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STUDY OF THE IMPACT OF THE GLOBAL POSITIONING SYSTEM ON ARMY SURVEY

Approved For Public Release
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This report was initiated to determine the impact of one new technology, the Global Positioning System(GPS), on Army survey. This report presents a brief synopsis of current field army survey units, methods, and equipment. It also gives a general description of the envisioned Global Positioning System with specific emphasis on the user segment, which will be deployed to the field. In addition, possible initial applications of GPS though augmentation of current survey methods and the possibility of deriving advanced concepts for operational deployment and techniques are presented. The conclusions are discussed which

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show that the GPS will significantly impact position and velocity determination particularly in four primary areas: response time manpower equipment, and accuracy

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1.0 INTRODUCTION

This report is prepared and submitted by DBA Systems, Inc. in response to the requirements set forth in contract No. DAAG-53-76-[redacted] entitled, *"Study of Impact of GPS on Army Survey"*. The descriptions, results and conclusions presented herein are based on an extensive literature search enhanced by interviews of personnel involved with the NAVSTAR Global Positioning System and with Army surveying units and missions.

Army structure, and particuliary the topographic community structure has been in a dynamic state of reorganization for the past few years and it appears that the topographic community will remain in such a state for the next four to five years. The army has recently undergone restructuring through an Echelons Above Division (EAD) concept which has eliminated the field army structure. The topographic community has reorganized into an Engineer Topographic Battalion, Theater Army and has eliminated the Engineer Base Topographic Battalion and the Engineer Topographic Battalion, Army. The Theater Army Battalion has not yet been fully implemented worldwide and the Topographic Corps Company, although being phased out, still remains. The topographic community now awaits the impending implementation of a new modular concept, the Topographic Support System (TSS). Although the missions, responsibilities and chains of command remain as dynamic as the army structure, the requirement for relative and absolute position determination in support of military maneuvers/missions remains unchanged. Throughout the Army Survey reorganization exercises, the basic equipment, methods and techniques of position determination have remained relatively unchanged. This study was initiated to determine the impact of one new technology, the Global Positioning System, on Army survey. In order to determine the relevancy of this report, the reader is encouraged to refer to the bibliography and particularily to the dates of documents made available during this investigation.

Section 2.0 of this report presents a brief synopsis of current field army survey units, methods and equipment. The descriptions presented are necessarily abbreviated in that only minimum requirements are presented. The section is presented to provide a ready reference of current activities as well as to add perspective to the report. Section 3.0 gives a general description of the envisioned Global Positioning System with specific emphasis on the user segment which will be deployed to the field. Section 4.0 illustrates possible initial applications of GPS through augmentation of current survey methods. Until such time that the GPS has been fully tested and implemented and a degree of confidence established in the system, such augmentation will prevail. Section 5.0 presents, through the use of brief, selected scenerios, the possibility of deriving advanced concepts for operational deployment and techniques.

Section 6.0 contains conclusions derived from the preceeding sections relevant to the impact of GPS. Finally, Section 7.0 presents recommendations and considerations for future developments in methods, missions, training, and expansion or improvement of mathematical models employed by the system. The appendicies are provided for a more detailed definition of survey types and descriptions of equipment and methods.

The Global Positioning System is a great step forward towards modernization of army survey. It will eventually relieve the field surveyor of the requirement of tying to existing control and of the laborious task of establishing base control surveys. It will also afford the surveyor with the luxury of real time, or at worst, near real time position determination and eliminate the tedious task of data reduction. The elimination of conventional surveys methods and equipment will not occur in the forseeable future, as many aspects of GPS remain to be investigated and tested. The GPS concept is definately a valid one and will certainly impact heavily on army position determination methods.

2.0 SYNOPSIS OF CURRENT FIELD ARMY SURVEY

This section is designed to give an overview of army field survey as it is currently defined and as it is envisioned in the very near future. Contained in this section are brief discussions relating to classification of survey, types of surveys, and unit missions and responsibilities.

2.1 Classification of Survey

Surveying, as defined by TM-5-232, is the science of determining relative positions of points on, under, or near the earth's surface. Furthermore, surveying can be categorized either technically or functionally. Technically, surveys are classed based on the size of the area to be covered, the precision of the equipment/methods used and the accuracy of the results obtained. Functionally, surveys are classed by the types of mission/work they support.

2.1.1 Technical Surveys

Two technical classes of survey exist. The first class is Geodetic and consists of surveys which account for the size and shape of the earth (e.g. earth curvature) and which employ very precise methods and equipment to obtain very accurate point locations from which other surveys may commence. The second class is the plane survey which does not consider the shape of the earth. Such surveys consider the earth to be a plane, and employ relatively imprecise methods and equipment. As the size of the area to be surveyed increases, the accuracy of results decreases.

Both types of technical surveys may be broken into several orders and classes based on the final accuracy obtained. Military requirements, along with unit capabilities define the order or class of survey required for a specific mission. First order survey is the most accurate survey to be performed. This order is divided into three classes with the maximum closing error of 1 part in 25,000 units. This order is strictly an engineer survey and is used for scientific purposes, to establish a basic national control net, or to extend surveys of the same or lower order. Second order surveys are divided into two classes with maximum closing error of 1 part in 10,000 units. This order survey is used for the subdivision of areas between first order control, for extension of control and for high order mapping and cadastral surveys. This order survey is also an engineer survey. Third order surveys have a maximum allowable error of 1 part in 5,000 units and are used for densification of basic control nets for mapping, hydrographic survey, artillery and local surveys. This order of survey is performed for the artillery by the engineer and is the only order of survey that requires both engineer and artillery coordination. Fourth order survey is the highest order of survey performed strictly by artillery units. Its allowable error is 1 part in 3000 units. It is used to extend control to using units. Fifth order surveys are the lowest numbered order survey with a maximum allowable error 1 part in 1000. The survey is performed by artillery personnel and is used to extend control to the firing units and other elements of the battalion. Lower order surveys with allowable errors of 1 part in 500 are performed by elements having very limited survey capability.

2.1.2 Functional Surveys

There are five basic functional classes of survey that exist:

Construction survey - Used to plan, locate or lay-out engineering projects. Considered a plane survey.

Artillery survey - Used to determine relative positions of targets and weapons and to extract associated firing data. May be considered a plane or geodetic survey.

Topographic survey - Used to establish horizontal and vertical control for the compilation of maps/map products. Considered a geodetic survey.

Basic Control survey - Used to establish horizontal and vertical control from which other surveys may commence. Considered a geodetic survey.

Special survey - Consist of special purpose surveys to include; astronomic, satellite, hydrographic, field classification, gravity, land and engineering surveys. These may be considered either geodetic or plane surveys.

Figure 2-1 depicts the categorization and classification of Army Survey.

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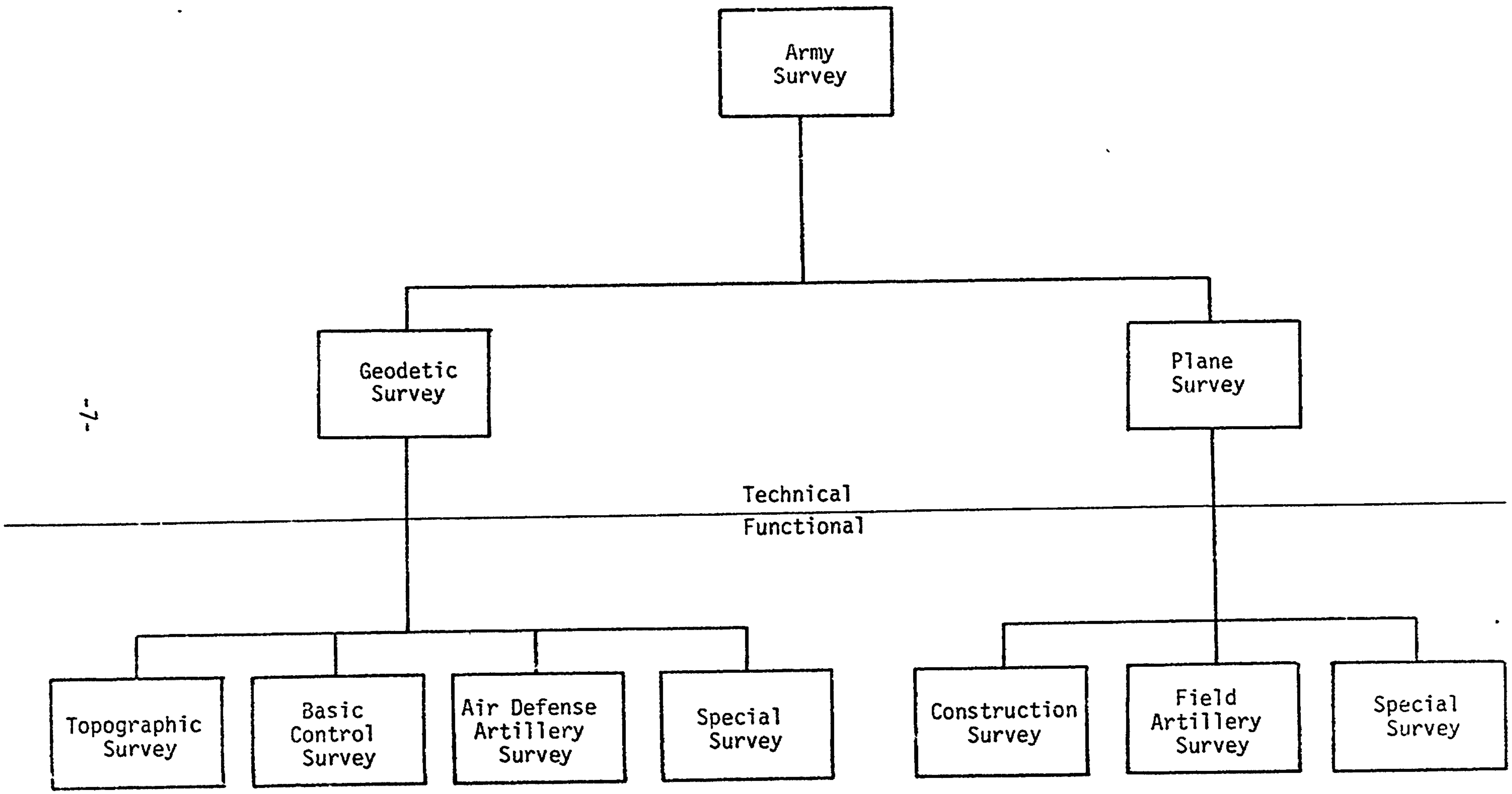


FIGURE 2.1 Categorization of Army Survey

2.2 Control Extension Techniques

The majority of survey projects conducted by the Field Army consists of control extension rather than initial control establishment. Several techniques have been developed, and when combined with the appropriated equipment and proceedures, will allow the surveyor to extend control throughout the theater of operations to the required accuracy. Separate techniques have been developed for extending vertical and horizontal control. Vertical control is extended by either differential or indirect leveling techniques. Horizontal control is extended through the techniques of Traverse, Triangulation or Trilateration. The following are definitions of these various techniques.

2.2.1 Vertical Extension

Direct Leveling - This method utilizes an instrument which consists of an optical telescope and level vial (spirit level). The spirit level is used to insure that a line of sight of the telescope is parallel to a horizontal datum. This instrument is used to extend vertical information in two steps. First, a reading is taken to a point known elevation and the distance of the line of sight above the known point is determined. This distance is added to the known point elevation and results in the height of the instrument (line of sight). The instrument is then sighted on a graduated rod over an unknown point and the height of the line of sight above that point is read. The height is subtracted from the height of the instrument and the resultant value is the elevation of the unknown point.

Indirect Leveling - Indirect leveling consist of two techniques, trigonometric and barometric. Trigonometeric leveling uses the principle of the right triangle. Two observations are required; one is the distance to the unknown point, and the other is the vertical angle from the horizontal line of sight to the unknown point. The difference in elevation between the height of the instrument line of sight and the unknown point can thus be determined and algebraically added to the instrument height to determine the elevation of the new point. Barometric leveling is based on the Aneriod barometer capability to determine elevation based on differences in atmospheric pressure as elevation changes. As atmospheric pressures may vary due to a variety of parameters (e.g. storms, winds, etc.), this is the most unreliable form of leveling.

2.2.2 Horizontal Extension

Traverse - The technique of traverse is defined as the extension of control by a series of measurements of lengths and directions of a series of straight lines. Traverses are classified as either closed or open. A closed traverse must start and end on points of known horizontal position. A closed loop traverse starts and ends on the same point and a closed connecting traverse starts and ends on different points. An open traverse starts on a point of known control, however, it ends on a point of unknown (to be determined) position.

Triangulation - Triangulation is the technique wherein control is extended through a series of triangles or more complicated figures formed by triangles such as quadrilaterals with diagonals. The technqiue employs the trigonometric concept of measuring the angles in a triangle to obtain the lengths of the sides. As several size triangles may be formed from any three angles, a baseline length is required to begin the system. Two classifications of triangulation exist, the conventional and the braced. Conventional triangulation employs only the method of angle measuring. Braced triangulation uses the method of angle measurement along with the length measurement of at least one other line in a quadrilaterial figure. With the use of electronic distance measuring equipment, this method provides more strength and accuracy to the figure.

Trilateration - Trilateration employs the same scheme of triangles or triangular figures, however, all the sides of the figure are measured rather than the angles. This relatively new concept in military surveying is not fully documented in current technical manuals. It is available to the field surveyor when conditions warrant its use.

The foregoing definitions of survey classifications and types have been basic and brief. Indepth discussions of survey types, specific equipment, and methods/techniques are presented in Appendix A, Appendix B, and Appendix C respectively. The definitions previously presented are intended to give some idea as to the scope and magnitude of field army survey.

2.3 Unit Missions and Responsibilities

The majority of Army survey is performed by units from two branches, the Corps of Engineers and the Artillery. The bulk of survey responsibility falls on the Corps of Engineers for all types of survey. Engineer survey can be broken into two broad classes. The first class is construction survey which is carried out by elements of construction units, combat units, port construction units. pipeline construction units, the civil works side of the Corps of Engineers, etc. The second broad class of survey is topographic survey. This class is carried out by specialized Engineer topographic units.

As the engineer topographic units are responsible for the majority of precise position determinations required in the theater of operations, and as GPS is envisioned as a precise positioning system, emphasis in this report will be placed on the topographic community.

Artillery survey is carried out by elements of the Field Artillery Battalions and the Field Artillery Target Acquisition Battalions (FATAB) depending on the Echelon of survey work required. Subsection 2.3.1 (Missions/Capabilities) defines those activities of survey elements as stated in current field manuals and technical manuals. Subsection 2.3.2 (Current Employment) defines changes in Army structure and the effects to topographic support as currently implemented. Subsection 2.3.3 (Future Concepts) define the topographic support system (TSS) as currently envisioned. Subsection 2.3.4 (Functions) defines the basic survey functions required for Army Theater of Operations support.

2.3.1 Missions/Capabilities

Survey missions relevant to this report can be broken into two general categories; the Engineer survey mission, and the Artillery survey mission. The general mission of Engineer topographic units is to provide direct mapping support to their respective assigned commands and furnish initial and sustained survey support for artillery, missile and other military users as required. The general mission of Artillery survey units is to provide a common grid which will permit coordinated artillery operations throughout an area. These general missions can be broken down into specific responsibilities by units as follows.

2.3.1.1 Engineer

There are three primary types of engineer topographic units responsible for survey missions; the Engineer Base Topographic Battalion, (Base Survey Company); the Engineer Topographic Battalion Army, (Survey Platoon) and the Engineer Topographic Company Corps, (Survey Platoon). Figures 2-2 thru 2-4 are provided to depict the magnitude of the currently defined topographic units. The survey missions and capabilities of each are as follows:

