LEVEL II

ARI TECHNICAL REPORT
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Field Measurement and Data Collection System for Engagement Simulation Field Exercises

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Engagement simulation techniques now being used to train Army combat units require better instrumentation and methods to gather accurate data for unit evaluation. This report describes six systems for locating vehicle positions, in terms of requirements for engagement simulation data analysis and in terms of usefulness at a specific site at Fort Carson, Colorado. Optical ranging, optical triangulation, radio-based ranging, laser ranging, unattended ground sensors, and benchmark-aided judgments were evaluated. Radio ranging--pulsed

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20. radar and Loran provided the most precise location data and are also operationally available. A separate field study of optical ranging and triangulation methods details their utility and limitations for gathering position data.

FOREWORD

The research presented in this report was conducted under Project SYSTEC (Systems Analysis Approaches to the Evaluation of Combat Units), under the auspices of the Unit Training and Evaluation Systems Technical Area of the Army Research Institute for the Behavioral and Social Sciences. The goal of Project SYSTEC is to build a subsystem of unit evaluation which addresses, in an integrated way, the related problems of combat unit data modeling, collection, processing, and interpretation. The subject research focuses on data collection methodology applicable to engagement simulation training and evaluation. This effort is part of ARI's Five-Year program of engagement simulation research.

BRIEF

Engagement simulation represents a potentially powerful training device for increasing and evaluating unit proficiency. Army, Navy and Air Force experience with engagement simulation all reinforce the proposition that the next best substitute for actual combat experience is engagement experience with a simulated enemy force, with as much realism and simulation accuracy as possible. Based upon this rationale, the Training and Doctrine Command (TRADOC) is now establishing requirements for instrumented test range facilities that can provide the necessary degree of simulation accuracy and measurement precision to accomplish training and evaluation objectives.

The U. S. Army Research Institute for the Behavioral and Social Sciences (ARI) is now engaged in various relevant research programs. These are directed toward upgrading engagement simulation technology and methodology for training diagnosis and examining models that may be useful for increasing the empirical value of engagement simulation as a training modality and methodology for the study of combat dynamics.

The following short-term study evaluates vehicle position location systems for data acquisition potentially applicable to methodological development of engagement simulation.

Requirement

Two technical objectives were addressed in the work reported upon: (A) review and analysis of low-cost, portable vehicle location data collection systems, and (B) preparation of recommendations for prototype development of such a system.

The two technical objectives were broken down into two separate tasks: (A) an engineering evaluation of position location techniques potentially suitable for engagement simulation purposes; (These include description of physical and operating characteristics, costs and accuracy estimations as well as method-induced constraints and personnel requirements) (B) the development of recommendations of a prototype system that might satisfy both near-term study requirements as well as longer-term requirements. The development of recommendations for meeting near-term needs was to be supported by a preliminary map survey, followed by a site survey at Ft. Carson, which represents the next opportunity for a field study effort.

Procedure

The objectives of the study effort were broken down into two relatively independent efforts: (A) a detailed study of the state-of-the-art in position location technology across the entire spectrum of optical, radio, laser and more subjective techniques available, including evaluation of each class of technique and vendor equipment with respect to relevant evaluation criteria; and (B) a field study of Ft. Carson to determine site related idiosyncricies and how these idiosyncracies influence choice of field measurement systems. Optical ranging and optical triangulation initially represented reasonable possibilities for field measurement purposes, and these techniques were evaluated at Ft. Carson and later at Ft. Belvoir with respect to their potential for upgrading engagement simulation data.

The engineering evaluation of potential data collection methods included examination of both vendor literature as well as federal data from such agencies as the National Oceanic and Atmospheric Administration, U. S. Army TARADCOM and Armor Board, the Law Enforcement Assistance Administration, Defense Mapping Agency, Coast Guard, Navy Electronics Navigation Office, etc.

Findings

The findings were clear-cut. Cost and accuracy factors clearly pointed to the merit of radar position location systems as the choice for procision position location. Optical methods, such as optical ranging and optical triangulation, were also determined to be suitable, but at the cost of increased manpower, staff training and time. Optical ranging was found to be of value, but limited to relatively short distances, while optical triangulation could be used across a relatively large test range area.

No single method was found to be ideally suitable across the full range of behavioral, physical and environmental variables. While radio ranging techniques, such as Loran C/D were found to be less terrain dependent, they could not supply the position location precision necessary for ARI research purposes. In contrast, the low-cost radio ranging systems, such as Motorola "Miniranger" and the Del Norte "Multitracker" provided the necessary degree of accuracy, but at the cost of increased terrain dependency, as electronic "line-of-sight" systems.

The Motorola system appeared to be preferable, and with the addition of further human factors and software innovations, would appear to be a good candidate for meeting future ARI study program needs. The hardware system is available at this time and can be delivered within a 30-day period, but certain human factors and software refinements would make this system more useful, particularly given the desirability of acquiring, analyzing, and displaying relevant behavioral activity data above and beyond time/position data. This system can be purchased for a price in the $100,000 range, but the costs of recommended improvements with respect to building capabilities for acquisition, transmission, storage and analysis of behavioral activity data are likely to represent an expenditure of three to four times the hardware system costs.

Utilization of Findings

In view of the magnitude of costs incurred routinely for supporting engagement simulation exercises, it is recommended that serious consideration be given to such a portable system procurement and follow-up development effort. Both TRADOC and ARI could find good uses at a variety of training and field study locations.

