs presented here for an advanced map update capability both satisfy basic requirements in terms of sensor capability and product accuracy, and are significantly more efficient for map update compilation than existing equipment and techniques. The two methods of photogrammetric solution, the monoscopic pseudo-orthorectification, and the stereoscopic analytical mapping technique allow either system to process both stereo and mono input imagery to Class B output accuracy.

The mono solution (pseudo-ortho) is critical to both map update systems and will require further development and testing to refine the compilation procedures to be used. The online cartographic edit is also integral to both systems' efficient throughput and has been assumed to be available GFE as a proven production tool. It is important that this capability will indeed exist when a prototype map update system is developed.

The two advanced map update systems improve compilation throughput by reducing the times required for project planning, preparation of working materials, compilation, edit and drafting. However, there remains one area of the map update compilation process not treated by the systems' design. The reproduction of multicolor map update products still depends primarily upon lithographic printing, except for limited cases, and this can consume a significant portion of the map update compilation time. For very low volume issue, direct plotting on overlays or map stock, wash-on or photographic reproduction, and diazo foils can be used for multicolor products, but all these methods soon become ineffective from a time standpoint as the required issue quantity increases.

Color electrostatic reproduction has been demonstrated to be satisfactory in reproduction quality for various topographic products. A commercial color copier has been available for several years and is of comparable size, reliability and ease of operation to equivalent black and white copiers. There are no apparent technical barriers to developing a color copier capable of 1:50,000 series map reproduction that could be field deployed. If a suitable copier could be obtained it would do much to provide a fully optimal Field Army map update capability.

If a prototype advanced map update system is developed, it is recommended that the stereo system be selected. This system is more efficient than the mono system when stereo imagery is input and is somewhat more versatile in that vertical measurement is easily accomplished. A prototype stereo system will permit test of both the mono and stereo photogrammetric solutions and will allow evaluation of both stereo and mono system designs. It is also recommended that the compilation subsystem servo optics, voice entry and CRT interactive graphics be incorporated in the prototype development. Test and evaluation can be used to confirm and precisely define each optional component's cost effectiveness, and it will be more practical to discard components for a production system than to enter into a retrofit redesign.