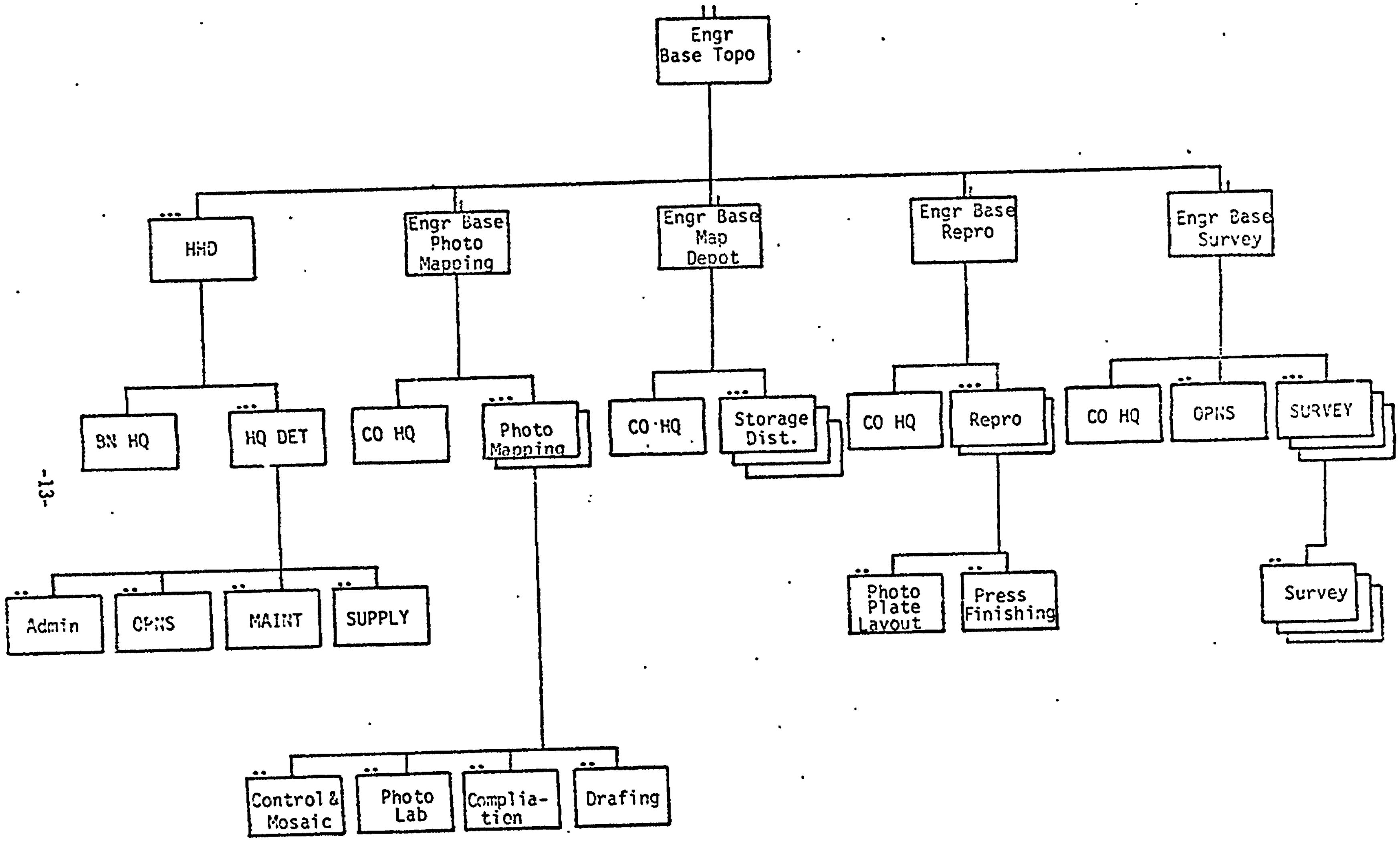


FIGURE 2-2. Engineer Base Topographic Battalion

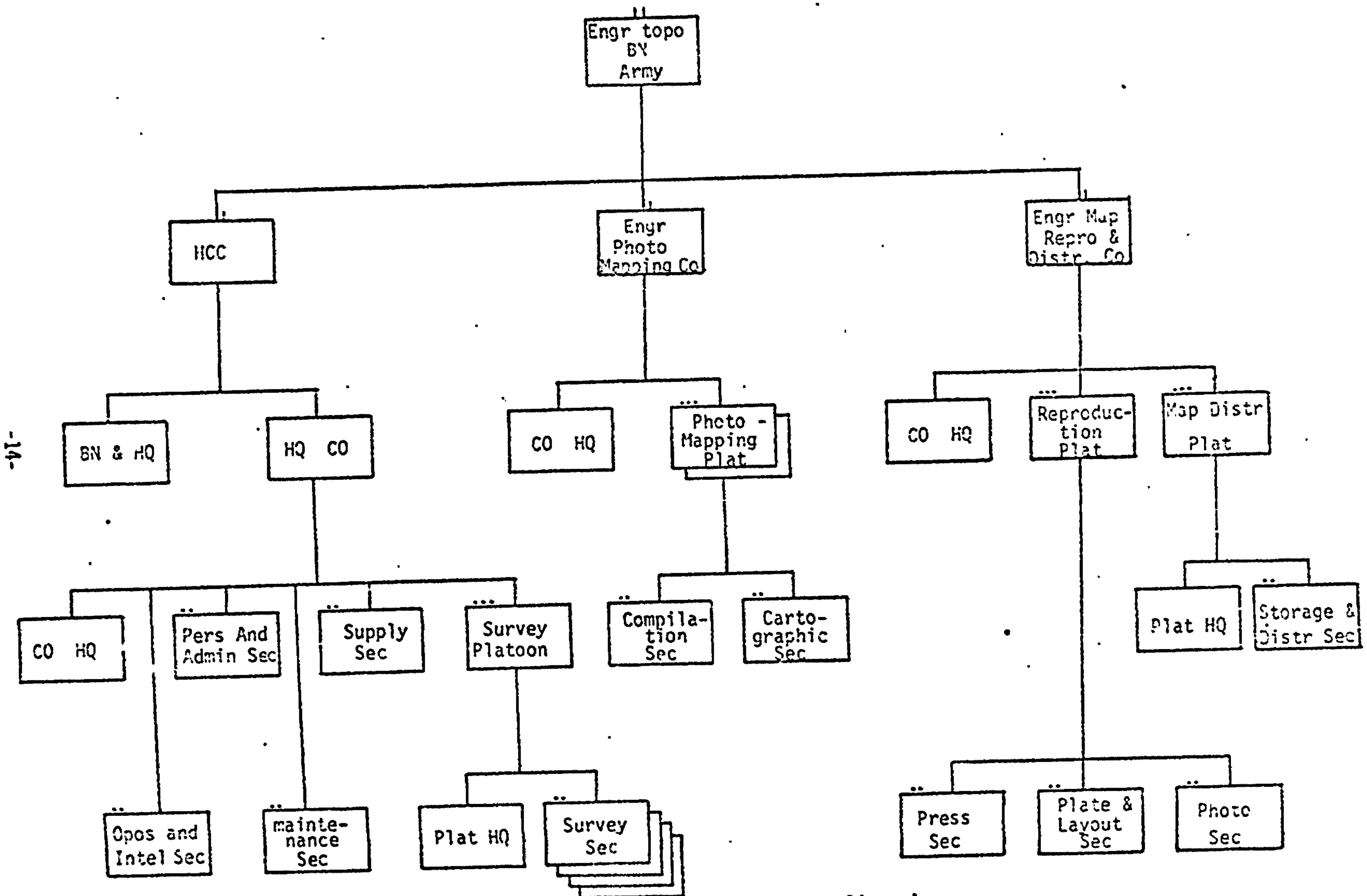


FIGURE 2-3. Engineer Topographic Battalion, Army

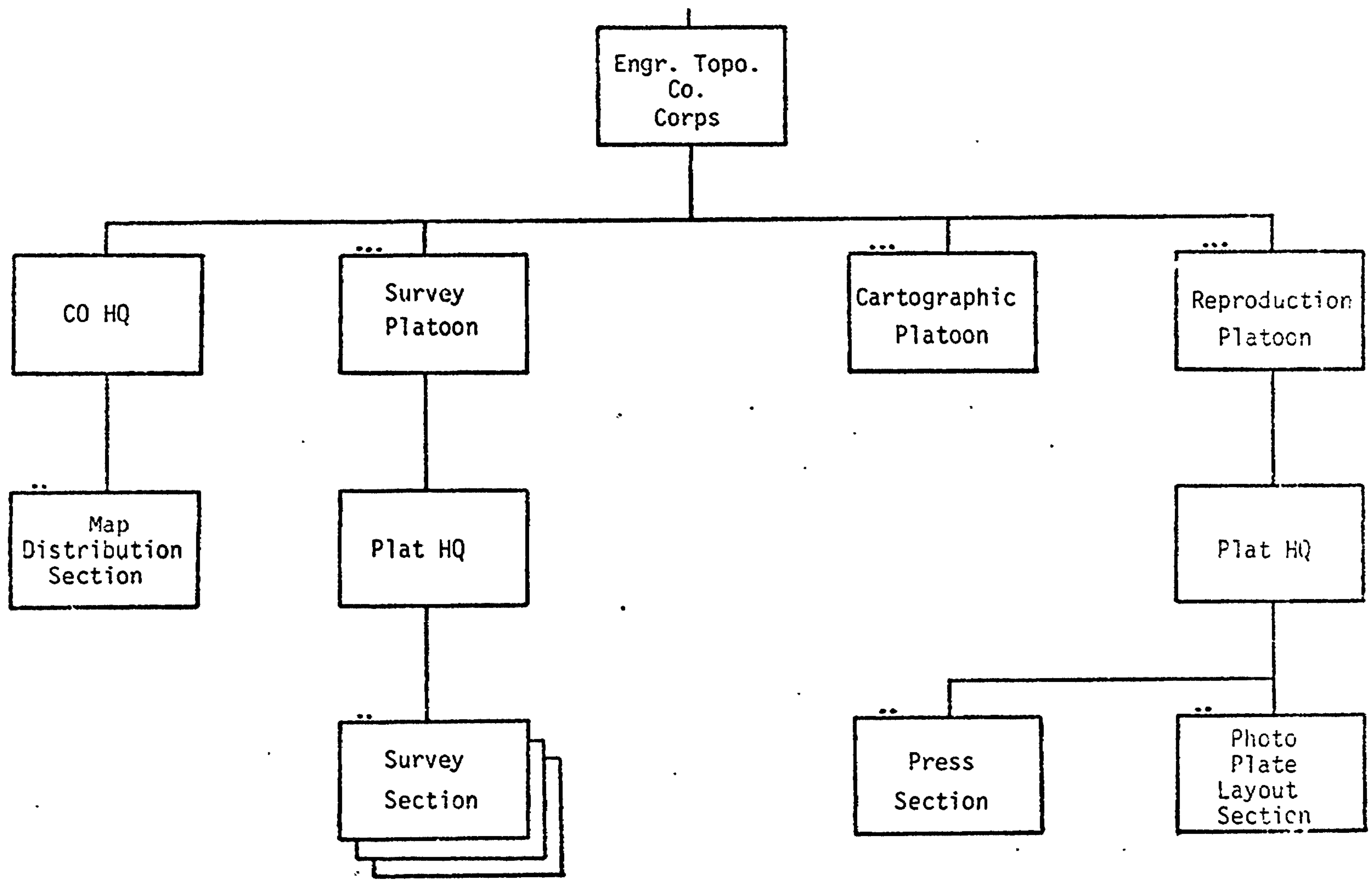


FIGURE 2-4. Engineer Topographic Corps Company

ENGINEER BASE TOPOGRAPHIC BATTALION, BASE SURVEY COMPANY -

Mission - The mission of this unit is to accomplish plane or geodetic surveys as required and to make necessary computations to establish, recover, or adjust geodetic position control to a given control system for use in new mapping and/or revision projects. The unit also provides position and azimuth control to other surveying elements of the army and extends ground control to the rear boundary of army areas in support of surveying elements of the Engineer Topographic Battalion, Army.

Capabilities - At full strength, this unit is capable of providing topographic, artillery and missile file control survey support to one or more field armies in a theater of operations, to a communications zone, or to the zone of interior; providing first, second, and third order geodetic survey, including first order astronomic position determinations, second and third order leveling and the establishment of base lines; providing topographic artillery fire control surveys using conventional field methods, and providing geodetic control data to elements of the battalion and to Army and Corps for compliation of new maps or revision of existing topographic maps and for artillery and missile fire control survey by photogrammetric methods.

ENGINEER TOPOGRAPHIC BATTALION, ARMY SURVEY PLATOON -

Mission - This unit has the responsibility to accomplish essential surveys, perform necessary computations, and provide related technical information and materials required to support a field army.

Capabilities - At full strength this unit is capable of performing surveys required for topographic mapping; carrying forward second order ground control and azimuth data in support of Corps survey elements; providing survey support as required for artillery and missile units; and establishing geodetic control for the Army Topographic Battalion, the Corps Topographic Company and Artillery units.

ENGINEER TOPOGRAPHIC COMPANY, CORPS, SURVEY PLATOON -

Mission - The platoon mission is to accomplish survey, perform computations, and provide artillery and topographic survey data to support a corps or task force type operation.

Capabilities - At full strength, the platoon has the capability of accomplishing second and third order survey required for mapping and other functions; furnishing ground control to corps artillery and missile units, and computing and adjusting field date.

2.3.1.2 Artillery

There are two primary types of Artillery units responsible for carrying out the Artillery survey mission. They are:

FIELD ARTILLERY TARGET ACQUISITION BATTALION, SURVEY PLATOONS -

Mission - The survey mission of the FATAB is to provide survey control for each division artillery, for each field artillery battalion assigned to the Corps, and for each FATAB target locating installation.

Capabilities - The capabilities of those units consist of providing common survey control assigned units as required, primarily by traverse; performing fourth and fifth order triangulation; performing low order astronomic azimuth, and performing low order triangulation and barometric leveling.

DIVISION ARTILLERY SURVEY SECTIONS -

Mission - The division artillery survey mission is to perform those survey operations necessary to place organic, assigned or attached field artillery units on a common grid.

Capabilities - The capabilities of these units are the same as those of the FATAB units.

2.3.1.3 Other Units With Limited Survey Capability

Although the previously mentioned units carry the primary responsibility for the field army survey requirements, there is a variety of other units which have limited survey capability. There are:

- Engineer Topographic Teams
- Engineer Intelligence Teams
- Engineer Construction Group
- Engineer Combat Group
- Engineer Combat Battalion
- Engineer Combat Company
- Field Artillery Battalion, Pershing
- Field Artillery Battalion, Honest John
- Field Artillery Group
- Field Artillery Battalion, Sergent
- Field Artillery Battalion, 175mmSP
- Field Artillery Battalion, 155mmSP & T
- Field Artillery Battalion, 8 " Sp & T
- Field Artillery Battalion, 105mmSp & T
- Field Artillery Battalion, 105mm Airborne

2.3.2. Current Employment

The recently instituted Echelons Above Division (EAD) concept has eliminated the field army as a command echelon and has restructured the Corps to provide flexibility of composition and an undefined area of responsibility. The impact of this concept has had great impact on the structure of topographic support. The engineer base topographic battalion has been eliminated and the corps company mission and structure has been absorbed into a new unit, the Engineer Topographic Battalion, Theater Army. This new unit concept is only partially implemented and is basically an interim structure to a new concept, Topographic Support System (TSS), to be discussed later. The structure of the Engineer Topographic Battalion is outlined in figures 2-5 and 2-6. This concept provides a modular concept that can be directed as required. The battalion consists basically of a headquarters company with assigned terrain teams, four cartographic companies to provide cartograpnic, reproduction and distribution support, and one survey company to provide survey control as required. The terrain teams are assigned direct support missions to the corps with one held in reserve for general support. The cartographic companies are also in direct support to each Corps with one in general support to the Theater Army. The survey company currently is in general support to the Theater Army. The current structure of topographic support is a combination of the Engineer Topographic Battalion, Theater Army and the Engineer Topographic Company, Corps. The missions and capabilities of these units are similar to the previously discussed Engineer Topographic Battalion, Army and the Engineer Topographic Company, Corps.

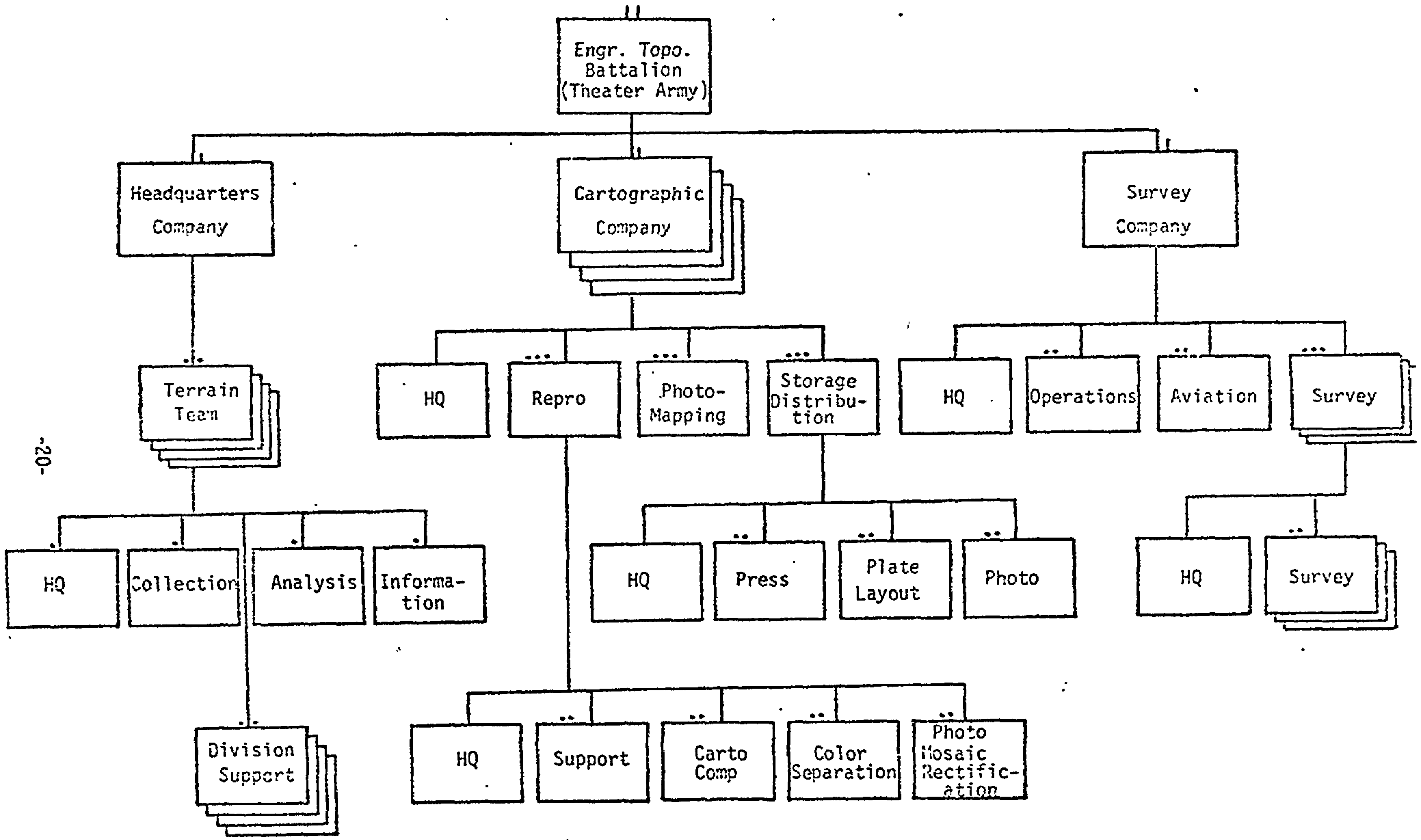


FIGURE 2-5. Engineer Topographic Battalion, Theater Army

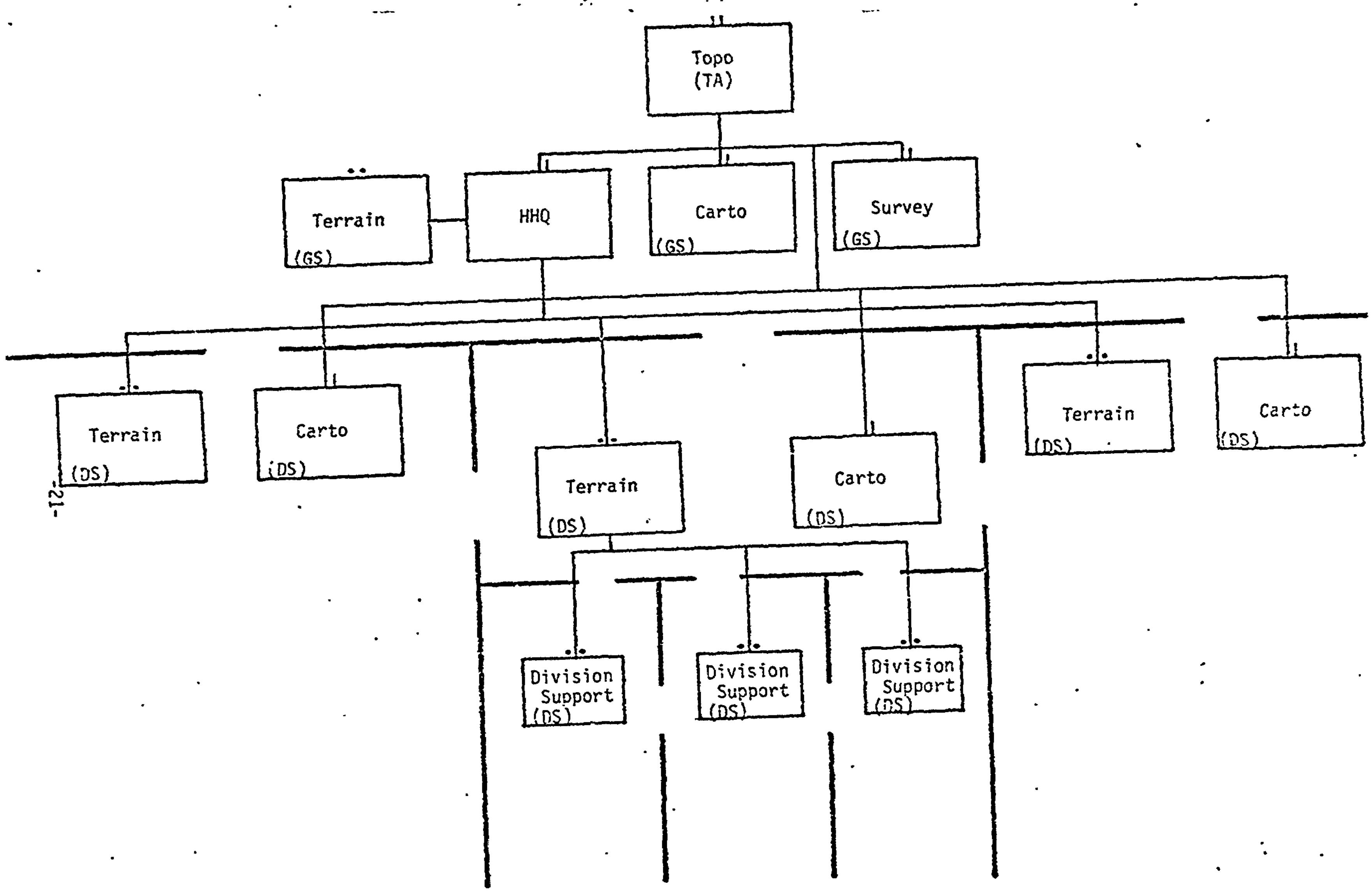


FIGURE 2-6. Doctrinal Deployment of Topo. BN. (TA)

2.3.3. Future Concepts

The topographic community is currently evaluating a system known as the Topographic Support System (TSS) which is a modularized set of subsystems designed to provide timely topographic support in the manner required by the field situation. The concept, although visualized prior to the Echelons Above Division concept, is extremely compatible with the flexibility of the Corps defined in EAD. TSS is organized into seven functional subsystems (Figures 2-7). They are:

The Command and Control (C & C) Subsystem - To provide the administrative and operational management of TSS. It will also be the entry point for support requests,

The Storage, Retrieval and Distribution (SRD) Sub-System - To house the data bank of general and special purpose topographic information. It will also maintain a stockpile of finished products for distribution,

The Reproduction (REPRO) Subsystem - To reproduce the outputs in the volume required by the user. It will also reprint stocked products which become depleted,

The Cartographic Revision (CR) Subsystem - To convert manuscripts prepared by other subsystems into reproducible form. It will also incorporate new data for updating the graphics into manuscripts or reproducibles,

The Image Base Products (IBP) Subsystem - To perform all photographic processes and transformations to include; differential and frame rectification, mosaicing, scale change and routine photographic reproduction, *The Military Geographic Information (MGI)* - Subsystem to be the store house and center for analysis and synthesis for the terrain aspects of topographic support. It has the capaiblity to output simple direct answers to specific questions, or to provide graphics of full analyses of terrain for specified military operations, and

The Survey (SURVEY) subsystem - To acquire and store coordinate values for control points required for topographic support. It will also have the capability to determine coordinates for specific points identified by users.

As envisioned, such a system would have an initial operating capability around the thrid quarter of 1980. As the situation warrants such a system can be specifically structured through adding or deleting modules of any subsection to satisfy immediate requirements. For the purpose of this report we shall look at the proposed functions/requirements of the survey subsection.