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INTRODUCTION

The U. S. Army is increasingly directing its training activities toward event-oriented training and unit designated operational capabilities, which involve prescribing combat missions, conditions and standards for its units. Underlying this orientation is the premise that the next best alternative to actual combat experience is experience derived through engagement simulation.*

Previous Air Force emphasis upon event-oriented training management was developed from analyses of Tactical Air Command performance in Southeast Asia. TAC analyses of shortcomings in mission performance concluded that air crews should train in peacetime under conditions which approximate as closely as possible those they can expect to encounter in battle. These conditions should include simulated engagements that occur under representative environmental conditions.**

One outgrowth of the Air Force's experience was the establishment of an elaborate and expensive training complex at Nellis AFB, which was then used to provide event-oriented training in bombing and air-to-air combat simulation.

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* Tactical Training for Combined Arms Elements, REALTRAIN. U. S. Army Armor School, TC 71-5 (1975)

** Gorman, MG P.F., Toward a Combined Arms Training Center. (unpublished) (1976)

Subsequent Air Force experience with event-oriented training revealed that proficiency improved proportionate to the quality of simulation achieved. In effect, with higher degrees of correspondence between simulation and actual battle conditions, higher degrees of proficiency were observed. These findings were also consistent with earlier Navy data, which showed that after exposure to such simulation, Navy pilots performed to remarkable degrees in Southeast Asia combat environments.

Based in part upon Air Force experiences, the Army's Training and Doctrine Command (TRADOC) has begun to evolve the concept of the highly instrumented, national training center (Gorman, 1976). When completed several years from now the center will provide extensive quantities of accurate, high resolution data on the dynamics of engagement simulation exercises.

However, a more immediate requirement exists for development of low-cost, portable data collection systems for engagement simulation research. Instrumented ranges do exist but are few in number, very expensive to operate, and present accessability limitations. The Army Research Institute for the Behavioral and Social Sciences (ARI) is now designing a study program concerned with development of methodology appropriate for studies of engagement simulation and simulation model development. Through this program is expects to enhance the effectiveness of engagement simulation as a training modality for Army combat units.

Contract DAHC19-77-C-0031 entitled "Field Measurement and Data Collection System for Engagement Simulation" with Behavioral Technology Consultants, Inc., was negotiated in order to support a 60-day study that would provide feasibility information and associated recommendations toward the development of a measurement system for anticipated ARI needs. Cost and portability were established as primary considerations for guiding contractor study efforts, although a number of other considerations were also viewed as necessary and desirable criteria.

GENERAL ORIENTATION TO ARI INFORMATION REQUIREMENTS

Field studies of engagement simulation exercises currently operate under significant limitations. Research objectives are secondary to training priorities, so that simulation scenarios cannot be subjected to the experimental controls that are routine in laboratory research. Consequently, field studies of this kind are studies of opportunity, which require complex trade-off considerations as well as flexibility and creative thought on the part of investigators. Time and budget constraints also represent important considerations in such field studies.

In the current ARI engagement simulation research program, studies are involved at different locations. Terrain features of test range locations at these different Army forts vary considerably. Different infantry, armored and air support configurations are involved from one exercise to another. Research personnel support varies from one time of the year to another, which puts severe strains on manpower-intensive research protocols. Technical and engineering support is meager, which presents system reliability and maintainability problems. By and large, opportunities for providing input into exercise protocols are limited, and constraints are placed upon the degree to which research requirements can alter scenario design. In addition, training schedules are subject to change with respect to location, time, and other variables.

POSITION LOCATION - BASIC FACTORS

Locating an object in space is based on absolute or relative position, i.e., absolute position on the earth surface as located on a map or other graphic representation or position relative to an observer or mark whose position is known, as in the observer benchmark aided system or the signpost transmitter system.

A line of position (LOP) is generated by an azimuth (direction vector) by a range arc. Thus, a directional radar reading (radio direction and range) provides both an azimuth LOP and a range arc, whose crossing locates the target. The crossing of two azimuth lines, e.g., RDF or optical, will also locate a target. A range estimate from photo interpretation of image size, optical range finder, or scaled reticle system gives one LOP and a distance to locate the target. For accuracy and for detection of false or inaccurate LOPs, three or more crossing

LOPs are preferable to two.

The crossing of two LOPs establishes the correct position of a target in a plane horizontal to the observer. However, when using this technique to determine a location on a terrain, the horizontal plane position must be corrected for altitude differences between the target and the observer. Note that a LOP is a straight line from the observer to the target. For example, assume an observation post on top of a hill is higher than a target such that the angle of the depression is 5^{o} below the horizontal. The horizontal distance is the LOP times the cosine of 5^{o}. In a hilly terrain and with short distances, this factor may be substantial -- well over 25 meters. The correction can be computed mathematically.

CONTEMPORARY METHODS FOR POSITION LOCATION

A variety of alternative methods for position location exist and offer possibilities for use in engagement simulation studies. These general techniques are listed below and are subsequently discussed with respect to their applicability to ARI needs:

I. Optical ranging

II. Optical triangulation

III. Radio-Based Positioning

IV. Benchmark aided, evaluator judgments

V. Unattended ground sensors

VI. Laser ranging

Inherently, high frequency wave (optical) systems are more accurate than low frequency, but are generally short range line-of-sight. Relatively low frequency (radio or radar) systems give longer range (beyond the line-of-sight), and to some degree are insensitive to intervening cover, but are less accurate. Thus an optical bearing (light) or a laser of X-band pulsed radar range can be extremely accurate, but cannot "see" through trees or beyond line-of-sight. Systems such as RDF, LORAN, or so-called pulse lock phase interference trilateration, although less inhibited by terrain, are less accurate. These basic constraints are well known, but are important in recognizing that no existing system can be "all things to all people": great accuracy at long range is not feasible, and high frequency systems are accurate. They are limited to line-of-sight.