The survey subsection will provide all horizontal and vertical data referred to the appropriate datum, required by field units witnin the TSS area of responsibility. The primary functions are to intensify existing control networks in critical areas of military operations, and to determine the location and elevation of point designed by the user. Specific examples of requirements for survey as envisioned in the TSS concept are:

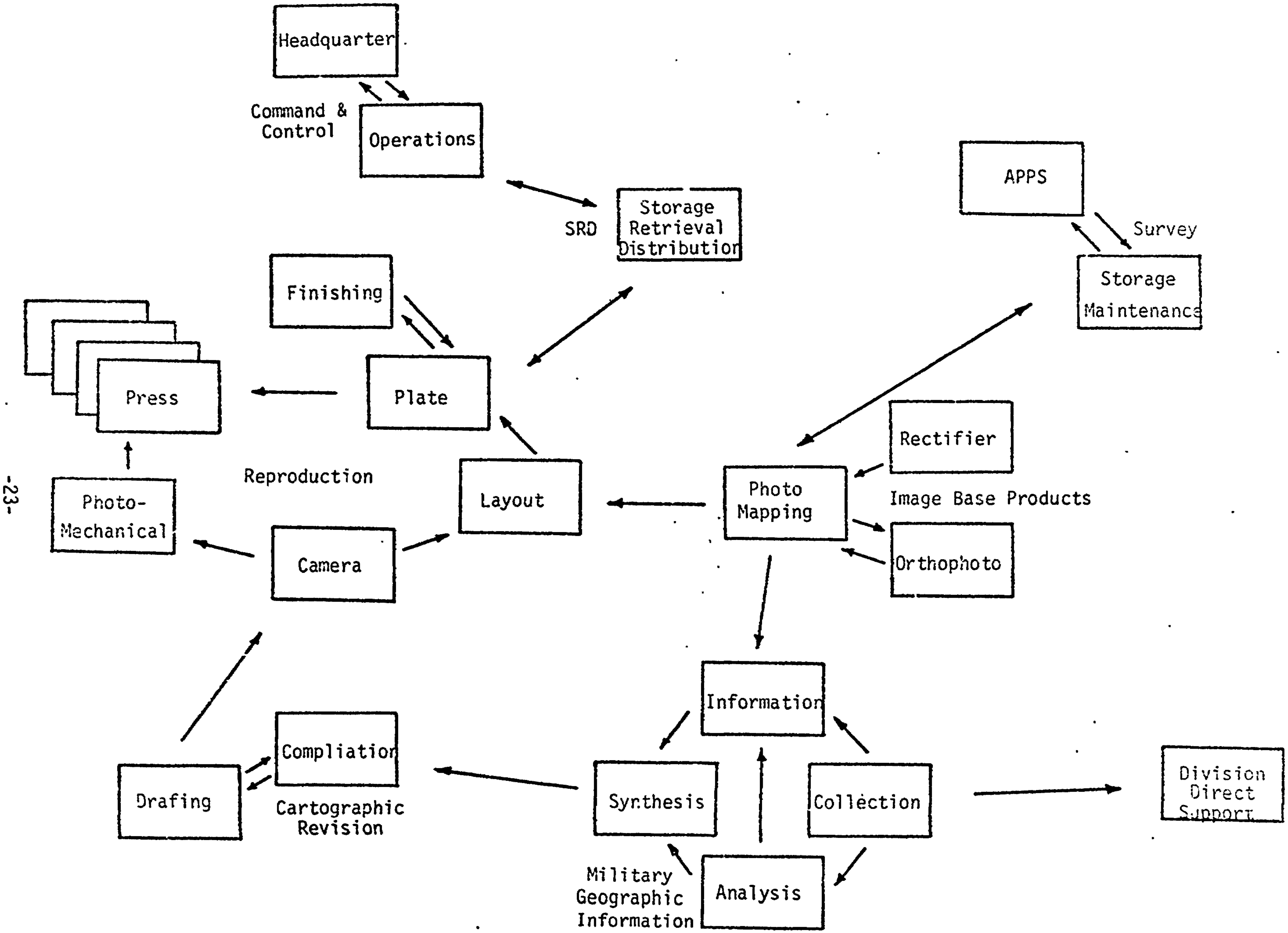


FIGURE 2-7. Topographic Support System (TSS)

Field Artillery - The required accuracy for weapon site surveys is stated as 20-30 meters CEP in position, 5-10 meters probable error in elevation and .3 to .10 mils in azimuth. The engineer accuracy requirements computed to provide for the final accuracy are 18 to 29 meters CEP in position, 1-9 meters PE in elevation and a standard deviation of .05 to .7 mils in azimuth.

Missile Artillery - Position and elevation requirements are the same as field artillery, however azimuth requirements are stated at .1 to .3 mils standard deviation. To accomodate these accuracies the TSS must achieve 19 to 29 meters CEP for position, 4 to 10 meters PE for elevation and .04 mils standard deviation in azimuth.

Air Defense Artillery - TSS is envisioned as providing on-site control and as such, TSS requirements are the same as the users, that is; 20 to 30 meters CEP in position, 10 to 15 meters PE in elevation and a standard deviation of .3 to .10 mils in azimuth.

Topographic Support - Various topographic functions primarily those utilizing photographs as source information, require adequate ground control. Field mapping is envisioned at class "B" standards for 1:25,000 and 1:50,000 scale graphics. Azimuth control is not required for such mapping and a CEP for position is computed as between 7 and 14 meters with the elevation proable error computed at from 5 to 10 meters.

In order to be responsive to the assigned Corps needs, the TSS is termed a "system" rather than a battalion or company and is unencumbered by traditional hierarchial structure. The command and control subsystem will be responsible for the TSS and will be directly responsive to the Corps headquarters.

2.3.4 Functions

There are six basic survey functions required to support Field Army operations, global mapping and geodesy, and other essential Army missions. There are:

2.3.4.1 Surveys for Mapping Operations

This function is accomplished entirely by the Corps of Engineers military and civilian survey personnel and include both tactical and global mapping operations.

2.3.4.2 Surveys for Geodesy Programs

This function is accomplished by the Corps of Engineers personnel in coordination with Air Force and Navy personnel to support the DOD global geodesy program. This includes the use of both satellite and airborne positioning systems as well as conventional survey.

2.3.4.3 Military Construction Survey

This function is accomplished entirely by engineer surveys in support of tactical construction.

2.3.4.4 Civil Works Surveys

This function is usually accomplished entirely by Corps of Engineers or contractual civilian surveyors to support civil works construction programs.

2.3.4.5 Special Survey

This function includes all the specialized surveys performed by the Corps of Engineers and which are not covered by another function.

2.3.4.6 Artillery and Missile Surveys

This final function involves personnel from both artillery and engineer units. Coordination is mandatory to establish and extend ground control on a common grid from which artillery and missile units can successfully implement fire missions. This category can be broken into several sub-functions which are defined as follows:

Control Establishment - Corps of Engineer responsibility to bring basic control into an area for support of artillery.

Control Extension - This is an Artillery function to extend control established by Engineers in order to support the artillery operational missions.

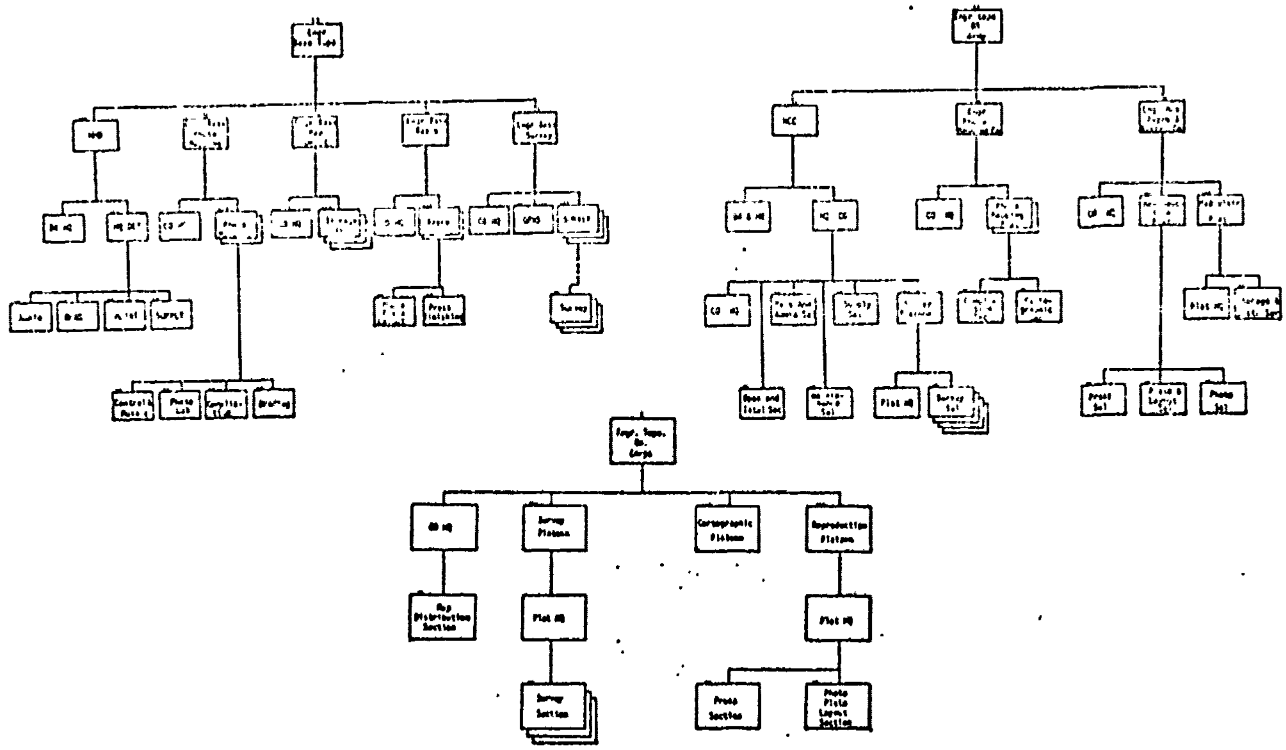
Position Area Survey - This responsibility is to the Artillery for the operation of weapons and relationships between weapons.

Target Area Survey - This subfunction is performed by the Artillery to establish positions of observation points, flash observation points, radar, etc.

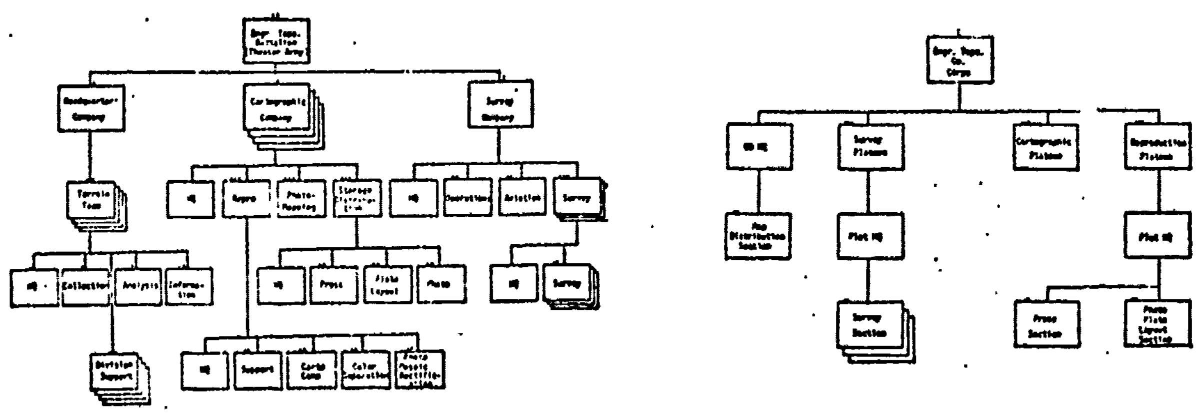
Connecting Surveys - Performed by the artillery to provide a common grid among the position area and target area such that common information may be relayed for target acquisition.

2.3.5 Summary

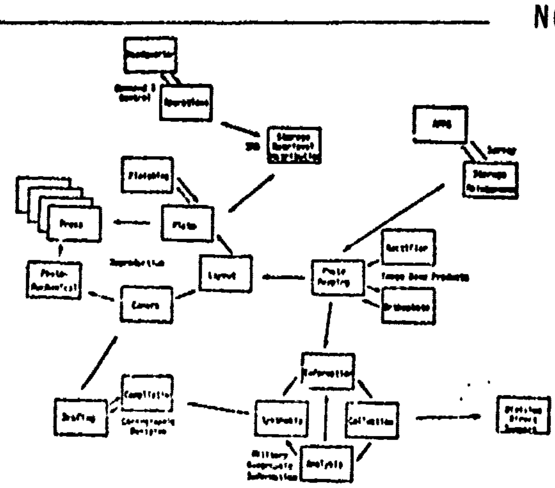
As can be discerned from the previous discussion the structure of topographic support to the Field Army has been, and appears to remain in a dynamic state. Figure 2-8 graphically illustrates the recent and proposed changes to this extremely important support element. Until such time that stability occurs to unit structuring, difficulty will remain in specifing responsibilities and specific missions, and thus affect the determination of equipment required by each unit. However, functions and requirements for survey control establishment and extension will remain in high priority.



Field Support - Pre-1974



Field Support - 1974 - 1980?



Field Support - 1980 ? - ?

Figure 2-8
Topographic
Community

3.0 DESCRIPTION OF THE GLOBAL POSITIONING SYSTEM (GPS)

This section presents a brief description of the Global Positioning System to include detail of the user system segment; the system navigation method and factors affecting performance, and testing and evaluation to include preliminary results of multipath and foliage attenuation tests conducted by the U.S. Army Engineer Topographic Laboratories.

The Global Positioning System is an outgrowth of an idea pursued since the 1960's by the Navy and Air Force, that navigation and positioning could be accomplished using radio signals transmitted from space vehicles. It is this idea that is incorporated into the current GPS System to be described. The current system, when fully implemented (around 1984) will consist of a 24 satellite constellation which broadcasts extremely accurate positioning information continuously any place and any time in the world. GPS is designed to provide instantaneous position, velocity and time information with relatively low cost user equipment. It is a universal positioning system with the following characteristics:

- Accurate three-dimensional positioning and velocity,
- Worldwide common grid,
- Passive and all weather operations,
- Real time and continuous information,
- Support for unlimited number of users,
- Denial to unauthorized users, and
- Resistant to jamming.

3.1 GPS Concept

The Global Positioning System is a segmented system consisting of: a space system segment, a user system segment, and a control system segment. The space system segment will consist of three planes of satellites in circular, 10,000 natuical mile orbits, with an inclination of 63°. Each plane will contain eight satellites. This configuration will provide for continuous, three dimensional positioning and navigation. Each satellite will transmit on two L-Band frequencies (L_1 and L_2) consisting of a protected (P) and a clear acquisition (C/A) navigation signal. The user segment will incorporate receivers/processors that will use the navigation signal from each of four satellites to determine four independent pseudo-ranges and pseudo range rates to the satellites. The processors will convert these measurements into three-dimensional positions, velocity and system time. The position will be in earth-centered coordinates and can be converted to any coordinate system the user desires. The control system segment will consists of monitor stations to track the satellites and collect ranging data; a master control station to process the data, determine the orbits and eliminate systematic errors; and upload stations to update satellites data (ephemerides, clock drift, etc.) as required.

New systems such as GPS may have a wide variety of applications. Figure 3-1 illustrates those applications already identified.

MISSIONS	SPECIAL USES
. *LAND*	
TROOP	. ARTILLERY
. CONVOY	. FIRE SUPPORT
. ARMOR	. TROOPS IN CONTACT
. MOBILE ARTILLERY	. CLANDESTINE FORCES
. GEODESY	
. *SEA*	
. PATROL	. SSBN
. PASSIVE RENDEZVOUS	. ASW
. TASK FORCE OPERATIONS	. SAR
. HARBOR CONTROL	. PILOTAGE
	. BUOY/SHOAL/REEF LOCATIONS
	. BEACH HEAD
. *AIR*	
. CLOSE AIR SUPPORT	. BLIND/VISUAL AIDED BOMBING
. FERRYING	. MISSILE INITIALIZATION/INERTIAL UPDATE
. TACTICAL DEPLOYMENT	. MIDCOURSE GUIDANCE
. REFUELING	. CARP/HARP
. RECONNAISSANCE	. RPV/RCV
. APPROACH/LANDING	. BARE BASE
. *SPACE*	
. SATELLITE EPHEMERIS	. SPACE TRANSPORTATION SYSTEM
. SPACE VEHICLE POSITION	. SATELLITE TRACKING
. *SPECIAL OPERATIONS*	
. INTELLIGENCE	. PASSIVE ELINT
. RANGE INSTRUMENTATION	. PHOTO RECCE/MAPPING
	. TARGETING
	. SENSOR IMPLACEMENT
	. COR/WEAPON SYSTEM TEST SCORING

FIGURE 3-1. GPS Applications

3.2 The User System Segment

Of primary interest for this report is the user system segment as it may apply to military survey. The user system segment will consist of a receiver, antenna, data processor, software, control and display units. The unit is to have coded modules which can perform self-tests to detect malfunctions. Modules are designed for in field interchangability to assist in rapid repair and maintenance.

Three equipment sets are to be developed; set X, set Y, and set Z. Sets X and Y will have an integration capability with auxiliary sensors. Set Z is designed to operate on the clear access (C/A) navigation signal only and is designed as the lowest cost user set. Primary attributes of each set type are shown in Figure 3-2. At full operational capability GPS will provide horizontal positioning to an accuracy of 8 meters and vertical positioning to 10 meters in addition to velocity to within .1 knots. The type of user equipment envisioned for survey use must be of high accuracy, high immunity to jamming, low weight, and low power. User dynamics are envisioned to be low, in that the user will not be required to make exceedingly high speed maneuvers during position acquisitions. High accuracy is defined as an accuracy of better than 10 meters absolute in all axes. As military survey is particularity impacted by the man pack version of GPS, such physical characteristics as size, weight and power are critical. Figure 3-3 illustrates the design specifications for sets X, Y, and Z.

Equipment Set	Operating Frequency	Signals		Simultaneous Signals	Ionospheric Correction Method		Auxiliary Sensor Set		
		AQC	NAV		Direct RF	Static Model	Inertial Measurement Unit	Air Mass Unit	External Time Reference
X	L_1 and L_2	P and/or C/A	P or C/A	≥ 4	Yes or No	Yes or No	Yes or No	Yes or No	Yes or No
Y	L_1 and L_2	P and/or C/A	P or C/A	≥ 1	Yes or No	Yes or No	Yes or No	Yes or No	Yes or No
Z	L_1 only	C/A	C/A	≥ 1	No	Yes	No	No	No

FIGURE 3-2. User Equipment Attributes

	X			Y			Z		
	Weight (kg)	Volume (m^3)	Power (w)	Weight (kg)	Volume (m^3)	Power (w)	Weight (kg)	Volume (m^3)	Power (w)
Receiver	27	.04	200	23	.04	120	11	.01	120
Data Processor	20	.06	400	20	.06	400	1.4	.002	
CDU	2.3	.002	10	2.3	.002	10	2.3	.002	10
Antenna Preamp	2.3	.002	2.5	2.3	.002	2.5	2.3	.001	1
Power Supply	In RCVR	--	--	In RCVR	--	--	In RCVR	--	--
Interfaces	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Other Eng. Control Display	4.5	.09	20	4.5	.09	20	4.5	.09	20
Total	56.1	.20	632	52.1	20	552	22.5	.11	151

FIGURE 3-3. Physical Characteristics

In order to determine the accuracy of a system, several parameters must be taken into consideration to account for errors propagated. The total error propagation is a function of User Equivalent Range Error (UERE) and the geometric dilution of precision (GDOP). GDOP is the relationship between the user's navigation accuracy and his relative position to the space vehicle constellation. UERE is the unincorporated portion of the user range error. Principle errors of UERE to be considered are: Space vehicle ephemeris, atmospheric delay, space vehicle group delay, receiver noise and multipath. Space vehicle ephemeris error is defined as the difference in actual satellite ephemeris and the satellite ephemeris computed by the user from the navigation signal data. The primary error source propagated, by the epheremis error is the satellite radial position error. As an example, a three foot in-track error projects to a one foot error in range. Atmospheric errors are defined as the difference between actual signal propagation delay through the Ionosphere and Troposhere, and the delay determined by the user employing suitable Ionsphere and Troposhere models. Space vehicle group delay error is defined as the sum of delay uncertainty in the space vehicle, such as unmodeled clock drift and uncalibrated delay in signal equipment. Receiver noise and resolution errors are the contributions to error propagation by the receiver hardware and software which may perturb the solution. Mulipath error is the effect of several propagation paths from the space vehicle. Environments may cause mulitpath arrivals that are comparable in amplitude to a line-of-sight arrival. GPS receivers are designed to search for the first signal to arrive rather than the strongest. If time of arrival for two signals is sufficiently close, the receiver may not be able to discriminate between the signals. Thus the magnitude of the ranging error will depend strongly on the location and nature of the reflecting surfaces in the user environment. The user system segment consists of five basic subassemblies: The antenna assembly, the receiver assembly, the data processor/computer software, the control/display unit and the power supply. The two primary subassemblies which provide for the proper use and interpretation of data are the data processor/computer software and the control/display unit. The minimum design functions are as follows:

3.2.1 Data Processor/Computer Software

1) Determine and use the set of GPS transmitters from those available that will provide the best user position and/or navigation performance on a continual basis,

2) Provide navigation signal acquisition and tracking-aiding data to the receiver,

3) Accept control commands from the control/display unit and provide for altering the processing of programs or other functions as required,

4) Convert the system data and pseudo-range/rangerate measurements into three-dimensional positions and time,

5) Provide for go/on-go and self-test function to the maximum extent practical,

6) Compute and output to the control/display unit on command:

- Present location,
- Position of selected rendezvous point,
- Azimuth to selected rendezvous point with reference to true north,
- Distance to selected rendezvous point,
- Time-of-day (day-of-week),
- Probable error of the position.

7) Provide as continuous output to the control/display unit, the number of GPS transmitters being tracked.

3.2.2 Control/Display Unit

1) Allow operator to manually input approximate position, time, current altitude etc. as needed for processing,

2) Allow the operator to manually input rendezvous coordinates,

3) Allow the operator to display position and time information either continuously or on command,

4) Display selected rendezvous locations,

5) Display the azimuth to selected points,

6) Display distance to selected points,

7) Display the number of GPS transmitters being tracked,

8) Display the probable error of the position.

3.3 System Navigation Method

Each satellite in the constallation generates a navigation signal consisting of a pseudo random noise code generated on a carrier frequency in the L-Band. This signal is transmitted through an earth coverage antenna which is directed at all times to the center of the earth. Other information such as satellite ephemeris data is superimposed on this code for transmission to the users. The signal is received by the user equipment which performs a biased range measurement to the satellite by determining the apparant time interval between the code received and an identical code generated in the receiver. These apparant ranges to the satellites are referred to as pseudo ranges. By obtaining simultaneous pseudo range measurements to at least four different satellites, and by knowing the ephemerides of those satellites, the receiver can compute a position in three dimensions. Similar computations enable the user to determine velocity based upon doppler measurements extracted from the navigation signal carrier.

3.4 Factors Affecting Navigation Performance

The ability of a satellite system to provide near instantanuous position and velocity data depends to a large extent on orbital characteristics, signal structure, and mathematical models.

3.4.1 Orbital Characteristics

In order to provide for accurate and timely position and velocity computations several conditions as to the geometric relationship between the user and the satellites must be considered. One condition that must be met is that a minimum of four satellites must be visible to the user at all times irrespective of his location. Additionally, the system geometry must not degrade to the point where excessively large or infinite system errors are obtained irrespective of the accuracy of user signal measurements.