It should be noted, however, that for relatively small areas, some systems under development that use relatively low frequencies, promise good accuracy not limited to line-of-sight. The cargo security system developed by Hoffman Information Identification for "LEAA"*, using three commercial radio and other transmitter stations, gives promise of accuracy less than 100 feet in a circa 30 x 30 mile area. A system under development by Kaman Science Corporation for TARADCOM**, using three

*Pulsipher, J. A., Automatic Vehicle Location Systems for Law Enforcement Applications. Volume I: Executive Summary. The Aerospace Corp., ATR-76 (7914-01)-1, Vol. I (1976).

**A Study Directed Toward Applying Navigational Grid System Information to Remote Control Target Vehicles. TARADCOM R&D Laboratory Technical Report No. 12298 (1977).

transmitters and not requiring line-of-sight, gives promise of accuracies under one meter within a small area (4 x 6 kilometers).

The most inexpensive instrumentation involves the use of a sextant. The angles between a reference point and two other references on either side are measured at the target. The sextant can measure angles accurately to less than one minute of arc, and is effective for distances of many kilometers from the reference points. However, since it can measure only one angle at a time, the sextant must be used at the target's location. This method of estimating location requires adjacent angles which precludes its use for moving targets.

VARIABLES INFLUENCING METHOD SELECTION

The principal variables for selecting a method for a portable engagement simulation data collection system are as follows:

I. System acquisition costs
II. System portability
III. Terrain applicability
IV. Availability/delivery
V. Position location accuracy
VI. Invasive constraints
VII. System useability
VIII. Reliability and maintainability
IX. Data accessibility
X. Operating conditions

Generally, electronic systems are expensive, but may well be cost-effective when all the true cost elements, including manpower, are considered. Note that in using electronic systems, it is desirable to determine actual measured errors, which typically are three or more times larger than the theoretical limits of the equipment.

SCHEMA FOR METHOD SELECTION

A general schema for method selection and technique evaluation can be devised to present the data in a comparison matrix. In its most basic form, this matrix is represented in Table 1, which allows for evaluating prospective methods on the basis of the ten variables enumerated. This general schema can be elaborated further to take into account more detailed considerations. Examples of these further elaborations of the general schema are provided in Appendix D, which presents details for method evaluation and associated recommendations.

COSTS

The figures listed in Appendix D identify arbitrary categories that represent the range of acquisition cost for various classes of locations sensing equipment. The figures represent the approximate upper bound for each category. For instance, a theodolite system that costs $4500, would be classified in the $5000 category. A system costing $5,100, would also fall into the $5,000 category.

The purchase price figures represent the cost of a minimal location sensing system, generally with a single remote unit for target (if required). Additional costs are the unit costs for each additional remote target device.

Table 1

METHODS

Evaluative Criteria	Optical Ranging	Optical Triangulation	Radio Ranging	Benchmark Aided	Ground Sensors	Laser Ranging
Costs	+	+	±	+	-	-
Portability	+	+	±	+	+	+
Terrain Applicability	-	-	±	-	-	-
Availability/ Deliverability	+	+	±	+	-	-
Positioning Accuracy	-	+	±	-	+	±
Invasive Constraints	+	+	±	-	+	±
System Usability	-	-	+	-	-	-
Reliability/ Maintainability	+	+	±	±	-	+
Data Accessibility (Behavioral Data)	+	+	±	-	-	-
Operating Conditions	+	+	+	+	+	+

+ = Acceptable
- = Unacceptable
± = Variable

PORTABILITY

"Portability" refers to the ability to transport the equipment. Only the basic data gathering units are considered. Additional devices such as computers and displays may be useable from stationary locations only.

TERRAIN APPLICABILITY

The "Line-of-sight limitations" should be interpreted for the class of instruments being evaluated. Optical instruments require visual line-of-sight -- target must be able to be seen by an observer. Radio instruments may -- not always -- require an electronic line-of-sight. An antenna can receive a radio signal in light foliage even though the target is invisible to an observer.

AVAILABILITY/DELIVERY

"Commercially available" means that the instrument is in production and being used in the field. "Available in 12 or 24 months" generally refers to devices which have completed prototype evaluation, are being put into production and as yet are available only as prototypes. "Prototype undergoing development" identifies those units that have progressed through the initial engineering development and are being field evaluated. Production availability has not been scheduled for such units.

POSITION/ACCURACY

The figures presented in this report represent the actual accuracy achieved during field tests. Generally these figures are considerably lower than the manufacturers claims. Only the average or typical accuracy is considered. Some instruments -- handheld laser ranging device, for example -- have shown a tremendous variation in accuracy. Other devices, although subject to large variations in accuracy, internally compensate for the variations through multiple estimates and data averaging.

INVASIVE CONSTRAINTS

These items identify possible invasions of engagement simulation realism. "Visual line-of-sight" requires that the targets have an antenna positioned to receive signals. For instance, armor vehicles cannot strap the position sensing antenna down during approach maneuvers. "Interference (radio) sensitive" devices are affected by significant RF power or carrier harmonics. Interference should not be present on properly maintained equipment typically used in engagement simulation exercises.

SYSTEM USABILITY

Most of these items are self-explanatory. However, "Gap free data" refers to the ability of the system to estimate location data consistently. Providing that the usage constraints are met. "Gaps in data" will occur in those systems that measure discrete interval lanes only. "Manpower intensive/independent operation" refers to the minimal requirements for operating the system. However, it would be advisable to assign at least one person to monitor automated devices.

RELIABILITY/MAINTAINABILITY

"System reliability" refers to the functioning reliability of the system hardware. "Observer reliability" is an indication of the human factors engineering applied in the equipment design. Item 5 does not mean that especially trained technicians must set the system up. However, it is recommended that such technicians at least be present when setting up the more complex electronic systems. The other items should be self-explanatory.

DATA ACCESSABILITY

These items are self-explanatory.

OPERATING CONDITIONS

The "daytime" and "24-hour" items indicate the dependence of the location measuring system upon sunlight for visual operations. Equipment will be classified as "weather dependent" if the system becomes inoperable during weather conditions likely to be encountered during engagement simulation. The "Master station" refers to the site at which a remote, non-mobile sensing station is established. The "Remote station" -- remote to the "Master station" -- is a response unit mounted on a target. "Battery powered" identifies those units designed for low voltage, DC power. Even the higher voltage line-powered equipment can be operated from batteries, but the devices were not so designed. "Line power" would normally be obtained from power transmission lines or portable generators.

REVIEW OF DATA COLLECTION TECHNIQUES

Each of the six general methods for data collection referenced previously is employed in a variety of commercially available instruments. Recent increases in military demand have made position location system developments an active area of engineering development. Development is especially active in radio ranging systems as well as in laser ranging and unattended ground sensors. It is important, therefore, to distinguish between commercially available systems that may or may not be available within the next year or so. It is also important to obtain as much literature as possible concerning tests of system specifications independent of sales literature describing system specifications. Controversies can exist between manufacturer claims and evaluative reports published by government sources such as the National Oceanic and Atmospheric Administration. Previously published surveys indicate that costs of the different data collection methods can fluctuate significantly. Although hundreds of thousands of dollars may be required to purchase some radio ranging systems, alternative radio ranging systems may cost a small fraction of this amount. In short, while a particular manufacturer's equipment may be ideally suited for near-term ARI uses, costs can be prohibitive.

Within a given class of methods, invasive constraints and data accessibility vary considerably. It is possible for example, to obtain behavioral data concerning unit behaviors via voice channel in conjunction with time/position data, although this requirement has not typically been included in radio ranging instrumentation. A number of systems across various method categories require minor invasive constraints, such as radio "line-of-sight." In this case, an antenna must be in electronic view of a transmitter for adequate operation of the system.

This section provides an overview of the general data collection methods available for ARI uses. More detailed descriptions and evaluations follow in the appendices of this report.

OPTICAL RANGING TECHNIQUES

One of the most inexpensive and easy-to-use methods for obtaining position location is optical ranging. Optical ranging refers to the technique of locating a target's position in polar coordinates, relative to an observer's location. Such a system can simply consist of a telescope containing a reticle used for estimating distance in terms of the size of the target. A more complex and more accurate system can be constructed through mounting an optical rangefinder to an optical transit or theodolite. The transit is used to determine the angle or rotation from a predetermined landmark. The rangefinder then measures the length of the vector to the subject.

Three classes of optical rangefinders exist. The simplest device is a fixed power telescope containing a finely graduated reticle and requires a target's precisely known size. In addition, the target must be perpendicular to the observer's line-of-sight. The accuracy of this instrument is a function of the size of the virtual target image which decreases with distance. An alternate form of this system uses a variable power telescope to maintain the virtual target image size up to the maximum range. A different system uses binocular vision to estimate distance. Due to the logarithmic operation, this instrument is generally useless beyond 250 meters.

The main disadvantage of optical ranging lies in its limited range and the inaccuracy of the obtained data, which increases proportional to the distance between the observer and the target, for some instruments. The time required for locating and estimating distance for multiple subjects is such that rapid sampling intervals are precluded. Measurement errors also result when the target or subject is higher or lower with respect to terrain level than the observer. These may be substantial. In addition, the system cannot be operated in adverse weather conditions. Optical ranging is limited to 1 Km. Most instruments cannot measure distances greater than about 200 m with any reasonable accuracy.

A typical observation station would include three persons. Due to the high frequency of operation, the instrument man should be free to solely operate the ranging device. In order to reduce data transcription errors, a person should be dedicated to recording data. Automated digital recording is not available for optical ranging systems. A third person is required to select targets and back up the other two.

About three dedicated days of training are required to achieve minimal proficiency on an inexpensive rangefinder/transit system. This could be reduced to one day if the transit is replaced with an appropriate theodolite.

The more important features of optical ranging systems are summarized in Table 2. The evaluation data reflect systems being used at ranges up to 1 Km.