3.4.2 Signal Structure

The structure of a signal to be used in such a system as GPS is of prime importance in that it will impact on the design, performance and obtainable accuracies of all system segments. Considerations of objectives of an ideal signal structure are as follows:

1) To provide an accurate one-way ranging capability with accuracies on the user ± 1 foot,

2) To provide the capability to control and monitor epheremis of the satellites from the continental United States,

3) To be able to tolerate a substantial amount of interference and intentional jamming of a protected signal,

4) To provide two signal frequencies for ionospheric delay corrections,

5) To provide a clear signal for low cost users,

6) To provide an acquisition signal for rapid synchronization of the protected signal,

7) To tolerate multiple access effects caused by as many as 12 simultanuous signals,

8) To tolerate a significant amount of multipath caused by ground or sea reflections,

9) To allow user equipment to operate in a purely passive mode.

3.4.3 Mathematical Models

The mathematical modeling and appropriate algorithms must take into consideration various error sources which may be random or systematic. Such error sources must allow for uncertainties in satellite ephemeris ionospheric and tropospheric propagation delays, satellite clock drifts, receiver noise, the effects of multipath, and atmospheric and foliage attenuation.

3.5 Testing and Evaluation

A multitude of tests and studies have been derived to examine and evaluate the performance and applicability of the GPS system. The volume of testing proceedures and requirements are too numerous to mention in this report. The reader is referred to the NAVSTAR Global Positioning System Master Test Plan for indepth descriptions. Of interest to this report, however, are the specific tests required by the individual services, particuliarly, the Army and DMA requirements. The following excerpt of such requirements is presented.

3.5.1 Army

1) Performance - determine the improvement in user unit operations with respect to; accruacy, responsiveness, flexibility, resistance to countermeasures, security, and mission reliability,

2) Survivability - determine how the system will impact on user survivability,

3) Determine the operational reliability, availability and maintainability,

4) Determine the efforts of rapid strategic and tactical deployment,

5) Determine the selection criteria on operator and maintenance personnel,

6) Determine the training required for operators and maintenance personnel,

7) Determine signal attention and signal path anomalies due to foliage and other natural obstructions,

8) Determine alternate methods and equipment required to satisfy azimuth bearing requirements.

3.5.2 Defense Mapping Agency

1) Validate the training accuracy of the monitor stations,

2) Validate orbital prediction accuracies,

3) Validate GPS positioning accuracies,

4) Determine methods with which the system can deliver accuracies of 1 meter or better for control survey support,

5) Determine absolute and relative position accuracies using GPS on precisely determined stations by collecting sixteen to thirty data samples for redundancy,

6) Determine capability of GPS to provide accurate differences in elevations,

7) Determine the repeatability and accuracy of GPS in both the simultaneous and sequential mode,

8) Determine the effects on capabilities under the following conditions:

- Land -water interface,
- Day, night, twilight,
- High latitude positions,
- Equatorial positions,
- Southern hemisphere positions.

9) Determine the precise electrical center of the receiver over different ground conditions,

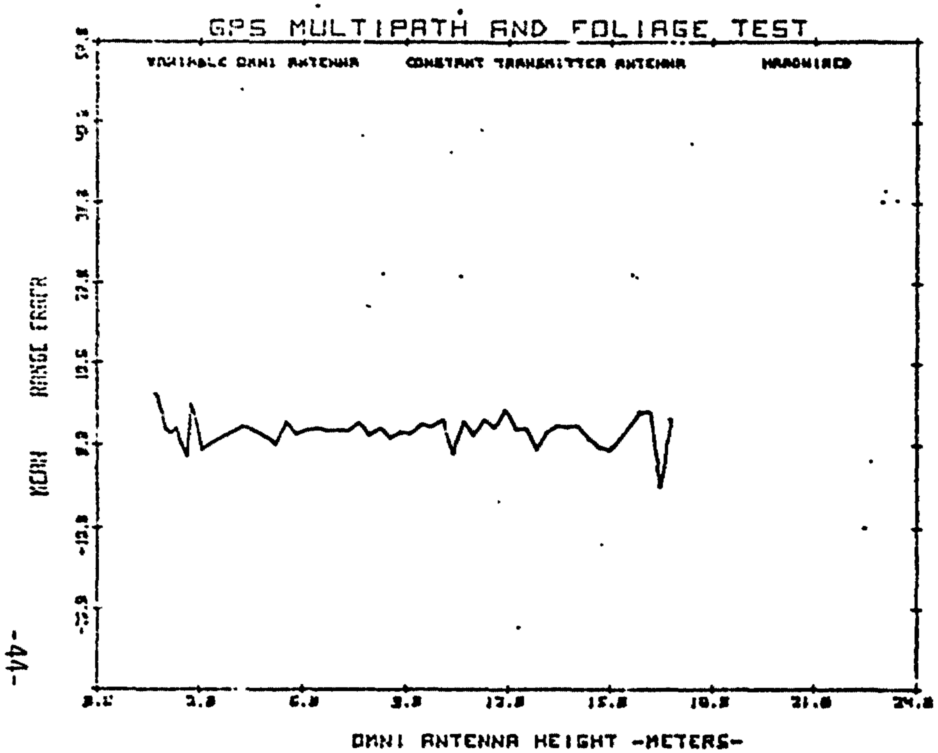
10) Determine the improvement of positioning using after-the-fact updated ephemeris information for non-real time applications.

11) Determine the accuracies of time transfer in the system for applications to the Autoatic Astro-Positioning System,

12) Determine the performance of GPS for supporting land gravity surveys in areas void of local control.

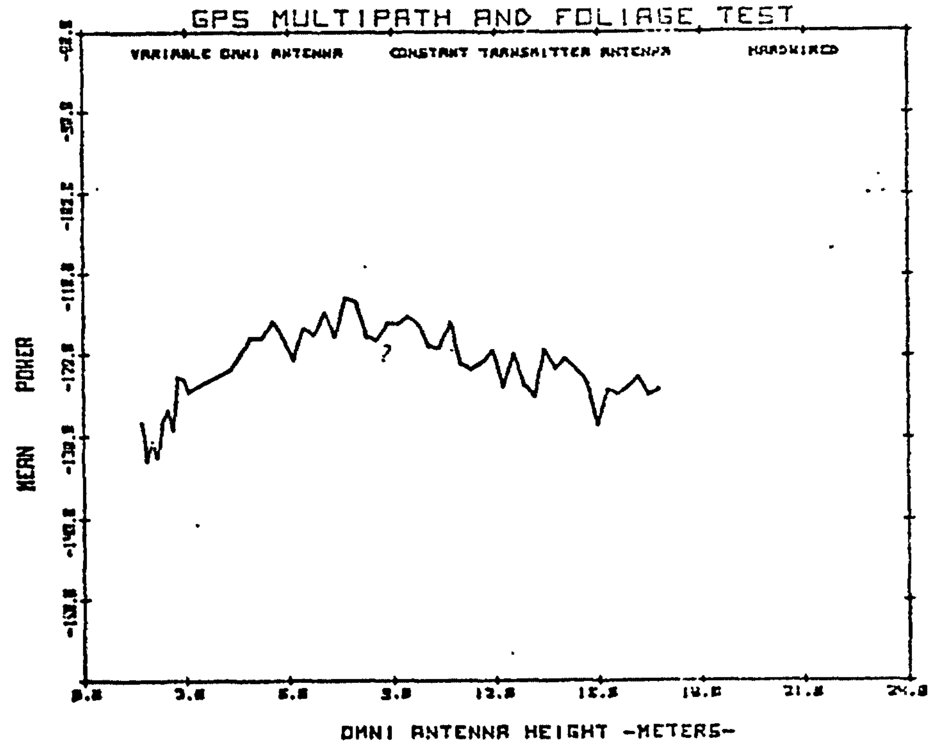
3.6 Results of Mulipath/Foliage Attenuation Tests conducted by the Engineer Topographic Laboratories (ETL).

The U.S. Army Engineer Topographic Laboratories have conducted a series of actual field tests for determining the effects of multipath and foliage attenuation. The results are presented in a combined form and selected graphic results for mean range error and mean power are presented in Figures 3-4 through 3-8. As a result of these tests, a computer simulation was designed to enable various parameters and environments to be duplicated in an effort to separate the individual effects of multipath and foliage attenuation. To date the separation has been only partially successful, however, the simulations have provided a useful tool in analysis of these two effects.



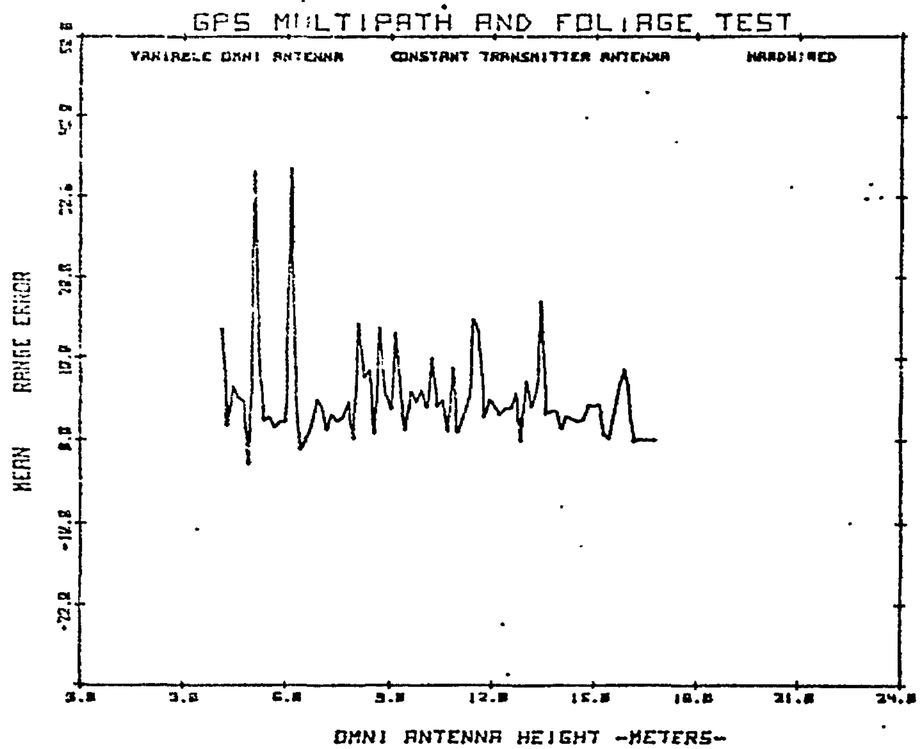
NOTE: All range errors are measured in meters.

LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 3
DATE: 8 May 75 TIME: 0930
TRANSMITTER ANTENNA HEIGHT: 34 ft
DIST. BETWEEN TRANS. & REC. ANT.: 30.5 m
FOLIAGE TYPE: So red oak, Bluejack oak, Gum, longleaf pine
FOLIAGE DENSITY: Ave. 52 trees in signal path
AVER. VEGETATION HEIGHT: 20' 1st canopy, 65-70' 2d canopy
TEMPERATURE: 82°F HUMIDITY: 80-85%
CLOUD COVERAGE: Overcast with int rain

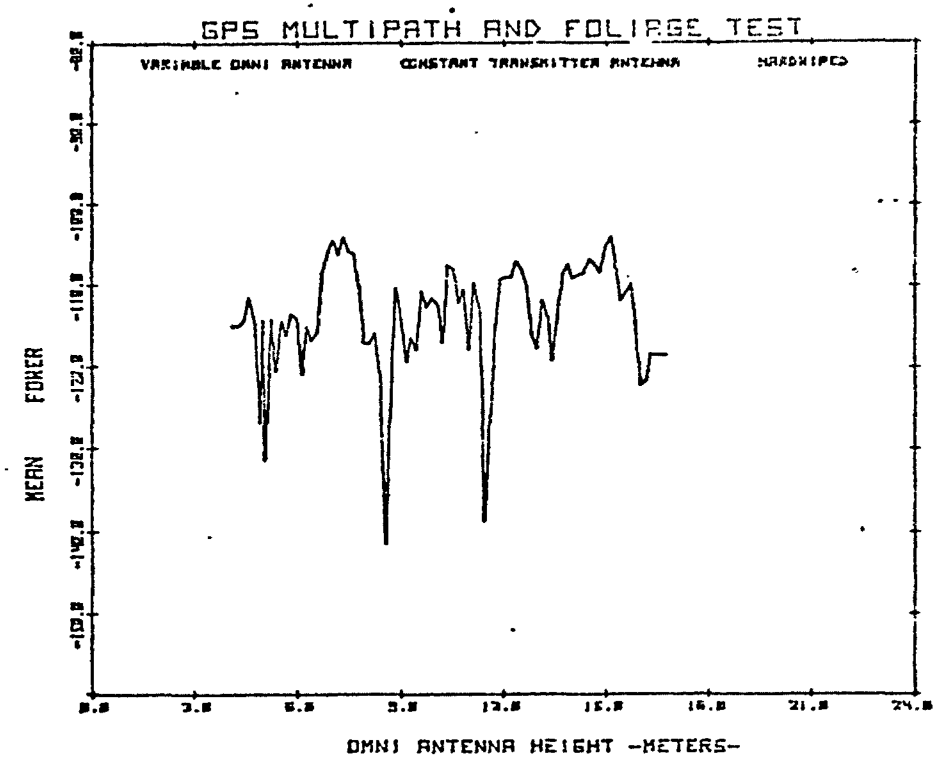


LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 3
DATE: 8 May 75 TIME: 0930
TRANSMITTER ANTENNA HEIGHT: 34 ft
DIST. BETWEEN TRANS. & REC. ANT.: 30.5 m
FOLIAGE TYPE: So red oak, Bluejack oak, Gum, longleaf pine
FOLIAGE DENSITY: Ave. 52 trees in signal path
AVER. VEGETATION HEIGHT: 20' 1st canopy, 65-70' 2d canopy
TEMPERATURE: 82°F HUMIDITY: 80-85%
CLOUD COVERAGE: Overcast with int rain

FIGURE 3.4. Multiple Canopy Multipath and Foliage Attenuation Results

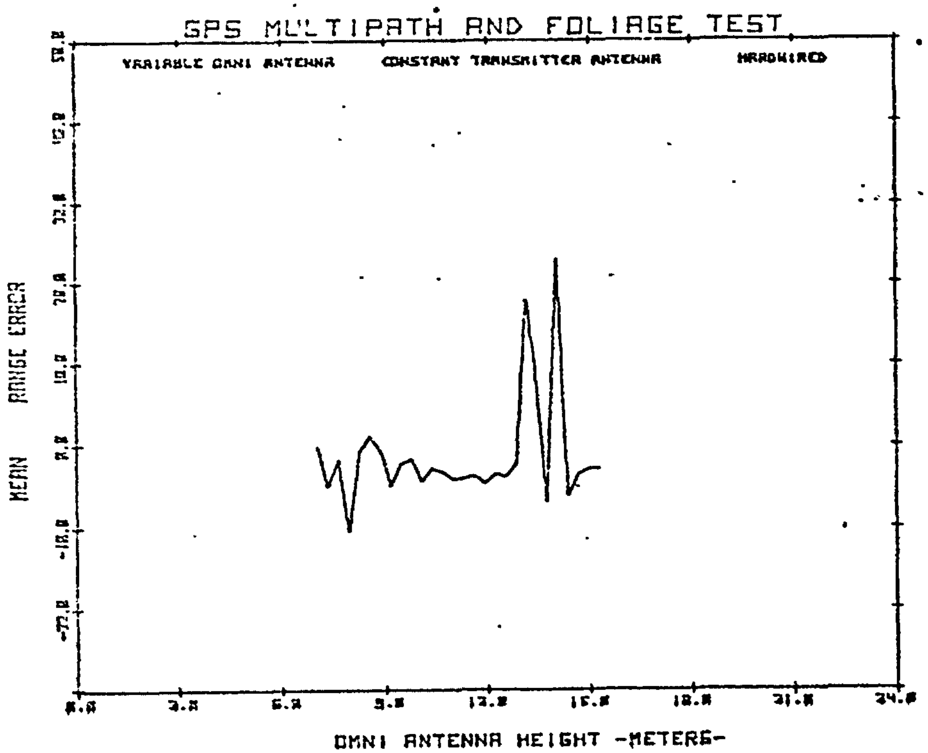


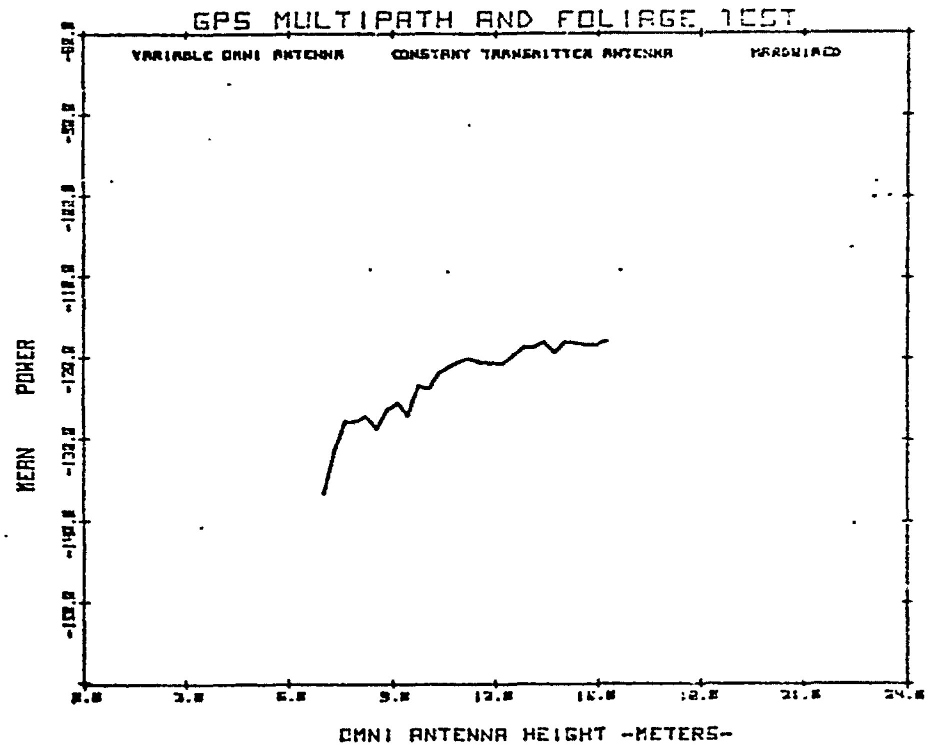
LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 3
DATE: 15 May 75 TIME: 0800
TRANSMITTER ANTENNA HEIGHT: 55 ft
DIST. BETWEEN TRANS. & REC. ANT.: 47.6 m
FOLIAGE TYPE: Southern Red Oak, Laural Oak, Longleaf Pine, Gum
FOLIAGE DENSITY: 63 trees in signal path
AVER. VEGETATION HEIGHT: 20' 1st canopy, 65' 2d canopy
TEMPERATURE: 78°F HUMIDITY: 100%
CLOUD COVERAGE: Rain



LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 3
DATE: 15 May 75 TIME: 0800
TRANSMITTER ANTENNA HEIGHT: 55 ft
DIST. BETWEEN TRANS. & REC. ANT.: 47.6 m
FOLIAGE TYPE: Southern Red Oak, Laural Oak, Longleaf Pine, Gum
FOLIAGE DENSITY: 63 trees in signal path
AVER. VEGETATION HEIGHT: 20' 1st canopy, 65' 2d canopy
TEMPERATURE: 78°F HUMIDITY: 100%
CLOUD COVERAGE: Rain

FIGURE 3.5. Multiple Canopy With Rain Multipath and Foliage Attenuation Results

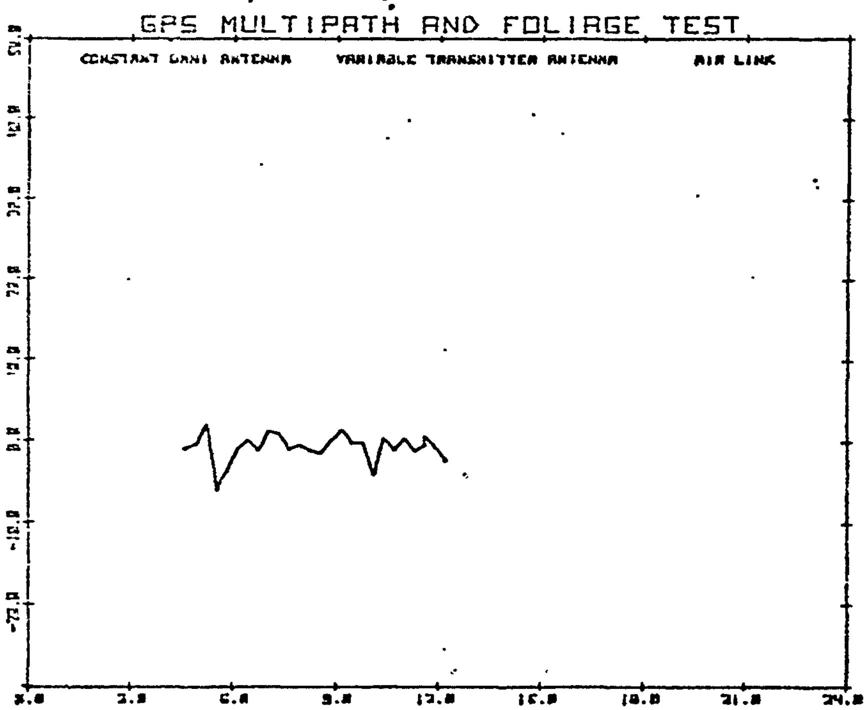


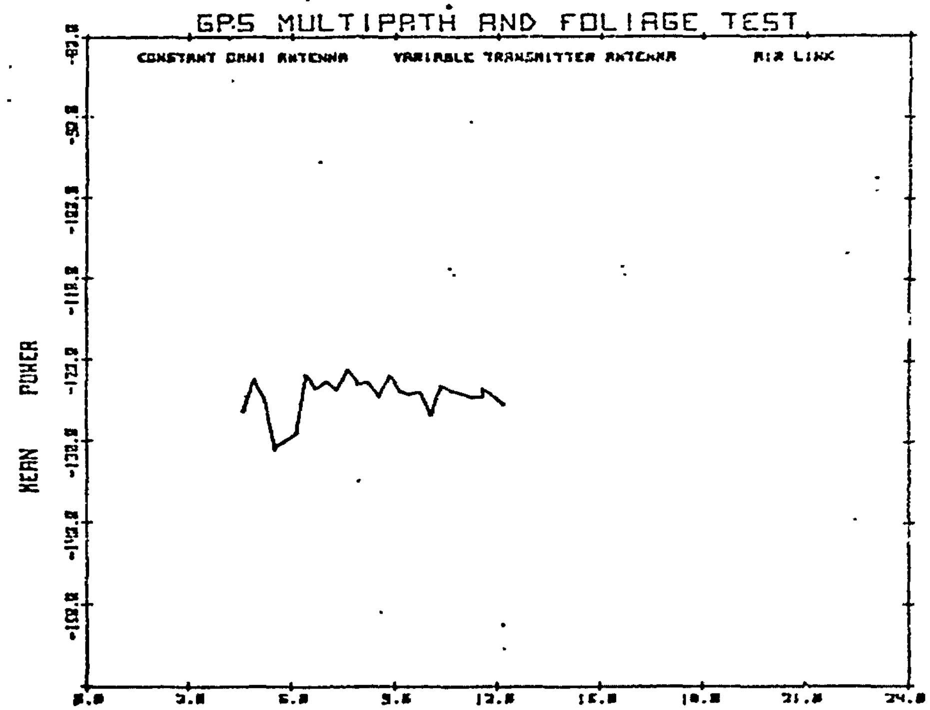


LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 4
DATE: 17 Apr 75 TIME: 0915
TRANSMITTER ANTENNA HEIGHT: 50'
DIST. BETWEEN TRANS. & REC. ANT.: 20.7 m
FOLIAGE TYPE: Gum Bumelia, Blk Gum, American Holly
FOLIAGE DENSITY: Low: 18 trees in signal path
AVER. VEGETATION HEIGHT: 20 ft
TEMPERATURE: 78°F HUMIDITY: 60%
CLOUD COVERAGE: Clear

LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 4
DATE: 17 Apr 75 TIME: 0945
TRANSMITTER ANTENNA HEIGHT: 50'
DIST. BETWEEN TRANS. & REC. ANT.: 20.7 m
FOLIAGE TYPE: Gum Bumelia, Blk Gum, American Holly
FOLIAGE DENSITY: Low: 18 trees in signal path
AVER. VEGETATION HEIGHT: 20 ft
TEMPERATURE: 78°F HUMIDITY: 60%
CLOUD COVERAGE: Clear

FIGURE 3.6. Single Canopy, Low Humidity High Temperature Multipath and Foliage Attenuation Results.