OPTICAL TRIANGULATION

Optical triangulation techniques are based upon simple geometric principles. All the parameters of a triangle can be calculated, given: (1) one side length and any two angles, (2) two side lengths and the vertex angle, or (3) three side lengths. Field triangulation techniques measure two angles and one distance between vertices. Measurement is usually accomplished by first locating U. S. Geological Survey or military "benchmarks," implanted markers that have been precisely located through surveying. The distance between the benchmarks can be easily determined using survey instruments. It is then necessary only to obtain angular data for target position estimation. If benchmarks are inaccessible at a particular test site,

Table 2

EVALUATION OF OPTICAL RANGING SYSTEMS***

	Binocular Range Finder, Leitz No. 8026-15	Fixed Power Graduated Reticle, "Mil Formula"	Variable Power Graduated Reticle, Redfield Accu-Range
COSTS	1	1	1
PORTABILITY	1	1	1
TERRAIN APPLICABILITY	1, 2	1, 2	1, 2
AVAILABILITY/ DELIVERY	1	2	2*
POSITION/ ACCURACY	2**	2**	2
INVASIVE CONSTRAINTS	1	1	1
SYSTEM USABILITY	1, 3, 5, 7	1, 3, 5, 7	1, 3, 5, 7
RELIABILITY/ MAINTAINABILITY	1, 4, 8, 9, 11, 14	1, 4, 8, 10, 11, 14	1, 3, 8, 9, 11, 14
DATA ACCESSABILITY	2	2	2
OPERATING CONDITIONS	1, 3, 4	1, 3, 4	1, 3, 4

*Modification to standard product required

**Accuracy seriously degrades with distance

***Reference indicators described in Appendix D temporary benchmarks must be precisely located relative to permanent ones.

Instrumentation available for optical triangulation varies considerably in cost and precision of measurement. Portable optical theodolites can measure angles accurately to one second of arc. Consequently, with benchmark data, theodolites can be used to measure distances accurately at many kilometers. Less expensive optical instrumentation can also be used, with attendant losses of precision. Optical instruments used for optical triangulation achieve greater accuracy than rangefinders.

The characteristics of optical triangulation equipment are summarized in Table 3. A representative transit and a theodolite suitable for ARI's position data needs are evaluated. These systems are discussed in greater detail in Appendix A.

RADIO-BASED RANGING

Radio-based locations are derived by first determining the azimuth. The distance can then be estimated using range arcs, radio frequency time of arrival (pulse lock phase interference), or high frequency pulsed radar ranging.

Phase measuring systems have lower accuracy and higher price tags than pulse systems. Short-range systems are generally limited to a few targets, whereas medium-range systems handle a relatively large number of targets. These systems inherently suffer from ambiguity problems corresponding to 1/2-wave-length

Table 3

EVALUATION OF OPTICAL TRIANGULATION SYSTEMS*

	Lietz Transit No. 115	Dietzgen Theodolite No. 6020-A6E
COSTS	2, 8	3, 8
PORTABILITY	1	1
TERRAIN APPLICABILITY	1	1
AVAILABILITY/ DELIVERY	1	1
POSITIONING ACCURACY	1'	1'
INVASIVE CONSTRAINTS	1	1
SYSTEM USABILITY	2, 3, 6	2, 3, 6
RELIABILITY/ MAINTAINABILITY	1, 3, 7, 9, 11, 14	1, 3, 7, 9, 11, 14
DATA ACCESSABILITY	2	2
OPERATING CONDITIONS	1, 3, 5	1, 3, 5

* Reference indicators described in Appendix D

of lowest modulating frequency; lane count losses are far and away the greatest user complaint. A summary comparison chart comparing most of the available radio ranging systems is found in Appendix C.

Radio Triangulation

Target location can be fixed by crossing three or more directional LOP after determining the azimuth of a target radio signal transmitter from the observer. The observer's receivers employ an actual or RF constructive loop which receives the transmitted signal at greatest amplitude on the azimuth of the transmitter. Thus the process is one of signal detection across the radio spectrum (in an Army exercise, target transmitter frequency can be predetermined, eliminating the need for frequency scanning), making rough determination of transmitter azimuth and fine tuning the receptor "loop" to point of highest strength. This point gives the target transmitter direction.

Accuracy of radio triangulation is a function of signal strength, signal characteristics, receiving equipment accuracy and range. Generally speaking, accuracies are poor, long range being hundreds of feet. Equipment accuracy limitations are in the order of 2.5° RMS*.

Even homing beacons, such as those used for downed aircraft, lifeboats or weapon (torpedo, missile) recovery are found

*DF-301E Direction Finder Product Description. Collins Radio Company of Canada, Ltd. (1973).

in practice to provide LOP only sufficiently accurate to guide the observer (recovery unit) to the scene where more precise (optical) measures can take over.

Radio Trilateration

Radio trilateration systems using the vehicle transponder or the fixed transmission stations system provide long-range, 24 hours a day, relatively all-weather, non-line-of-sight (although large obstructions can cause shadow zones or signal warp distortion), and reasonably accurate capability. The most familiar applications are in Loran C and Loran D, using fixed transmitter stations. Loran D uses 16 pulses/sec. versus 8 for Loran C, and has special coding. It is somewhat more accurate at shorter ranges. Navigation-Management Corporation (MINIRAN) (2 m accuracy at 45 Km) and the Aerospace/Hoffman system (100 foot accuracy equipment capability) are examples of radio trilateration.

Radio trilateration has two measures of accuracy: predictability and repeatability. Predictability refers to a prediction of a location on the surface of the earth based on the intersecting hyperbola or range arcs, with known corrections entered. Repeatability refers to accuracy in returning to the same point. Repeatability accuracy is commonly 10 times greater than predictable accuracy. Thus, predictable accuracy can be greatly improved by intensive "pre-mapping" of the operational area.