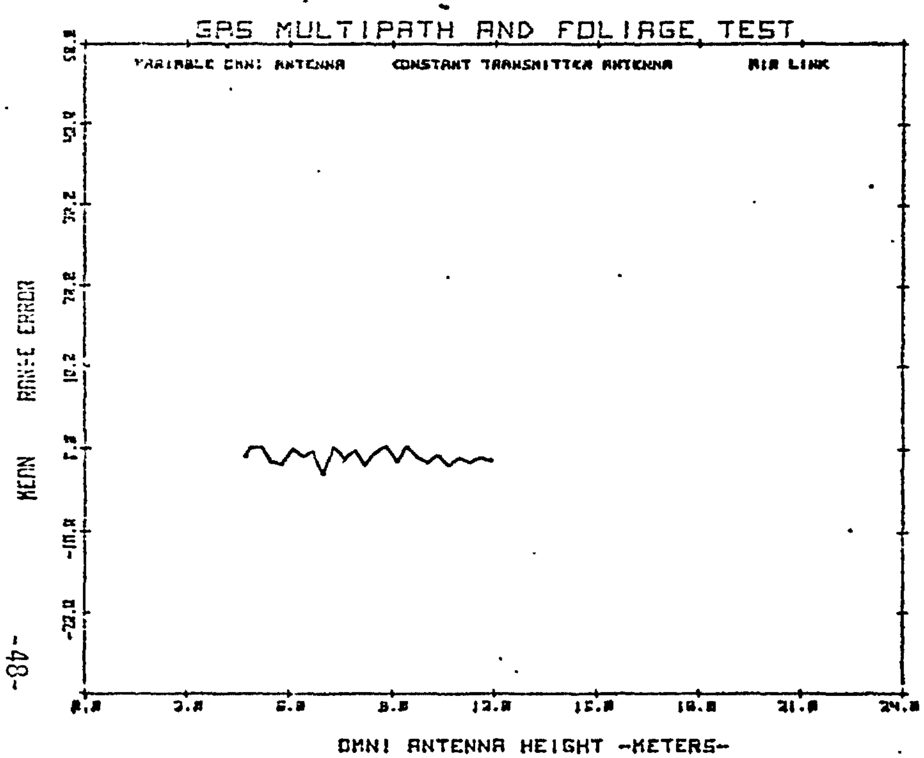




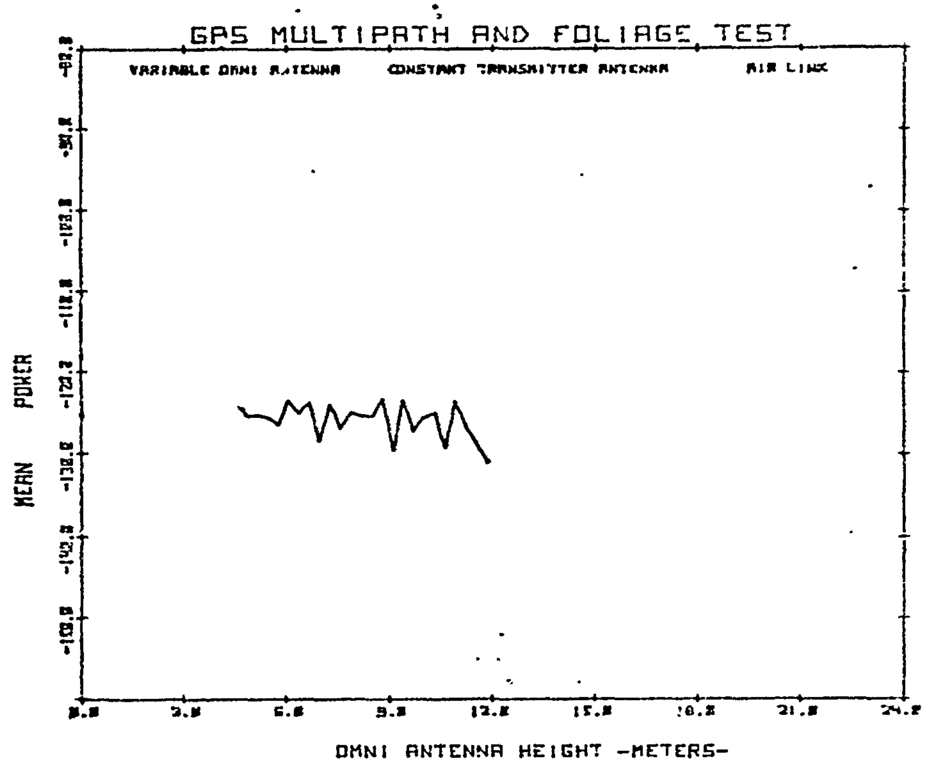
LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 6
DATE: 5 Apr 75 TIME: 0930
TRANSMITTER ANTENNA HEIGHT: Omni: 45 ft
DIST. BETWEEN TRANS. & REC. ANT.: 98.8 m
FOLIAGE TYPE: Southern Red Oak
FOLIAGE DENSITY: Ave: 32 trees in signal path
AVER. VEGETATION HEIGHT: 10'-14'
TEMPERATURE: 50°F HUMIDITY: 65%
CLOUD COVERAGE: Clear

LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 6
DATE: 5 Apr 75 TIME: 0930
TRANSMITTER ANTENNA HEIGHT: Omni: 45ft
DIST. BETWEEN TRANS. & REC. ANT.: 98.8 m
FOLIAGE TYPE: Southern Red Oak
FOLIAGE DENSITY: Ave: 32 trees in signal path
AVER. VEGETATION HEIGHT: 10'-14'
TEMPERATURE: 50°F HUMIDITY: 65%
CLOUD COVERAGE: Clear

FIGURE 3.7 Single Canopy, Low Humidity, Low Temperature Multipath and Foliage Attenutation Results



LOCATION: EGLIN AFB, FLA. TEST SITE NO.: 6
DATE: 31 Mar 75 TIME: 0915
TRANSMITTER ANTENNA HEIGHT: 45 ft
DIST. BETWEEN TRANS. & REC. ANT.: 98.8 m
FOLIAGE TYPE: Southern Red Oaks
FOLIAGE DENSITY: Ave: 32 trees in signal path
AVER. VEGETATION HEIGHT: 10-14 ft
TEMPERATURE: 53°F HUMIDITY: 25%
CLOUD COVERAGE: 40-50% Broken Clouds



LOCATION. EGLIN AFB, FLA. TEST SITE NO.: 6
DATE: 31 Mar 75 TIME: 0945
TRANSMITTER ANTENNA HEIGHT: 45 ft
DIST. BETWEEN TRANS. & REC. ANT.: 98.8 m
FOLIAGE TYPE: Southern Red Oaks
FOLIAGE DENSITY: Ave: 32 trees in signal path
AVER. VEGETATION HEIGHT: 10-14 ft
TEMPERATURE: 53°F HUMIDITY: 25%
CLOUD COVERAGE: 40-50% Broken Clouds

FIGURE 3.8. Single Canopy, Very Low Humidity, Low Temperature Multipath and Foliage Attenuation Results.

4.0 CURRENT METHODS AUGMENTED BY GPS-AUE

Technological advances over the past decade or so have provided the army with a degree of mobility never before realized. The timely placement of troops, supplies and weapons has been made practical by newer land, water and aircraft which can move divisions in a matter of hours. The physical emplacement of weapons and the means of delivering firepower has duly been enhanced through new equipment and techniques. However, this mobility is dependent on knowing where to deploy, where to deploy from, and by what route to deploy. In order to obtain this information, positions, both relative and absolute, must be determined through the means of survey. Many of the current survey methods are of the 1940 to 1950 vintage and supress the full capability of current mobility, although survey equipment has been improved throughout the years, the basic functions of the equipment have changed little. The extension of control, for whatever means, still remains a long and tedious process which can be hampered by terrain, accessibility and weather conditions. When one thinks of improvements to or modernization of survey, one considers increases in efficiently, increases in accuracies, and decreases in time and man power requirements. The Global Positioning System will provide a real time acquisition of positions and provide for increased capabilities in mobility. The improvements to position determinations for target acquisition, mapping, etc. are yet to be realized and can not be fully appreciated until the system is operationally deployed to the field.

Initial implementation of the GPS system may be envisioned as augmentation of current survey techniques. In this light, this section is intened to illustrate possible combinations of such equipment/methods and the improvements to current activities. Considerations are given to the manpack version of GPS only as it applies to field operations.

Primarily two categories of field surveying will be enhanced with the advent of GPS. Those are the topographic survey and the artillery survey. The general topographic survey mission is to provide for timely control establishment or control extension for support map compilation projects. Ground control provides the information necessary to orient and scale those areas being photogrammetrically compiled for map production. Additionally, such control is required for other photogrammetric applications. GPS will afford the topographic surveyor the opportunity to locate selected picture points in real time without such physical constraints as inclement wheather or broken lines of sight. Such real time position acquisition will greatly decrease the response time inherent with conventional survey and also decrease the data reduction time currently required by providing digital readout of positions. In addition to time requirements, GPS will decrease the manpower required to perform such control surveys. One or two men can provide more control more rapidly than current methods requiring teams of five to ten or more men. For densification of control or where control is closely spaced in an area, or for initial control establishment and extension, GPS can be used for the initial establishment of control and conventional methods can be utilized for extension with GPS affording check points throughout the area. In the initial stages of GPS, horizontal control may be established with GPS and vertical control may be brought in via conventional leveling.

The artillery surveyor will benefit from GPS through the capability of providing positions throughout an area to the same common grid. The forward observers may locate their position with GPS and, by combining such equipment as the GYRO-Azimuth surveying instrument, can locate the position of desired targets. The artillery battery can locate its position on the same grid with GPS and thus provide the common tie required between the target area and the weapons position. This method can result in the elimination of the current connecting survey. In cases where individual weapons in a battery must be precisely located relative to the target area, GPS will permit the establishment of this common control which may then be extended, using conventional methods, to individual weapons. GPS control establishment will eliminate the lag time of conventional establishment. When considering that dynamics of operations are not limited on one party in a conflict, the ability to locate a target and position a battery almost simultanuously, greatly enhances both the probability of greater effectives in fire power and the element of surprise for unobserved fire.

Another application of an augmented system is in the field of land navigation. Currently several types of inertial navigation devices are under investigation and field testing to provide a real time navigation system for all types of land vehicles. Examples of such system include the Position and Azimuth Determination System (PADS) and the Inertial Positioning System (IPS). Those systems, however require periodic position updating such that position errors do not accumulate beyond an acceptable error level. By augmenting such a system with GPS, these periodic updates could be observed and applied in real time and positions could be obtained continously for updating at any convenient interval.

Survey has, and does, limit the response time for position determination required in topographic and artillery operations as well as navigation. All improvements to mobility and firepower delivery systems are fruitless unless positions can be determined in a manner such as to exercise the full capabilities of such systems. Firing data, movement tables, navigation aids, manpower and missions are dependent on rapid and accurate position determination. Initial applications of GPS in conjunction with conventional survey techniques and equipments provides the initial step towards fulfilling these timely requirements and in capitalizing on advanced concepts.

Ideally, GPS would be a stand-alone system, however, until the system has been fully operational for some time, it appears that such combinations with conventional methods and equipment will prevail. Much additional research and testing must be done before surveys for azimuth or straight line distances only can be accomodated with GPS. Conventional methods and equipment will continue to dominate these surveys for some time. Where GPS can be combined the survey community will see a tremendous increase in response time.

5.0 ADVANCED CONCEPTS

As with any new system development, new applications and concepts employing such a system are envisioned. With GPS, the functions are already defined and new concepts in positioning and surveying methods and techniques must be considered. As the methods and techniques of conventional methods, previously discussed, are assumed under ideal conditions, the impact of inclement weather, difficult lines of sight, difficult access, and other physical constraints are not considered. With GPS, not only will many of these physical problems be eliminated, thus reducing in-field manpower/time requirements, but also the near real time acquisition of positions will improve the overall response time of the topographic or artillery surveyor. Assuming the system is at full operational capability, several selected scenerios are presented to illustrate how new technqiues may be developed and employed. These scenorios will include geodetic control establishment, picture point control for mapping, target area artillery control, position area artillery control and construction site ties.

5.1 Geodetic Control Establishment

Geodetic control is the highest accuracy (order) of control established in an area and as such is extremely tedious and time consuming. It is performed mainly for scientific studies. Currently the control is established with the cumbersome T-4 or equally cumbersome geoceiver and related equipment. With the geoceiver or other doppler type system, it is estimated that position determination would take a minimum of 5 days at the pole and 10 days at the equator, due to satellite orbital configurations. Another time consuming method of geodetic baseline establishment, which is relatively new, is the Very Long Baseline Interferometry technique based on different rates of return of lightwaves from selected celestial bodies. This method, although very precise, is dependent on visibility of common stars from each end of the baseline. With the GPS, the geodetic surveyor need only to set up his instrument and collect a determined number of passes, possibly up to 30, over a very short period, possibly only one day. As geodetic positioning is performed only after significant planning has been done, locations may be carefully selected which will have little to no effects from foliage attenuation or multipath. The primary sources of error to be considered therefore, are ephemeris error and satellite clock drift. However, raw data may be collected at the positions and may be processed and reduced at a later date applying appropriate ephemeris and clock drift algorithms. As the GPS is not affected by weather conditions (i.e. visibility of stars) the time savings for observation alone could be significant.

5.2 Picture Point Control

Depending on the scale of photography and/or the scale of the final manuscript, the density of picture points in an area may vary widely. The aim of picture point control is to establish an absolute frame of reference for orientation and scaling during map compilation. Currently picture points are controlled by traverse of triangulation procedures utilizing electronic distance measuring equipment and theodolites. This process is again slow and tedious and dependent on intervisibility and weather conditions. Upon selection of points necessary to tie models/photos together, a survey team must be deployed to locate and position these points. Positioning may entail lengthly extension techniques which will, in effect, hamper the timeliness of compilation of an area until survey data is received and reduced. With the GPS, the topographic surveyor could be carried to each selected point, via truck, jeep or even helicopter and in a matter of minutes set up his receiver and obtain a real time position sufficiently accurate for most mapping projects. With warfare evolving to the state where boundaries are not definable, the conventional method of extension requires, in addition to the survey party, sufficient support to provide adequate protection during hostilities. With GPS, the project can be accomplished by one or two men and with minimum protection as the survey party is much more mobile and less susceptible to attack. Thus, with GPS, the timely production of maps and other graphics required by a mobile theater can be greatly enhanced.

5.3 Target Area Artillery Control

The basic idea of target area surveys is to provide coordinates of targets to firing batteries for effective firepower. These surveys are required, as most times artillery batteries are providing indirect fire rather than direct, and the targets cannot be observed by the batteries. Currently, the forward observer obtains target coordinates with the use of a compass and a map. This method may be highly inaccurate and leaves much room for error through misinterpretation of the map by the forward observer. This method may require considerable adjustment of fire before the effectiveness of the fire mission may be realized. With GPS, the forward observer can obtain his positions and azimuth to the target in real time and eliminate the chance of misinterpretation of coordinates. The GPS will also provide a greater accuracy in coordinates to the firing battery and thus increase the probability of first round effectiveness. The accuracy of a firing battery is directly related to the target information provided to it, GPS will afford a much greater accuracy than can be obtained by current means.

5.4 Position Area Artillery Control

The aim of position area artillery control is to provide a common grid for the firing battery in order to determine an azimuth and distance to the target area. Conventional methods call for the topographic engineers to extend or establish control to within a specified distance to the firing battery using either triangulation or traverse methods and equipment. From this control the artillery surveyor may extend control to the batteries or weapons. In addition, the artillery surveyor must perform a connecting survey to place both the target area and the position area on the same grid for communicating common coordinates. As a result of inclement weather and/or the increased mobility of todays artillery, conventional survey may lag several hours or more behind the battery. As a result of this lag and the greater dynamics of the theater of operations, the maximum effectiveness of a mobile artillery cannot be employed efficiently. With GPS, the artillery surveyor would accompany the battery and upon notification of a firing mission, the surveyor can establish a position in real time as the weapons are being prepared for firing. As this position is determined in the same means as the target area survey previously mentioned, a common grid is already established and the connecting survey is not required. Additionally, with the artillery surveyor using GPS, the dependence on control establishment by the engineers is eliminated. Thus GPS will enhance the effectiveness of current artillery mobility.

5.5 Construction Site Ties

Generally, only large construction projects are tied into a local survey net. Such projects may include cantonment areas and large dams. Control is established by the topographic engineer utilizing conventional techniques and equipment. Such survey missions when required, are not necessarily required in a timely manner and therefore, for the purpose of the survey, conventional methods and equipment would suffice. However, with the topographic surveyor utilizing the GPS, the positioning of the project could be obtained in a much faster manner and thus release the surveyor more rapidly such that he may return to this primary mission.

6. Conclusions

The Global Positioning System, upon full implementation, is indeed a tremendous step forward in position and velocity determination. The system, will, as previously mentioned, relieve the surveyor of the burden of initial control establishment and the tedious task of control extension into areas of interest. The ability of obtain position information any time and anywhere in the world in near real time is a definite asset to the survey operations of a dynamic theater. The increased mobility and dynamics afforded current military operations establishes timely requirements for position determination support form both the topographic community and the artillery community. Conventional methods cannot meet current or future demands and thus detract from the full capabilities of mobility and firepower.

The system, as currently envisioned, will significantly impact four primary areas. They are: response time, manpower, equipment, and accuracy. These areas of concern, among others, are discussed in the following subsections.

6.1 Response Time

Timeliness of response has been stressed throughout this report and is attainable through the system capability to acquire, process, and display positions in a real time mode. It is the ability to obtain positions rapidly for movement or artillery support that may define the events to follow, and possibly the final outcome, of hostilities. All ground survey is dependent on physical accessibility to an area, therefore, this factor may be held constant for both conventional and GPS surveys. Conventional surveys, however, are burdened with other parameters which affect timely response. Such factors may include: initial control establishment, length of control extension net, terrain, intervisibility, weather conditions, and data reduction. Where conventional survey may lag hours or even days behind the mobile Field Army, the GPS is essentially free from those limiting factors and can provide instantaneous positions.

6.2 Manpower Required

Manpower and the ability to utilize available manpower effectively is of concern for all military operations. The envisioned GPS manpack segment can effectively provide three-dimensional position coordinates with the option to display these coordinates in a variety of coordinate frames. This segment can be operated by one man. By comparison, the minimum ideal party organizations as defined in TM 5-232, (Elements of Surveying), are provided for the three basic categories of control extension. Following is a tabulation of the current manpower requirements for the various categories of control extension.

6.2.1 *Triangulation*

	Manpower Required
. Reconnaissance party	- 2 to 4
. Direction observation party	- 3 to 5
. Distance measuring party (base line)	- 2 to 6
Total	7 to 15

6.2.2 *Traverse*

. Distance measuring party	- 2 to 6
. Angle party	- 1 to 5
. Level party	- 2 to 4
Total	5 to 15

6.2.3 *Leveling*

. Level party	- 2 to 4
Total	2 to 4

The size of these parties is dependent on the requirements stated for order and class of survey as well as by technique employed. Detailed party descriptions are provided in TM 5-232. As is evident from the previous discussion, the GPS can allow for a savings of 14 or more men per type of control extension.

6.3 Equipment Required

The GPS is a self-contained instrument capable of providing positions independent of additional equipment. Such an instrument is resultant from developments in Large Scale Integrated (LSI) circuits which have provided the vehicle by which the capabilities and functions of relatively large equipment have been condensed into an easily transportable, compact piece of equipment. The following equipment, by type of survey, may eventually be eliminated as GPS survey capabilities increase.

6.3.1 *Triangulation*

- Theodolite
- Tripod
- Distance measuring equipment
- Target sets
- Tower sets
- Auxiliary equipment

6.3.2 *Traverse*

- Theodolite
- Electronic distance measuring equipment
- Tapes
- Tripods
- Auxiliary equipment

6.3.3 *Leveling*

- Level
- Rods
- Tapes
- Auxiliary equipment

The elimination of these various equipments additionally decreases transportation and maintenance support required.

6.4 Accuracy

The accuracy to be obtained with the GPS is yet to be determined and is dependent upon the methods, equipment and techniques employed. Accuracy may be enhanced by improvements in the equipment, better defined mathematical models, and precise methods and techniques with which to operate the system. As an example, conventional doppler positions are currently obtained to a relative accuracy of 1 to 3 meters. Industry has developed methods and techniques to obtain relative accuracies of less than 1 meter utilizing the same commercial equipment. Sophisticated data acquisition and reduction techniques have resulted in relative accuracies of 24 centimeters. In this light, similar methods and techniques can be developed for GPS data in an effort to increase accuracy.

The GPS, being self-contained and accommodating both data acquisition and reduction, decreases the probability of operator/recorder blunders. This is accomplished by the reduction or elimination of human intervention in data reduction and the elimination of human judgement in taking observations. It is not uncommon for a surveyor to observe different portions of a target during repetitive observations or for a recorder to transpose numbers during the recording or reduction process.

6.5 Summary

This system, as currently defined, provides a new platform from which to launch new research and development missions for improving equipment capabilities and user methods and techniques. The GPS system has the potential of obtaining the degree of accuracy attainable from current conventional equipment and techniques, while at the same time providing timely response to the ever increasing degree of Army mobility.

7. RECOMMENDATIONS

As with any advanced system, new areas of impact are investigated, which may be enhanced by that system's characteristics and capabilities. Additionally, studies are typically conducted to increase the effectiveness of such characteristics and capabilities Such is the case with GPS.

This section is devoted to unbiased recommendations derived from the preceeding sections and are presented for six broad categories: training and maintenance, combined methods, new methods, equipment, mathematical models, and unit missions/responsibilities. These recommendations are based on the assumption that those tests and criterion, as defined in the NAVSTAR Global Positioning System Master Test Plan, are implemented.

7.1 Training and Maintenance

Two primary areas of concern when introducing a new system to the field are training and maintenance. It is during the design and testing phases that a system's capabilities and limitations must be introduced to those who will be in positions of leadership and/or decision making at the time of system implementation. This is particularly true of GPS, in that this system will be implemented and will have a great impact on Army survey. Familiarization blocks of instruction should be designed and conducted for those personnel in attendance at the Defense Mapping School surveying and equipment repair courses. Students in such courses, who remain the military, should be Junior Non Commissioned Officers by the time of full GPS implementation. It would be extremely beneficial for such individuals to be familiar with the equipment, utilized by men under their direction, for mission planning. Similar blocks of instruction for Junior Officer courses should be implemented, particularly for the Mapping, Charting and Geodesy Officers Course. These officers may well be in positions of decision making relative to methods, techniques and unit missions employing GPS.

Maintenance, and particularly repair parts support has always been a problem area for nonstandard topographic equipment. Perhaps the increased density of GPS, in that both topographic and artillery surveyors will utilize the system, will dictate increased support. In any event, stockage levels by echelon of maintenance must be established and updated as experience warrants. These levels must be maintained from the initial implementation of the system in order to take advantage of the system capabilities.

7.2 Combined Methods

During the initial operational phases, where limited satellite availability will accomodate only two-dimensional positioning, consideration should be given to combining the GPS and conventional methods to obtain three-dimensional positions. As an example, horizontal positions could be determined with the GPS and the vertical dimension could be established with conventional leveling. For picture point location, not all points need be controlled in all three dimensions. Horizontal control may be sufficient for scaling. An additional combination to be considered for artillery survey would be the augmentation of GPS with an azimuth determining instrument such as the Gyro-Azimuth Surveying instrument. This combination would provide for more accurate position/azimuth determinations for target positioning. This combination would also be useful after the three-dimensional capability of GPS is available.

The navigation capability of inertial positioning systems would be enhanced if augmented with GPS. GPS can be used to provide updates for inertial systems in a real-time mode and eliminate the hazardous necessity of prolonged stops in a hostile environment. In addition, GPS can provide the means by which the error curve on an inertial system would be maintained at a reasonable level.

7.3 New Methods

With the compactness and versatility of GPS, consideration should be given to the gradual elimination of the cumbersome geoceiver and doppler-type systems now in use. Standardization of satellite surveys with the GPS will enhance all phases of surveying from training, through data acquisition/reduction, to maintenance.

As the distances between positions to be determined is decreased, the relative position accuracies begin to degrade due to inherent system errors. To reduce such effects, investigations into methods of translocation should be performed to analyze post-reduction of simultaneously acquired data. Current multiple station reductions in use by industry must be modified and implemented not only to eliminate the relative accuracy error, but also to improve individual position accuracies. Such investigations should take place over known survey control points in various terrain, latitudes and climatic conditions.

In addition to translocation methods, investigations into the application techniques of GPS, to include the number of observations required and method of data reduction, must be initiated to attain the degree of accuracy desired for geodetic, topographic or artillery surveys.

The accuracies of linear measurements and azimuths determined trigonometrically from GPS positions will not meet most accuracy requirements for distances or azimuths. This is resultant from inherent system errors generated over short baselines. Surveys involving strictly these types of determinations will, most likely, utilize conventional equipment and methods.

7.4 Equipment

Investigations need be undertaken for equipment modifications and improvements after GPS has been fully operational. Such investigations should determine: 1) the feasibility of eliminating human error, 2) methods for increased response time on multiple station reductions, and 3) means of reducing errors resulting from natural phenomena related to equipment characteristics.

Unless a method of hard-copy printout is employed with the GPS, the possibility of human blunders in data recording is ever present. An initial step in providing such optional hard-copy would be the addition of a small paper tape printer or electro static printer to the user equipment. This would provide a permanent record of position determinations in a standardized format.

In order to employ multiple station reductions on a timely basis, modifications to equipment must include a means of collecting raw data and transmitting such data through an appropriate data link to a central processing station for reduction with sophisticated equipment and techniques. This data link would eliminate the necessity of a survey party to return to a central location to deliver the required data.

For the majority of surveying missions, the topographic or artillery surveyor will not be able to pick locations in areas relatively free of undesirable terrain, as can the geodetic surveyor. Hence, the varying effects of multipath will be present. Such error is eliminated from the capability of an instrument to detect the first signal to arrive. If multiple path signals are sufficiently close to the first arrival signal, such other signals may generate the multipath error. The ability to detect various arrivals is dependent on the size of the code chip interval in the instrument. Development of smaller chip intervals needs to be investigated so as to effectively reduce or eliminate this error source.

As GPS equipment, methods and technqiues become more effective in providing required position support, conventional equipment and methods may be gradually eliminated from the field,which will greatly reduce maintenance and other support required by the surveyor.

7.5 Mathematical Models

The GPS accuracy is greatly dependent on mathematical models for both position determination and for determining various errors propagated from external parameters. As for position determination, sophisticated adjustment programs currently in use for doppler systems must be studied and either modified for GPS or deleted and new methods must be designed and implemented.

Errors to be modeled fall into three broad classifications: Bias Errors, to include space vehicle transmitter and ground station receiver calibration; Cyclic Errors, to include space vehicle ephemeris, delay variations, clock drift, user clock dirft, multipath, and tropospheric and ionospheric delay; and Random Errors, to include tracking noise and quantization. Each of these has its own mathematical model which attempts to describe the effects of each error type. These models need to be studied after actual implementation to determine the model required to improve error prediction.

7.6 Unit Missions/Responsibilities

The impact of the GPS on unit missions will be very significant. Consideration should now be given to assigning and defining new responsibilities to units equipped with the system. While designing new responsibilities, thought must be given to the reduction of manpower and equipment requirements afforded by such a system. With GPS envisioned as both a topographic and artillery system, the engineer topographic mission of artillery support may be eliminated. Likewise the system capability to provide a common grid to all users will provide for the elimination of the artillery requirement for a connecting survey between the position area and the target area.

The decrease in time, manpower and equipment afforded by the GPS will enhance the modular TSS concept of the topographic community in that survey support can be provided in a more timely manner to a greater number of requirements.

7.7 Summary

These recommendations will enhance the topographic, artillery and geodetic survey community. The real time mode should prove sufficient to most of the topographic and artillery requirements. However, before implementation for ultra-precise geodetic surveys, a study must be conducted to determine whether or not the accuracies attainable with the doppler methodology of the current Naval Navigation Satellite System can be attained with the pseudo-range and range-rate methodology of the Global Positioning System. Initially simulations must be designed and carried out for this determination, in an effort to identify equipment types and methods required prior to full implementation such that costly post-implementation modifications may be avoided.

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APPENDIX A

TYPES OF SURVEY

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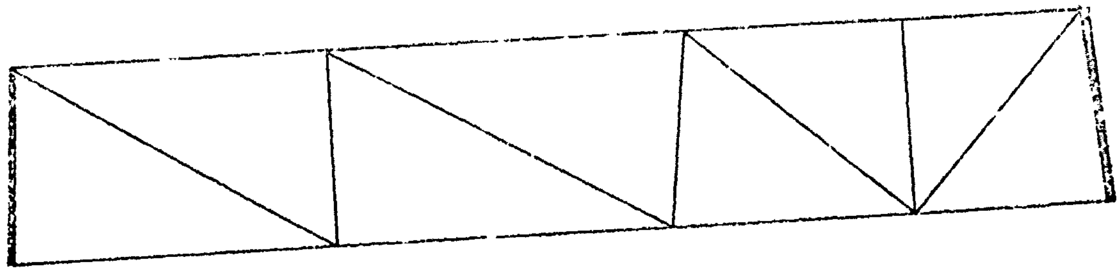
TYPES OF SURVEY

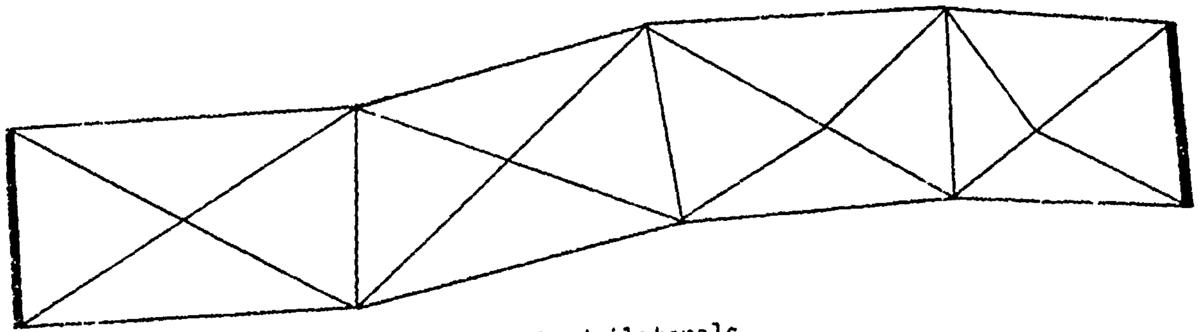
This Appendix contains detailed descriptions of the types of surveys available to the army surveyor for establishment and extension of control. These types consist of Triangulation, Traverse, Trilateration and Leveling.

A.1 Triangulation

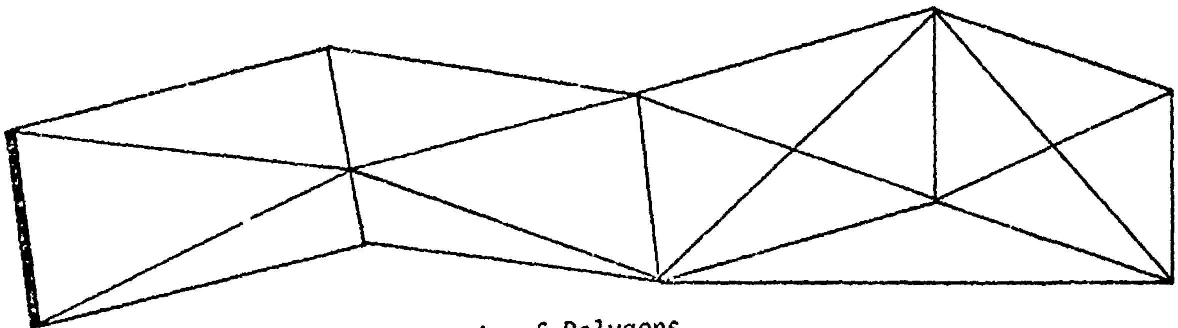
Triangulation is perhaps the most common method of carrying horizontal control for higher order accuracies and strength in computations. It is used for establishing control over extensive areas. The principle of triangulation is based on the geometry of a triangle and is accomplished by measuring angles and computing sides. As three angles may describe any number of triangles in size, a baseline must be established at the beginning of a net. Prior to performing any triangulation measurements a strength of figure must be determined. Strength of figure is the comparative precision of computed lengths determined by the size of angles, number of conditions to be satisfied and the distribution of baselines. There are two types of triangulation in use today, conventional and braced. Conventional triangulation involves measuring the angles of a triangle, chain of triangles or other geometric figure composed of triangles (figure A-1). Allowable figures for conventional triangulation consist of the standard quadrilational, the control point triangle, the control point quadrilational and polygons. Braced triangulation has come into use with the advent of electronic distance measuring equipment. This type of triangulation uses the method of conventional triangulation supplemented by distances of sides of the figures. Allowable



Chain of Triangles



Chain of Quadrilaterals



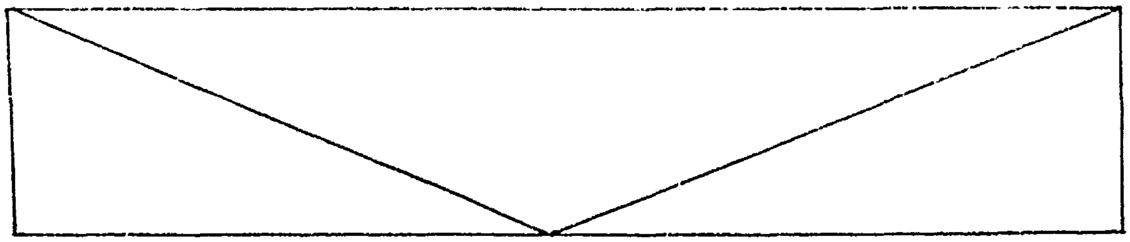
Chain of Polygons

FIGURE A-1. Conventional Triangulation Figures

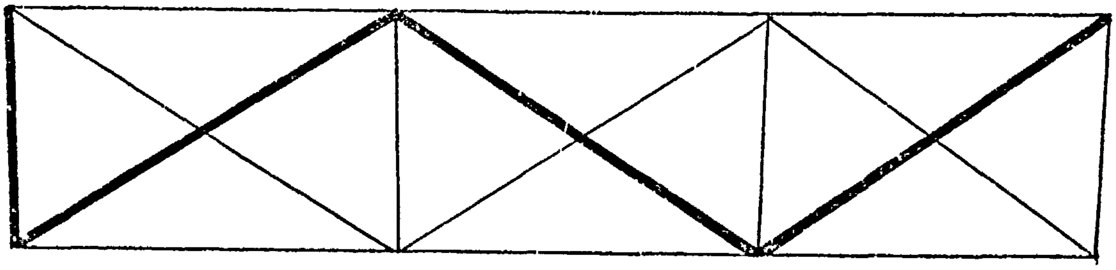
figures for braced triangulation consist of the single triangle or chain of triangles with all directions and distances measured and the standard quadrilational (Figure A-2). Triangulation field parties consist of one or more observing parties consisting of a minimum of two men, and ideally six observing parties with three men each. With braced triangulation additional personnel and equipment is required to measure lengths of prescribed lines. The method triangulation is to observe every station from every other station. Thus the more parties available, the less time required for observation. Conversely additional transporation and communications are required for more parties.

A.2 Traverse

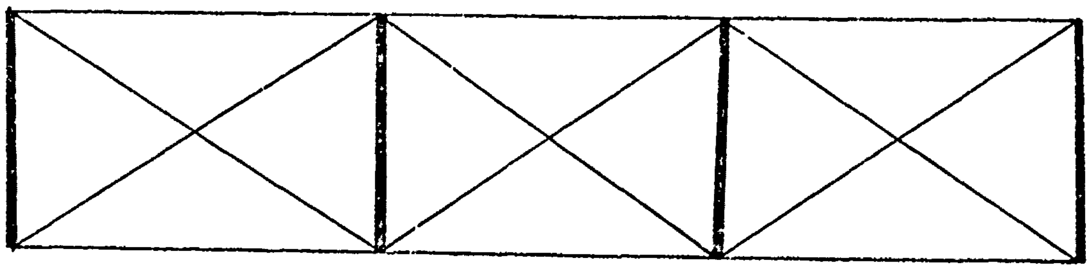
Traverse is a method of extending horizontal control employing the method of direction and distance of a series of straight lines. With the advent of electronic distance measuring equipment, the use of traverse has graduated from supplementary control to basic area control survey. There are two classes of traverse, the open and closed traverse. Open traverses start at a point of known control and terminate on an unknown position. Closed traverses start and end on points of known control. Closed traverses consist of loop traverses, starting and ending of the same point, and connecting traverses, starting and ending of different points (Figure A-3). Traverse parties generally consist of five teams. The reconnasisance team prepares route descriptions and monuments stations. The angle measuring team observes horizontal and vertical angles required. The distance measuring team measures the lengths of each line. The leveling team (required for first and second order) determines vertical elevation differences for taping traverses. The astonomic team establishes azimuth stations as required.