Loran manufacturers typically advertise about 100-200 meter predictability, 10-20 meter repeatability at long ranges. Terrestrial users of Loran are subject to perturbations not applicable to marine or airborne users such as structure effects on conductivity, carrier communications interference, and power-line influences; which limit predictable accuracy,* but can be partially overcome by detailed pre-mapping or operational procedures.

Of some pertinence is Loran accuracy as advertised and as observed. Interviews with professionals at NOAA, Navy, Coast Guard and other unbiased sources which monitor and keep current on Loran technology, generally reflect the opinion that one should not count on actual usable accuracy much better than 1/10 mile. The Coast Guard reportedly has sought, to date unsuccessfully, 100-yard accuracy for St. Lawrence Seaway navigation. As indicated, certain manufacturers state great accuracy. For example, Litton System's AN/PSN-6 MASSTER claims 47 m accuracy. Technology Inc. ** reports that the complex impedance technique, one of the best, gives average miss distance of 439 feet. Histograms in the report show miss distances on the order of 1000-3500 feet for salt water prediction, 100-500 feet for

*Loran C. Conceptual Analysis, DMV, New York State, NTIS #PB-258-251 (1976).

**Evaluation of Loran Target-Coordinates Prediction Techniques, Alexander & Mason, Tech Report TI-0497-73-1 (1973).

third-order polynomial prediction. Thus, actual tests do not necessarily bear out claims. However, in a small area, with careful and intensive pre-mapping, accuracy on the order of 20 meters should be attainable. KAMAN reports repeatability (1 m. in a 4 x 6 Km area) for their remote control system, and estimates potential predictability of a "few meters"*, but has not developed a system for position location.

Radar Ranging

High precision radar ranging readily gives range accuracies ± 2 m. over 10-30 km., and is not necessarily beyond cost parameters. It is limited to electronic line-of-sight and requires target transponders. Echo radar is also accurate, but cannot readily distinguish target from other echos (trees, rock, terrain). Data on military echo radars in a non-marine environment were not available. Police radars use the doppler effect to measure speeds, but are not designed for ranging.

Certain medium-range systems, like Accufix (Megapulse Corp., Medford, Mass.), Argo, HiFix, Hydrotrak, LORAC, Maxiran, OMI, RAYDIST, TORAN, and a number of short-range systems like Artemis, Autotape, Syledis, Trident, give acceptable accuracy, but are not appropriate to ARI objectives because of relatively

*Erskine, J.S., A Feasibility Study of a Navigational Grid System for Remote Control Target Vehicle Applications. TARADCOM R&D Laboratory Technical Report No. 12222 (1976).

high costs and elaborate system installation requirements*.

Conclusion

Of the systems that were evaluated, three seem technically adequate to meet ARI's data requirements:

- Motorola Miniranger III
- Del Norte Technology Trisponder (or Multitracker)
- Litton Industries Position Location System, AN/PSN-6

The first two systems use pulsed radar. Litton's system is a Loran C unit. All three have been used for several years in a variety of land environments. The Motorola and Litton units are currently being used by the Army. Of these two, the Motorola system costs less than the Litton system and provides date more reliably and accurately.

Table 4 provides an evaluation summary of the systems for ARI's data requirements. Appendices B and C contain more detailed system descriptions and technical comparisons, respectively.

Both the Del Norte and Motorola systems require few personnel present. In fact, the equipment is designed for unattended operation. However, it seems advisable to assign a person to monitor the equipment performance. Since few people are

*Munson, RA R.C. Positioning Systems, Report on the Work of WG4146. Presented at the XV International Congress of Surveyors, Stockholm, Sweden, June, 1977.

Table 4

EVALUATION OF RADIO RANGING SYSTEMS*

	Multitracker (Del Norte Technology, Inc.)	Miniranger III, Motorola	AN/PSN-6 Position Location System, Litton Industries
COST	5, 9	5, 9	4, 11
PORTABILITY	1, 2	1, 2	1, 2
TERRAIN APPLICABILITY	1	1	3
AVAILABILITY/ DELIVERY	1	1	1
POSITION ACCURACY	1	1	1, 4***
INVASIVE CONSTRAINTS	2	2	4
SYSTEM USABILITY	2, 4, 5, 6**,8	2, 4, 5, 6**, 8	2, 4, 6, 8
RELIABILITY/ MAINTAINABILITY	1, 3, 5, 11, 13	1, 3, 5, 11, 13	1, 3, 6, 11, 13
DATA ACCESSIBILITY	3, 4	3, 4	3, 4
OPERATING CONDITIONS	2, 5, 6	2, 5, 6	2, 5, 6

* Reference indicators described in Appendix D.

** If not line of sight.

*** Should be able to achieve 25m. accuracy by intensive pre-mapping the site. Otherwise, 100 m. accuracy can be expected.

required to operate the equipment, training requirements are minimal. At least one person should be trained to field install and operate the system -- two persons would be preferable. A one-time investment of about two weeks training per person should be sufficient.

Both systems can record the data in digital form on magnetic tape, thus eliminating a major source of error -- human data recording. Motorola supplies a general package of computer programs for transforming and reporting the data.

Benchmark, Evaluator Aided Judgments

Thus far, ARI has tended to use benchmark, evaluator aided judgments in its previous studies of engagement simulation. In this context, the term "benchmark" does not refer to precisely surveyed markers, but rather to the use of local landmarks that are arbitrarily chosen. This visual method is relatively crude from a position evaluation point of view because the method requires subjective estimates of distance from the chosen landmarks. However, evaluators can provide important behavioral data above and beyond position/time data, which can be important to the study of tactics and doctrine.

Evaluators usually are placed on tanks where they note position and activity data as a function of time. Particularly emphasized are recordings of crew behaviors at decision points where units split off on departures from platoons.

After a simulation exercise, observers typically meet to compare observations and reconcile discrepancies in the obtained data.

The main advantage of evaluator-aided judgments appears to lie in the fact that a nearby or mounted observer is in the best position for recording behavorial activity data. With respect to position location data, however, the method is heavily manpower intensive if accuracy requirements are to be met. Some of the caracteristics of benchmark-aided ranging are summarized in Table 5.

Unattended Ground Sensors

In Viet Nam, unattended ground sensors were developed to detect the passage of men and vehicles. More recent applications of unattended ground sensors have taken place in the Middle East, for detection of disturbances caused by the passage of target objects. The information is then transmitted to a distant monitoring site for data link. These early generation systems were active radiators, which transmitted information on a continuous basis. They were susceptible to weather differences, with attendant false alarm rates. They were also highly vulnerable to jamming. Additional limitations include terrain dependencies and range limitations. Linear-array sound-ranging designs were represented in these systems, which could not be deployed by artillary and could not process the high fire rates

Table 5

EVALUATION BENCHMARK-AIDED JUDGEMENTS*

	Benchmark-Aided Ranging
COST	1, 8
PORTABILITY	---
TERRAIN APPLICABILITY	1, 3
AVAILABILITY/ DELIVERY	1
POSITIONING ACCURACY	1**, 5**
INVASIVE CONSTRAINTS	1
SYSTEM USABILITY	1, 4***
RELIABILITY/ MAINTAINABILITY	1, 4, 6, 7
DATA ACCESSIBILITY	1
OPERATING CONDITIONS	1, 5

* Reference indicators described in Appendix D.

** Heavily dependent upon the observer's proximity to the benchmarks, observer's distance estimation skills, and the accuracy of surveying the benchmarks.

*** "Interference" refers to visual and behavioral distractions.

that can occur with modern weaponry.*

The Army is continuing its sophistication of unattended ground sensor systems at the cost of millions of dollars. The fact that these newer systems are still under development with consequent high costs precludes their practical considerations for ARI purposes. After 1984, however, it is possible that these techniques might be fruitfully employed for ARI purposes.

For future planning purposes, some discussion of the current development emphasis may be useful. The unattended ground sensor systems now under development (REMBASS) can be planted through a variety of means, including air- and artillery-delivery. Both magnetic and seismic/acoustic classification devices will be available. These units will be more "intelligent," so that discriminations between the nature of detected objects can be improved. Altering signals will be initiated only when a target is detected, rather than on a continuous basis, thus decreasing vulnerability to intentional or unintentional jamming. Division-level control centers will be able to decode signals, then record and display data to analysts who will report the activities detected. Both distance and terrain limitations will be overcome. Improvements are also planned in the functional life of sensors through improved battery designs.

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*White, J.W. The Changing Scene in Electronic Distance Meters. Presented at the ACSM Annual Meeting, St. Louis, Missouri. (1974)

Another improvement planned for these new generation systems involves function specialization. Contracts underway at this time include system designs especially constructed for artillery muzzle blasts and shell bursts, and designs especially constructed for man and armored activity detection/

Because of their cost and the past difficulties experienced with unattended ground sensor systems, their use is not recommended for ARI purposes at this time. Some of the characteristics of unattended ground sensors are summarized in Table 6.

Laser Ranging

Accuracies, in the order of centimeters, are possible with laser ranging. Conbined with a visual bearing, very accurate fires are obtainable. The equipment is not unduly complex and is relatively low in cost. However, laser or other light reflective systems currently have operational limitations which limit their use to relatively static situations.

Commercial laser or light beam ranging systems rely upon a mirror/prism or other target reflactor which must be carefully set up and aligned with the transmitter source for each reading.* Optimally, fifteen minutes, but more commonly thirty minutes, are required to line up and obtain a reading. One cannot expect a tank or APC to stop for half an hour while a man jumps out and lines up the equipment each time the observer station wants a

*White, J.W. The Changing Scene in Electronic Distance Meters. Presented at the ACSM Annual Meeting, St. Louis, Missouri (1974)

Table 6

EVALUATION OF UNATTENDED GROUND SENSORS*

	Extant Sensors' System	REMBASS Sensors
COSTS	1	no data
PORTABILITY	1	1
TERRAIN APPLICABILITY	2	3
AVAILABILITY/ DELIVERY	1**	4
POSITIONING ACCURACY	1***, 4***	1***, 4***
INVASIVE CONSTRAINTS	3, 4	3
SYSTEM USABILITY	2, 4, 6, 7	2, 4, 7
RELIABILITY/ MAINTAINABILITY	1, 6, 10, 11	1, 10, 11
DATA ACCESSIBILITY	3	3
OPERATING CONDITIONS	2, 3, 5, 6	2, 5, 6

*Reference indicators described in Appendix D.