Chain of Triangles - All Distances and Directions Measured

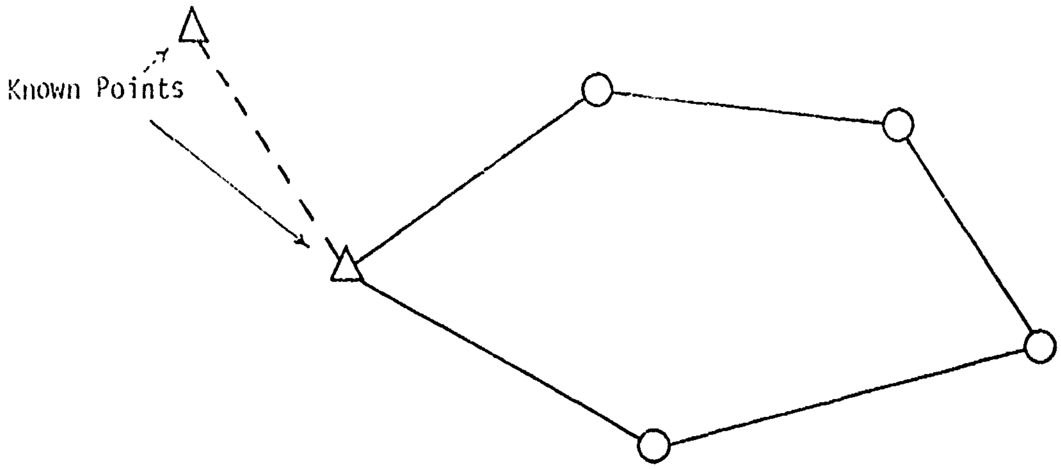


Chain of Quadrilaterals - One Distance Per Figure Measured

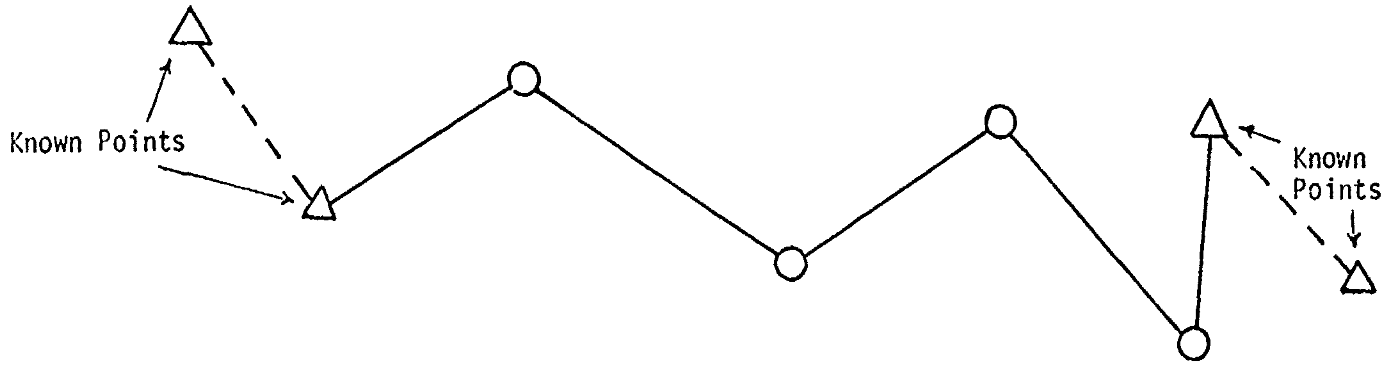


Chain of Quadrilaterals - Common Distance Measured

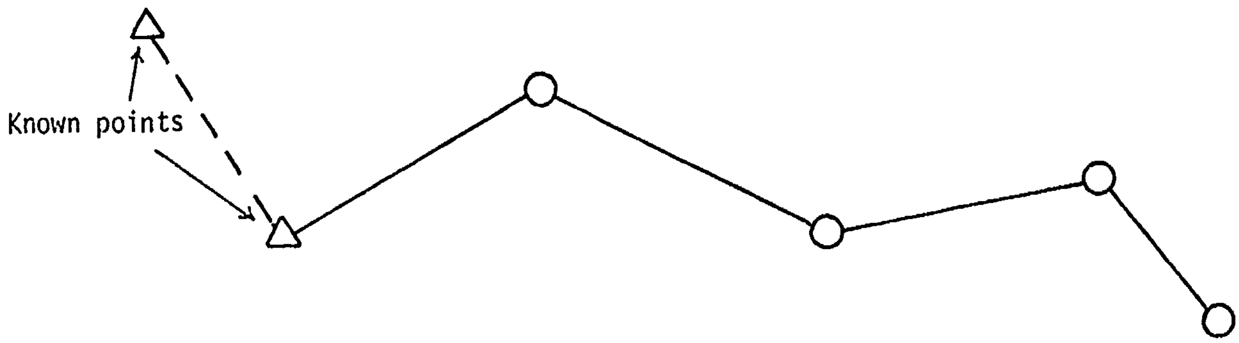
FIGURE A-2. Braced Triangulation Figures



Closed Loop Traverse



Closed Connecting Traverse



Open Traverse

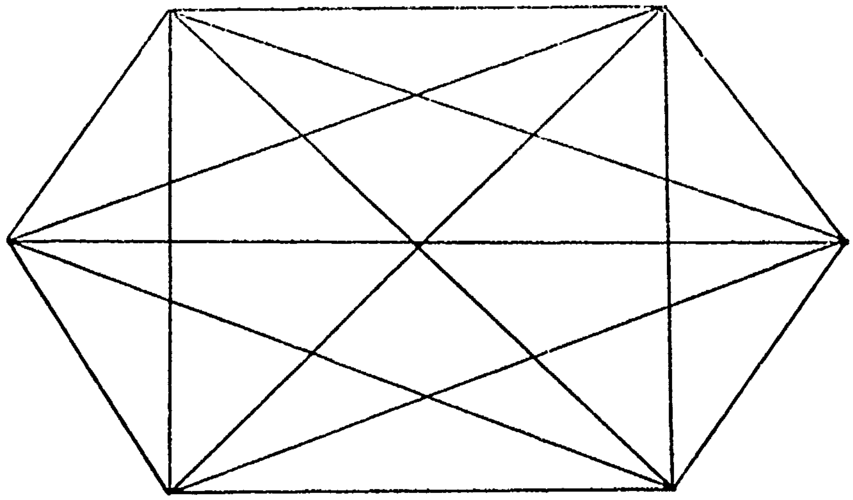
FIGURE A-3. Types of Traverse

A.3 Trilateration

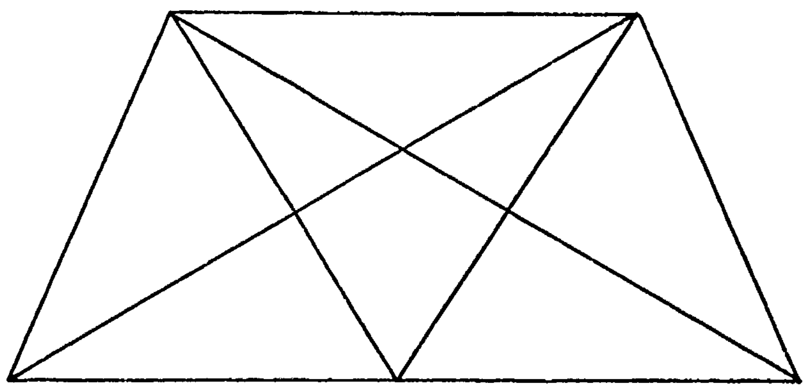
Trilateration, like triangulation is based on the geometry of triangles. The technique of trilateration consists of measuring sides of the triangles in a figure rather than the angles. This technique is not widely used and specifications for trilateration are designed for the specific mission rather than generalized as in triangulation and traverse. The basic figures for trilateration are the regular hexagon and the semi-hexagon with all sides, and diagonals measures (Figure A-4). Limitations affecting the measurements and computations in trilateration consist of: atmospheric instability affecting EDME measurements, distance errors propagating angular distortions, complication of figures, and the lines measured are slope distances and must be adjusted.

A.4 Leveling

Leveling is a means of carrying vertical control or elevation data throughout an area. Leveling is often combined with other types of survey as required. Vertical control is important in mapping for the absolute orientation of photogrammetric models, in order to depict true elevations on maps and charts. It is also important in artillery for the computations of trajectories and clearances. There are two classifications of leveling, direct and indirect, the most accurate and most common class of leveling is the direct method. This method may be referred to as differental or spirit leveling and employs the use of a level vial. The method consists of maintaining a horizontal line of sight, with the aid of the level vial while measuring differences in elevation using a telescope and level rod (Figure A-5a). The indirect method is the least accurate and consists of two



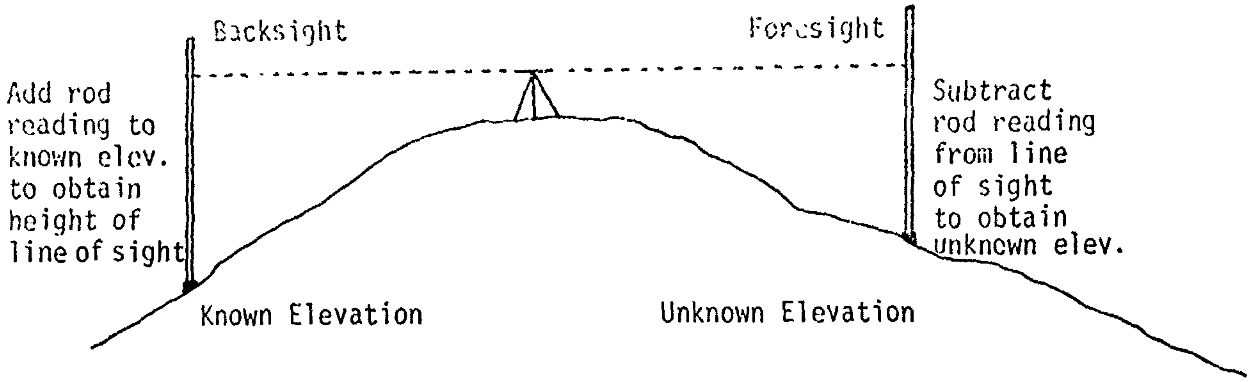
Regular Hexagon



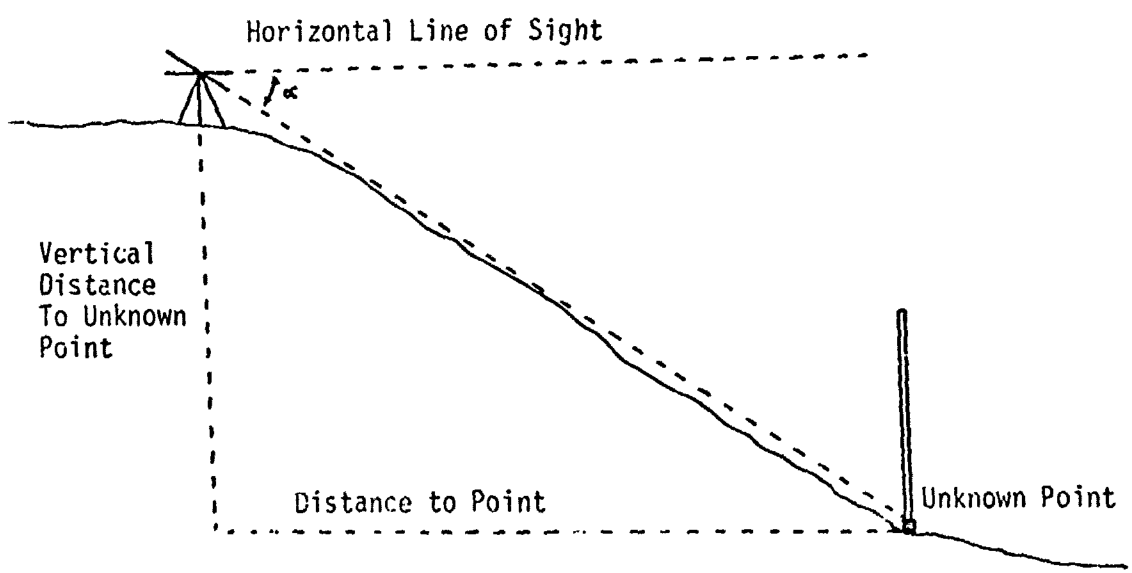
Semi Hexagon

FIGURE A 4. Trilateration Figures

methods, trigonometric and barometric. Trigonometric leveling employs the fundamentals of trigonometry wherein a vertical distance is observed from the horizontal, and when combined with the distance (stadia method) to the point yields the difference in elevation between the two points (Figure A-5b). The method is used for low order accuracy where terrain prohibits differental leveling. Barometric leveling in the least accurate and most susceptable to atmospheric changes. The method incorporates the general fact that atmospheric pressure decreases as elevation increases. The method can be influenced by sunlight, winds, storms, temperature, etc. Barometric leveling is used only when other methods are unfeasible. Figure A-6 presents a synopsis of the accuracies and use of each type of survey, detailed accuracies are presented in Appendix C.



A. Direct Leveling



B. Indirect (Trigonometric) Leveling

FIGURE A-5. Types of Leveling

Type of Survey	Order	Class	Minimum Accuracy/Closure Requirements: Length	Minimum Accuracy/Closure Requirements: Angle	Primary Use
Triangulation	1	I	1: 100,000	Each Figure: ± 3 sec. Ave. Closure: ± 1 sec.	Scientific purposes, crustal movements
		II	1: 50,000		Basic National Control Net
		III	1: 25,000		Extension of same or lower order survey
	2	I	1: 20,000	Each Figure: ± 5 sec. Ave. Closure: ± 1.5 sec.	Subdivision of areas between first order control, extension of control for mapping, cadastral and land surveys
		II	1: 10,000	Each Figure: ± 5 sec. Ave. Closure: ± 3 sec.	
	3		1: 5,000	Each Figure: ± 10 sec. Ave. Closure: ± 5 sec.	Densification of base control for mapping, Artillery and local surveys
	4		1: 3,000	Each Figure: ± 12 sec. Ave. Closure: ± 10 sec.	Extension of Artillery Survey
	5		1: 1,000	Maximum Closure: ± 1 minute	Extension of Artillery Survey
Traverse	1	I, II & III	1: 35,000 closure: .158 m $\sqrt{K}$*	2 sec $\sqrt{N}$**	Basic area control
	2	I & II	1 : 10,000 (Length < 16 K) 1 : 15,000 (Length > 16 K) Closure: .401 m $\sqrt{K}$*	10 sec $\sqrt{N}$**	Subdivision of area between first and second order triangulation
	3		1: 75,000 Closure: .6 M $\sqrt{K}$*	15 sec $\sqrt{N}$**	Detailed mapping control, survey for artillery missile support
	4		1: 3,000 Closure: 1 m $\sqrt{K}$*	.1 mil $\sqrt{N}$**	Extension of Artillery Survey
	5		1: 1,000 *K = Total distances in Km.	** N = number of stations	Extension of Artillery Survey
Leveling	1	I, II & III	± 3 mm $\sqrt{K}$ K = distance between stations in Km.		Establishment of main net of a country, proivde basic control for extension of mapping, engineer & local surveys
	2	I	± 8.4 mm $\sqrt{K}$ K = distance between stations in Km.		Subdivide nets of first order in support of mapping and local survey.
		II	+ 8.4 mm $\sqrt{K}$ K = distance between bench marks in Km.		
	3		± 12 mm $\sqrt{K}$ K = Length of the circuit in Km		Provide elevation for immediate control of artillery and mapping.
	4		As specified (1m. $\sqrt{K}$)		Control of picture points extension of artillery survey.
	5		As specified (± 2m)		Low order Artillery Control.

FIGURE A-6. Accuracy Requirements and Use For Common Surveys

APPENDIX B

EQUIPMENT

APPENDIX B

EQUIPMENT

In order for the military surveyor to accomplished his assigned mission to the accuracy required, he must employ a combination of parameters into the appropriate surveying system. These parameters include; equipment techniques, and methods/proceedures. In this Appendix, a brief description of the various types of equipments available in the field is presented. Equipment will be discussed by categorization of the primary function of each type. During this discussion, it must be remembered that an instrument rated at a specific precision will not necessarily provide a corresponding accuracy unless combined with the proper methods and technqiues.

B-1 Levels

The basic functions of any level is to provide a means with which elevation (vertical) data can be carried from one location to another. All types of levels consist of a level vial incorporated with a sighting device. The types of levels available to the military surveyor are:

. *Locator hand level* - Used primarily in construction survey for expedient horizontal line of sight.

. *Abney Topographic hand level* - More specialized hand level in that it provides a means of directly reading the precent of slope in an area through a graduated arc mounted on the instrument.

. *Engineer level (Dumpy level)* - Used for accomplishing fourth and lower order surveys and in construction survey for layouts. It is a rigidly supported instrument mounted on a tripod for stability.

. *Semiprecise level (Military level)* - Designed for use in accomplishing third order leveling. The sensitivity of this instrument is given at 30 seconds of arc per 2mm. spacing on the vial.

. *Precise level (Geodetic level)* - Used in topographic and geodetic surveys of the highest accuracy (1st and 2nd order). The sensitivity of the instrument is 1.7 to 1.9 seconds of arc per 2 millimeter graduation of the vial. To be considered a precise level, the instrument must be capabile of an accuracy of ± 3mm. per kilometer of level net.

. *Surveying altimeter* - The surveying altimeter is an aneriod-type barometer which measures atmospheric pressure. As pressure decreases with altitude, some estimate of elevation can be obtained with such an instrument. Readings can be affected by humidity, sunlight, or erratic pressures during winds or storms. This equipment can be used for low order survey elevations and artillery elevations. It is most commonly used as an accessory to electronic distance measuring equipment where atmospheric pressures are required for data reduction.

In addition to these instruments, special accessories are required for the performance of level projects. These include:

. *Level Rods* - These are essentially vertical tapes which provide a distance vertically from the ground point to the line of sight. There are three types of rods:

. *Standard* - For all level work through third order. These are generally wooden rods graduated in feet or meters.

. *Precise* - For first and second order work. These consist of a low coefficient of expansion metal strip mounted on a wooden staff. They are graduated in meters and in feet. Standardization must be performed with each rod such that temperature corrections can be applied to the rod length during reduction of the data.

. *Stadia Rods* - For low order work, these rods may be used for elevation and indirect distance observations. They are generally used in plane table surveys.

. *Rod Targets* - Consists of oval or rectangular targets attached to the rod. These targets enchance the ability of the instrumentman in locating the rod over long lines, during poor visibility conditions or through foliage.

. *Rod levels* - Levels attached to the rods to assist the rodman maintaining the rod perpindicular to the horizontal line of sight (level datum).

. *Miscellaneous* - Additional accessories consist of pins, pedestals and wooden stakes for locating turning points during a level circuit and umbrellas for shading the instrument from direct sun during high order surveys.

B-2 Direction and Angle Equipment

Direction and Angle instruments are used in all phases of surveying for measuring horizontal and vertical angles and for extending straight lines. For example, the instruments may be used for computing angles for triangulation and traverse control extension and for computing radii of curvatures during construction surveys. Types of Direction and Angle instruments currently used in military surveys are:

. *Engineer Transit* - Often called the universal surveying instrument. It can be used for all categories of low order survey to include measurement or horizontal and vertical angles, elevation differences and distances by stadia. The instrument is commonly used for construction survey for accomplishing layout work. These instruments are being replaced by low order theodolites but may be still available in the field.

. *One Minute Theodolite (T-16)* - This instrument is basically a direction-type instrument. It can be used to read horizontal and vertical angles. The instrument comes in two versions, the Artillery version (reading directly to .2 mils) and the Engineer version (reading directly to 1 minute). These are used for third and lower order Engineer survey, and for fifth order Artillery survey.

. *One-Second Theodolite (T-2)* - This is a precision direction-type instrument and is also issued in two versions. The artillery version reads directly to .002 mil, and the Engineer version reads directly to 1 second. These instruments are used for second and third order surveys and can be used for astronomic observations. The Artillery uses the instrument for fourth order work.

. *Two-tenth-second Theodolite (T-3)* - This is also a precision direction-type instrument and can be read directly to .2 seconds. It is strictly an Engineer instrument and is capable of first order accuracy. It is generally used for first and second order survey work.

. *One-tenth-second Theodolite (T-4)* - This is a very precise instrument used primarily for first order astronomic observations. The horizontal angle can be read directly to .1 second and the vertical circle can be read directly to .2 second. The weight of the instrument is about 110 pounds and makes it extremely cumbersome to move about, however, its weight provides excellent stability, even when used with a tripod, for accomplishing fine measurements. The instrument is commonly used on a poured concrete pedestal with well prepared footings for stability.

B-3. Distance Measuring Equipment

Distance measuring instruments are used in all forms of survey. This equipment is used for measuring the lengths of the legs in a traverse, the sides of a triangle in trilateration and the baselines in triangulation. Construction surveys use distance measurements in layouts and for computing material requirements and in structure classification.

B-3.1 Indirect Distance Measuring

Indirect measurements are used for expedient low order short lines. The principle of indirect measuring of distances is to compute trigonometrically a length based on similar triangles wherein an angle is observed which is subtended by a known distance perpindicular to the line of sight. There are two basic types of equipment issued for such measurements:

. *Stadia rods* - There are wooden boards graduated in feet or meters and are sighted on by an instrument with two horizontal wires. One reads the two intersections of the wires and by knowing the angle subtended by the wires and the distance between the wires, on can compute the distance to the stadia rod using the common angle and the stadia distance.

. *Subtense Bar* - This equipment uses the same principle as the stadia rod. However, the bar is of known length (2.0 meters) and is mounted horizontally. Using a theodolite, one sights on each end of the bar and observes the horizontal angle between the two observations.

B-3.2 Direct Distances Measurement

In direct distance measurements, the measurement required is observed directly with no mathematical manipulation required except for physical corrections required for improved accuracies.

. *Tapes* - The basic distance measuring equipment is the tape. Such equipment comes in various lengths, widths, graduations and materials.

. *Metallic tape* - This type is constructed by interweaving metallic threads in cotton or linen bands. This type of tape is used for low accuracy work and construction surveys.

. *Steel Tapes* - This type is the most common tape is surveying and is used for up to second order work. They may be graduated in feet or meters.

. *Low Coefficients Tapes* - These are the most precise tapes and must be handled with care They are capable of First and second order accuracies. Low coefficients tapes are less affected by temperature changes and thereby can carry accuracies more efficiently. For first order work, these tapes must be standardized by the National Bureau of Standards prior to and upon completion of a survey project.

. *Microwave Instruments* - These instruments are capable of very precise measurements of distances. The equipment operates on high frequency radio waves and determines distances by comparing phase differences in modulated radio waves. The measurements are affected by atmospheric conditions which must be recorded at the time of measurement with the aid of auxillary equipment.

. *Tellurometer* (MRA-1) - This is the oldest type of microwave instrument is the Army inventory. The master and remote units are not interchangable. Data readout is on a cathode ray tube (CRT). The range of the instrument is 154 to 64,000 meters.

. *Fairchild Micro-chain* (MC-8) - This is a transistorized DME with direct digital readout. It has a range from 200 to 50,000 meters and has an accuracy of 4 parts per million plus or minus 1.5 centimeters. This instrument can be used interchangably with the following instruments provided it is calibrated to the other instruments.

. *Applied Devices, Surveying Instrument Electronic (Model 99)* - This instrument has the same range and accuracy as the MC-8. It also is transistorized and completely portable. Like the MC-8, it also can be used in combination with either the MC-8 or the MRA-301 provided it is calibrated to the corresponding instrument.

. *Tellurometer (MRA-301)* - Like the MC-8 and the Model 99, this instrument has a range of 200 to 50,000 meters and an accuracy of 4 parts per million plus or minus 1.5 centimeters. It also is transistorized and, with proper calibration, can be used interchangably with the MC-8 or the Model 99.

. *Lightwave Instruments* - These are the most precise distance measuring instruments available to the field army. They are electro-optical instruments and determine distances using the velocity of light as a constant and the time it takes for a light wave to leave the units, be reflected and return. All forms of this category of distance measuring instruments consist of two units, a transmitter/receiver and a reflecting unit.

. *Geodimeter Model 2A* - As of the June 1971 edition of TM-5-232, this is the only model currently in the Army supply system. The instrument is one of the most accurate instruments in use with a rated accuracy of 1 part per million plus or minus 1 centimeter. It has a rated range of 50 kilometers and is used primarily in First order baseline measurments.

. *Geodimeter Model 4D* - This instrument has been used by the former U.S. Army Topographic Command (TOPOCOM), now the Defense Mapping Agency Topographic Center (DMATC). It has a rated range of 20 kilometer but can measure up to 8 kilometers in the daylight and, with the use of mercury vapor lamps, up to 40 kilometers at night. It has a rated accuracy of 2 parts per million plus or minus 10 millimeters. This instrument is generally used for first order traverse.

. *Geodimeter Model 6* - This model is considered for use by the military. Is has a range of from 48 fect to one to two miles (day) or 10 miles (night) with a rated accuracy of 2 parts per million plus or minus 1 centimeter.

. *Geodimeter Model 8, Laser* - Uses a laser beam rather than light. This is also considered for military use. It has a range of 15 meters to 60 kilometers and an accuracy of 1 part per million plus or minus 6 millimeters.

. *Laser Ranger* - A lightweight instrument weighting only 25 pounds. It is considered for military use and has a range of up to 6 kilometers with an accuracy of 1 part per million plus or minus 5 millimeters.

. *Range Master* - Considered for military use, this instrument has a range from 10 yards to greater than 40 miles. Its accuracy is rated at 10 parts per million or 1 centimeter, whichever is greater.

. *Geodolite* - Also considered for use by the military, the instrument has a range from 2 meters to up to 60 kilometers with an accuracy of 1 part per million plus or minus 1 millimeter.

. *Special Purpose Equipment* - Special purpose equipment is generally designed for a specific mission of function. As such, they have limited use in survey. Some special purpose equipment include:

. *Gyro - Azimuth Surveying Equipment* - This instrument is a portable gyrocompass combined with a T-2 type theodolite. It is primarily used to determine a true azimuth reference in any weather, day or night, without the aid of stars, landmarks or other visible objects. It is used for fourth and fifth order artillery azimuth determination.

. *Pendulm Astrolabe* - A special purpose type telescopic instrument for astronomic position surveys. This instrument is not common to field units but has the capability of third order astronomic surveys.

. *Planetable and Alidade* - This system is designed to provide a field expedient sketch or map manuscript of a relatively small area. It is ideal for contruction mapping and cantonment layout. The system consists of a tripod mounted drawing surface and a combination straightedge and sighting instrument. Distances are obtained either by stadia or taping.

Figure B-1 presents a synopsis of minimum equipment requirements by type of survey.

Triangulation	1	I	Baseline: Geodimeter 2A or Invar Tape Angles: Two-Tenths (.2) second theodolite (T-3 or equivalent)
	2	II	Baseline: Geodimeter 2A or Invar Tape Angles: Two-Tenths (.2) second or one second theodolite (T-2 or equivalent)
			Baseline: Geodimeter 2A or 4D, microwave, steel or invar tape Angles: Two-Tenths (.2) second or one second theodolite
	3		Baseline: Geodimeter 2A or 4D, microwave, steel tape Angles: One second theodolite
	4		Baseline: Tellurometer (MRA-1), DME (MC8), steel tape Angles: One second or one minute theodolite (T-16 or equivalent)
	5		Baseline: Tellurometer (MR-1), DME (MC8), steel tape Angles: One second or one minute theodolite
Traverse	1	I, II & III	Distance: Geodimeter 2A, microwave or invar tape Angles: Two-Tenths (.2) second theodolite
	2	I & II	Distance: Geodimeter 2A or 4D, microwave, steel or invar tape Angles: Two-Tenths (.2) second or one second theodolite
	3		Distance: Microwave (MRA-301 or MC8), Geodimeter 2A or 4D, steel tape Angles: One second theodolite
	4		Distance: Steel tape, tellurometer (MRA-1), DME (MC8) Angles: One second theodolite
	5		Distance: Steel tape, tellurometer (MRA-1), DME (MC8) Angles: One minute theodolite
Leveling	1	I, II & III	Precise levels and precise level rods
	2	I & II	Precise levels and precise level rods
	3		Semi-precise levels and semi-precise level rods
	4		Spirit levels (Dumpy of military or equivalent) and type of Philadelphia or stadia rod
	5		Spirit Levels, aneroid barometers, altimeters any type of stadia rod.

FIGURE B-1. Minimum Equipment Requirements For Common Surveys

APPENDIX C

METHODS/PROCEDURES

APPENDIX C

METHODS/PROCEDURES

As previously mentioned, it is not the precision of an instrument alone that defines the accuracy of a survey, but a combination of instrument/methods/procedures. This Appendix will deal with specific methods and procedures specified for various types and orders of military surveys. For the purpose of this report, only the basic requirements for the various types of surveys will be presented. A synopsis is presented in Figure C-1.

C.1 Distance Measuring

C.1.1 *Tapes* - Tapes may be used for the measurements of baselines for triangulation, legs of a traverse, construction surveys or artillery surveys. Two methods of taping exist: The first is horizontal taping and is carried out by supporting the tape only at the ends and keeping the tape level during reading. Horizontal taping requires a minimum of two men, however the standard taping party consists of four men. The second method is slope taping wherein the tape may lie supported on its entire length and parellel to the ground. An additional level party is required to convert the slope distances to horizontal distances. Slope taping may consist of four to nine men. Taping Procedures by order and survey type follows:

C.1.1.1 First Order

Baseline - Three tapes will be used as a minimum for each precise base. The portions measured by each tape will be approximately the same length. Each section will be measured forward with one tape and backward with another. Any discrepancy shall not exceed 10mm $\sqrt{k}$. The alignment shall not be off by more than 2.5cm per 50 meter length. To maintain alignment a theodolite is often used. Slope of a tape length should not exceed a grade of 10% if the slope exceeds 10%, the horizontal method will be used.

Traverse - Same as baseline above.

Construction Survey - Not used

Artillery Survey - Not used

C.1.1.2 Second Order

Baseline - Two tapes will be used. Each section will be measured forward with one tape and backward with the other. The discrepancy shall not exceed 20mm $\sqrt{k}$. The alignment will not be off by more than 5cm per tape length. Slope of a tape length should not exceed 15%. Again, if greater than 15%, use the horizontal method.

Traverse - Same as first order traverse.

Construction Survey - Not used.

Artillery Survey - Not used.

C.1.1.3 Third Order

Baseline - Two measurements of each section shall be made using two different tapes as for second order. The discrepancy between measurements shall not exceed 25mm $\sqrt{K}$. The alignment of the tape shall not be off by more than 15cm for each measured section.

Traverse - Same as second order except the abney level may be used to determine slope and invar (low coefficients) tapes are not used.

Construction Survey - Not used.

Artillery Survey - Same requirements as for traverse. Used for artillery missile support, and is performed by engineer survey personnel.

C.1.1.4 Fourth and Lower Order

Baseline - Not used.

Traverse - Generally used for picutre point control for map compliation. Specifications state that for 1:50,000 mapping the point cannot be more that 6 meters from its true location; for 1:25,000 the requirements are ± 3 meters. Methods and procedures are determined by party chief. Generally third order techniques are used.

Construction - Generally one measurement with a steel or cloth tape is made. Accuracy is determined by a construction project.

Artillery Support - Performed by artillery survey personnel. For fourth order traverse, the line is double taped and comparative accuracy is computed not to exceed 1:5000. For fourth order triangulation, intersection or resection, the line is double taped and a comparative accuracy is computed not to exceed 1:7000. For fifth order traverse, lines are singly taped and checked with pacing. For fifth order triangulation, intersection resection, lines are double taped and a comparative accuracy is computed not to exceed 1:3000.

C.1.2 Microwave

Microwave Instruments provide for relatively easy distance measurements for the military surveyor in performing measurements for baselines, traverse, triangulation, construction and artillery surveys. Minimum and maximum ranges must consider the properties of the instrument. Microwave procedures are given by order and survey type:

C.1.2.1 First Order

Baseline - Not used.

Traverse - Four independent measurements are taken, two with instruments on main stations and two with instruments on offset points. Two distances must agree within 1 part in 150,000.

Triangulation - Not used.

Construction Survey - Not used.

Artillery Survey - Not used.

C.1.2.2 Second Order

Baseline - Due to the inherent error of 4PPM ± 1.5cm in the equipment, a minimum of 10KM line must be measured. A minimum of eight sets of measurements are required. Usually 10 sets are taken. Each set shall consist of 2 course and a minimum of 10 fine readings. There should be a time lapse between successive sets and the number of sets should be divided equally over a two day period. Slope of the line should not exceed a 10% grade.

Traverse - Same procedure as first order except two distances must agree within 1:75,000.

Trilateration - Only proceedural guides are available and accuracies stated dictate the method used in trilateration. As the inherent error of microwave instruments cannot be removed by calibration, the distance of length or line measured must accept this error. For second order the minimum length is about 15KM.

Construction Survey - Not used.

Artillery Survey - Not used.

C.1.2.3 Third Order

Baseline - A minimum of four sets of measurements are required. Usually six sets are taken, three from each end of the line. Each set shall consist of 2 course and 10 fine readings. At least two sets should be taken under different atmospheric conditions than the rest.

Traverse - Absolute minimum length is 200 meters. Measure each line twice, once from each end. The difference in measurements must not exceed .6 meters.

Triangulation - Same as second order, however, the line may be less than 15KM but longer than 5KM.

Construction Survey - Not used.

Artillery - Same requirements as for traverse. Used for artillery missile support, performed by engineer survey personnel.

C.1.2.4 Fourth and Lower Order

Baseline - Not used.

Traverse - Same criteria as for taping.

Triangulation - Same as third order.

Construction Survey - For low order distances in excess of 200M. A Single set of measurements is adequate. Accuracy is specified by project specifications.

Artillery - For traverse with the tellurometer MRA1, one set consisting of 2 course and 4 fine readings for 4th and 5th order with a length error not to exceed 1M $\sqrt{k}$, where K is the distance in kilometers if greater than 9000m, or 3000 $\sqrt{M}$, where M is the total distance in meters if less than 9000m. With MC-8, measure in both directions with same error criteria. For triangulation, same as traverse except base error is not to exceed 1:3000 for 4th order and 1:1000 for 5th order. For trilateration, for 4th order only, measure in both directions and the comparative accuracy must be less than 1:25,000.

C.1.3 Electro - Optical

Electro Optical (lightwave) instruments provide the highest accuracy of all distance measuring equipment. They are used by the military surveyor for geodetic and topographic surveys, particularity for baselines, traverse and trilateration. Construction and artillery surveys do not warrant the use of these high precision instruments. Following is a description of electro optical procedures by orders and types of survey:

C.1.3.1 First Order

Baseline - The geodimeter model 2A is used and because of inherent errors in the instrument the length of baselines should be between 10KM and 30KM. The grade between ends should not exceed 10%. Eighteen length determinations are made on 3 frequencies of 6 sets each, the sets are to be equally divided over a period of two nights. All observations are done at night. No individual determinations must exceed the mean of the 18 determinations by more than 3 times the probable error of a measurement. The probable error of the mean for this order baseline is 1:1,000,000.

Traverse - The maximum length of the course should not exceed 20KM and not be less than 3KM. Length determinations consist of two measurements separated by not less than 2 hours. The probable error of the mean should not exceed 1:150,000.

Triangulation - Same as microwave.

C.1.3.2 Second Order - (Class II)

Baseline - Both the Geodimeter 2A and 4D may be used for class II second order survey. All observations may be made in one night provided a minimum of 2 hours elapse between the first half and second half. With model 2A, six length determinations should be made with at least four acceptable. With Model 4D, 12 determinations should be made with at least eight acceptable, rejection limits are the same as for first order. The probable error of the mean for this order baseline is 1:50,000.

Traverse - Minimum length of legs should not be less than 1KM. Determinations of length will consist of two acceptable measurements with the probable error of the mean to agree within 1:75,000.

Triangulation - Same as microwave.

C.1.3.3 Third Order

Baseline - Model 2A and 4D may be used. If electro-optical instruments are used, a determination will consist of two measurements with the probable error of the not to exceed 1:250,000.

Traverse - Electro-optical instruments are seldom used for third order. However, when used, the length of legs should not be less than 1KM and the determination will consist of 2 measurements with a probable error of the mean not to exceed 1:25,000.

C.1.3.4 Fourth and Lower Order - Not Used.

C.2 Direction and Angle Measuring

Directions and angles are measured during traverse, triangulation, construction and artillery surveys. Instruments are optical telescopic instruments and vary from transits for extremely low order construction survey to the T-4 theodolite for very precise astronomic work. The procedures here will be discussed by order and type of survey:

C.2.1 First Order

Traverse - Angles must be observed with a .2 second theodolite (T-3) or equivalent. Observations are to be at night using signal lights. Two sets of 16 positions are required with the sets separated by at least 4 hours. Mean values of the two sets shall not differ by more than 1.0 seconds. A set of observations will consist of eight positions from the rear stations turning to forward and eight positions from the forward turning to the rear. Any position within a group of eight differing by more than 3.0 seconds of the mean will be rejected and reobserved.

Triangulation - Angles must be observed with a T-3 or equivalent. Two sets of 16 observation should be made on each direction from all stations. The two sets should be separated by not less than 2 hours. Means of the sets should not differ by more than 1.5 seconds. Individual measurements shall not differ from the mean of a.set of more than 4.0 seconds. The closure of the triangles should not exceed ± 3.0 seconds.

Construction - Not used.

Artillery - Not used.

C.2.2 Second Order

Traverse - Angles may be observed with a .2 second (T-3) or a 1.0 second (T-2) or equivalent theodolite. Observations may be at night or during the day. If using the (T-3), 4 positions from forward to rear and 4 positions from rear to forward are required. If using the (T-2), six positions in each direction are required. No position shall differ from the mean by more than 5.0 seconds.

Triangulation - Observations may be done day or night.

1) T-3 or equivalent - for class I, 16 positions are required with a rejection limit of ± 4.0 seconds. For class II, eight positions are required with a rejection limit of ± 4.0 seconds of the mean.

2) T-2 or equivalent - for class 1, 2 sets of 16 positions are desired with a rejection limit of ± 5 seconds. The mean of the two sets should not differ by more than ± 3 seconds. For class II one set of 16 observations is required with a rejection limit ± 5 seconds. The angles of a triangle must close within ± 5 seconds.

Construction - Not used.

Artillery - Not used.

C.2.3 Third Order

Traverse - Angles are observed with a T-2 theodolite or equivalent. Observations may be done at night or during the day. Two positions from forward to rear and two positions from rear to forward are required. Any position differing from the mean by more than ± 5 seconds is rejected and reobserved.

Triangulation - The instrument generally used is the T-2 or equivalent. Observations are usually done during the day. One set of four positions is required on all directions with a rejection limit of ± 6 seconds. Triangles must close within ± 10.0 seconds.

Construction - Not used.

Artillery - For conventional artillery and artillery missile control, use either traverse or triangulation. Performed by engineer personnel.

C.2.4 Fourth and Lower Order

Traverse - Used basically for picture point control. Scale of map specifices accuracy required.

Triangulation - Accuracy specificed by mapping project. Angles measured with a 1.0 second theodolite and two to four positions are observed in each direction with a rejection limit of ± 10 seconds. This method is generally not used and third order procedures are substituted.

Construction - The engineer transit is generally used for grades, radii of curvature and layout work.

Artillery - Authorized equipment consists of The T-16 or equivalent (.2 mil) theodolite and the T-2 or equivalent (.002 mil) theodolite. Traverse and triangulation may be carried out by either. Fourth and fifth order traverse requires one direct or reverse position. Fourth order triangulation requires two positions with a 10 second limit between positions. Fifth order triangulation/requires only one position.

C.3 Leveling

Leveling equipment and procedures are required to carry vertical elevations to a specific accuracy from one location to another such that the three dimensional parameters are available for the specified mission. Procedures are discussed by order and type of level category.

C.3.1 First Order

First order leveling is not done by the military surveyor and procedures do not apply. For information, the accuracy of such surveys is $\pm$ 3mm $\sqrt{k}$.

C.3.2 Second Order

C.3.2.1 Class I

Direct Leveling - Use of precise levels and rods are required. Lines are divide into 1 to 2KM sections run both forward and backward. The two runnings must not differ by more than $\pm$ 8.4 mm $\sqrt{k}$. Surveys must begin and end on previously existing benchmarks of 2nd order or higher accuracy. Backsight and foresight for each section should not differ by more than 10 meters and the sum of backsights and foresights for the circuit shall not exceed 20 meters. Three wires are read for this procedure. Maximum lengths of sights should not exceed 75 meters.

Indirect Leveling - Not used.

C.3.2.2 Class II

Same as Class I except the lines are only run in one direction. Supplemental lines are required to detect blunders, or large errors.

C.3.3 Third Order

Direct Leveling - Semi-precise levels such as the dumpy level should be used with rods graduated to .01 foot (Philadelphia Rod or equivalent is acceptable). Lines should not exceed 30 miles in length and are run singly, but must close on lines of equal or greater order. Closing checks shall not exceed $\pm$ 12mm $\sqrt{K}$. Difference of individual backsight/foresight shall not exceed 10 meters and total difference in backsight/foresight shall not exceed 30 meters. Supplemental lines are not required. Maximum length of lines should not exceed 75 meters. Three wires are read for this procedure.

Indirect Leveling - Not used.

C.3.4 Fourth and Lower Order

Direct Leveling - Accomplished for control of picture points, the accuracy is specified by project or contour interval. Precise level should not be used. Use of military level, dumpy level, Wye level, etc. is acceptable and any stadia rod with readings of .05 ft or 1cm is satisfactory. Premissible error may vary from 1 to 5 meters. Only one wire is read. The length of sights may be as far as 600 meters, depending on equipment and conditions. Roughly balanced backsights and foresights are satisfactory.

Indirect Leveling - Two methods exist, first the trigonometric method, wherein a distance is observed along with a vertical angle and the height computed. The second method is barometric and detects differences in elevation resulting from atmospheric pressure changes due to altitude. Generally used only in large scale mapping projects and for artillery survey.

Types of Survey	Order	Class	[illegible]		
			Distance	Angle	Astro/Azimuth
Triangulation	1	I, II & III	Lines must not be less than three miles in length, with desired lengths of 10-15 miles. Strength of figure requirements must be met.	Two sets of 16 observations each set are required. There must be minimum of two hour lag-time between sets. They must be taken at night any direction differing from the mean of a set by ± must be observed.	For class I and II, astronomic observations must be taken every 6 to 8 figures. For class III, astronomic observations are required every 8 to 10 figures.
	2	I	No set limit on length of lines. They must be long enough to meet established strength of figure requirements.	Usually done at night. Sixteen positions are required with a rejection limit of 4 seconds with the T-3. With the T-2 sixteen positions are required with rejection limit of 5 seconds.	Astronomic observations of latitude, longitude and azimuth are required every 8 to 10 figures.
		II	No set limit on length of lines. They must be long enough to meet established strength of figure requirements.	Done during day or night. With the T-3, must have 8 positions with a 4 second rejection limit. With the T-2, must have 16 positions with a 5 second between limit.	Astronomic observations are required every 10 to 12 figures.
	3	I	Length of lines depends on the area to be controlled, the purpose of the survey and strength, of figure requirements.	Performed during day light. Four positions are required with a rejection limit of 6 seconds.	Astronomic observations of azimuth only are required every 10 to 15 figures.
	4	II	No set Limit	Two positions are required with a rejection limit of 10 seconds.	Azimuth clock is performed every 5 figures or when strength exceeds 200.
	5		No set Limit	One position required.	N/A
Traverse	1	I, II & III	Begin and end on 1st order control. Microwave: 4 independent measurements, 2 on main stations and 2 on offset points. Electro-optical: Two measurements separated by minimum of two hours. Tape: divide course into 1 kilometer lengths, measure once or if required, twice, must use invar tape.	Horizontal: Two sets of 16 observations with the difference in the mean of the two sets not exceed 1 second. Vertical: One set of four positions with an individual position rejected if it differs from the mean by more than 3 seconds.	Two sets of 16 positions are required with the probable error of the mean not to exceed .5 seconds.
	2	I & II	Begin and end on 1st and 2nd order control. Microwave: 4 independent measurements, 2 on main station and 2 on offset points. Electro-optical: Two acceptable measurements. Tape: Same as 1 st order.	Horizontal: Four positions with the T-3 or six positions with the T-2 with the rejection limit of a position at 5 second difference from the mean. Vertical: Same as 1st order	Eight positions with the T-3 or 16 positions with the T-2 with the probable error not to exceed .2 seconds.
	3		Start and end on 3rd or higher order control. Microwave: Two independent measurements, one from each end of the line. Electro-Optical: If used, two acceptable measurements. Tape: Same as 2nd order, except not with invar tape.	Horizontal: Two positions with a position rejected if it differs from the mean by more than 5 seconds. Vertical: Same as 1 st order.	Eight positions with the probable error not to exceed 5 seconds.
	4		Microwave: Measure in both directions. Tape: Double tape with steel tape	Horizontal: One direct and one reverse position required. Vertical: Same as horizontal.	
	5		Microwave: Measure in both directions. Tape: Single tape and check by pacing.	Horizontal: One position either direct or reverse. Vertical: Same as 4th order.	
Leveling	1	I, II & III	Lines are divided into one to two kilometer lenghts and are run forward and backward. The two runnings must not differ by more than ± 3 mm $\sqrt{K}$ where K is the distance between stations by kilometers.		
	2	I	Lines are divided into one to two kilometer lengths and are run forward and backward. The two runnings must not differ by more than ± 8.4 mm $\sqrt{K}$ where K is the length of sections in kilometers.		
		II	Lines are run forward and backward. The two runnings must not differ by more than ± 8.4 mm $\sqrt{K}$ where K is the distance between benchmarks in kilometers.		
	3		Lines should not extend more than 48 kilometers from 1st or 2nd order control and may be run in one direction only. The closing check should not exceed ± 12 mm $\sqrt{K}$ where K is the length of the circuit in kilometers.		
	4 & 5		These lower order level surveys are conducted in a similar manner to 3rd order except the closure error my exceed 3rd order specifications. For 4th and on the closing should not exceed ± 1 m $\sqrt{K}$ where K is the length of the Circuit in Kilometers.		

FIGURE C-1. Basic Methods For Common Surveys