** Available from military sources.

*** Heavily dependent upon the proximity of the sensors to a target and the accuracy of surveying the senors' locations.

reading. Further, laser or light reflector systems suffer the other limitations of high frequency systems; i.e., light-of-sight only. For the accuracy needed, laser or light ranging offers no advantages, other than initial cost, over other line-of-sight methods, such as pulsed X/C band radar, which do not entail similar time delays.

The Army has developed a handheld laser-ranging device to locate targets in the range of 200 to 10,000 meters. However, tests performed at Fort Benning in 1976* demonstrated that the unit was not safe for use by field personnel (without protective equipment), and were not sufficiently accurate. In fact, the average error rate for eight observations per trial or team ranged up to 10 percent. The standard deviations of these errors ranged to approximately 20 percent.

Therefore, while a brief generic description of the laser/light system follows, these systems are judged unresponsive to the objectives and are not further developed. Some of the characteristics of laser ranging systems are summarized in Table 7. A typical commercial system is included.

Laser ranging equipment directly measures line-of-sight distance using light interferometry. A modulated light beam is reflected from a target. The distance to the target is determined from the phase shaft in the reflected beam relative to the trans-

*Operational Test III of Handheld Laser Rangefinder, AN/GVS-5, TRADOC Project No. 8-EE-GVS-005-601 (1976)

Table 7

EVALUATION OF LASER RANGING SYSTEMS*

	Newlett/Packard No. 3810A	Handheld Laser Rangefinder AN/GVS-5
COST	4	no data
PORTABILITY	1	1
TERRAIN APPLICABILITY	1, 2	1, 2
AVAILABILITY/ DELIVERY	1	4
POSITIONING ACCURACY	1	5
INVASIVE CONSTRAINTS	1	1
SYSTEM USABILITY	2, 3, 5, 7	1, 3, 6, 7
RELIABILITY/ MAINTAINABILITY	1, 3, 6, 8, 9, 11, 14	1, 4, 7, 8, 11, 14
DATA ACCESSIBILITY	2, 4,**	2
OPERATING CONDITIONS	1, 3, 4, 6	1, 3, 4, 6

* Reference indicators described in Appendix D.

** Requires modification to instrument.

mitted light.* Commercial equipment can measure several kilometers with millimeters accuracy.

However, they have to be aimed very carefully to ensure the proper target is being ranged. This is not critical for commercial systems. The Army's system is designed to reflect from military targets and will also reflect from objects in the enviroment.

Photography

Fixes are possible by combining bearings with range estimates based on photographs. The target photos would be developed rapidly and ranges extrapolated from comparison with standardized photos of similar targets at known ranges, or by computing image size versus distance.

This method has been mentioned because of U. S. Department of Transportation photography usage in traffic analyses. However, photographic road traffic studies typically are motion pictures for traffic engineers to improve flow or for traffic safety engineers to study "near misses" not shown by accident investigations *per se*.

Use of photography would appear to have few advantages but many complexities and disadvantages relative to other optical systems. The advantages are a permanent reading available for

*McCullough, W.R. The Measurement of Distance Using Light. Presented to the 15th Survey Congress, Newcastle,N.E.W.,Australia. May 1972 after the fact, precision analysis, and perhaps low light (infra red) use. However, image displacement measurement would have to be calibrated or adjusted for angle of presentation in each of three axes, a very formidable task, even with computing equipment. Photo equipment of the precision indicated is not conducive to field use by non-professional (photographic) personnel. Obviously, optical, line-of-sight limited photography is less accurate for range estimates than are other means, and requires optical azimuth measurement.

While interesting as a concept, and not necessarily grossly inaccurate when used by highly trained photo interpretation personnel, photography as a field rangefinding methodology is inherently limited and complex. Location determinations by visual bearings and radar ranging appear simpler and more practicable.

Field testing might be justified, but it is doubtful if photography as a replacement for visual (eyeball) or electronic techniques would prove advantageous. Certainly at the present untried, untested stage, it cannot be recommended for FY 78 use. Some of the characteristics of photographic ranging techniques are summarized in Table 8.

Table 8

EVALUATION OF PHOTOGRAPHIC RANGING*

	Photographic Ranging System
COST	2
PORTABILITY	1
TERRAIN APPLICABILITY	1
AVAILABILITY/ DELIVERY	1
POSITIONING ACCURACY	2**
INVASIVE CONSTRAINTS	1
SYSTEM USABILITY	1, 4, 6, 7
RELIABILITY/ MAINTAINABILITY	1, 4, 5, 6, 8, 10, 11, 14
DATA ACCESSIBILITY	2
OPERATING CONDITIONS	1, 3, 4

* Reference indicators described in Appendix D.

** Heavily dependent upon target range and target orientation relative to the observer.

ENGAGEMENT SIMULATION DATA COLLECTION ANALYSIS

For the purposes of satisfying the ARI requirement to collect behavorial and positional data during the first quarter of CY 1978, a study was made of the engagement simulation area at Ft. Carson, Colorado. The study was primarily concerned with assessing the ling-of-sight constraints and estimating the ranging distances involved. The engagement simulation area studied is identified in Figure 1.

Figure 2 (Engagement Simulation Area Surface) was constructed from curves illustrating elevation variations between pairs of points. The points were the intersections of east-west lines north-south lines with the engagement simulation area in Figure 1. The curves were constructed at equal distance intervals and drawn together as a composite figure. The entire composite was slanted 45^{o} to the east to allow the north-south graphs to be viewed.

As seen in Figure 2, the terrain for the engagement simulation studies is gently rolling between the Northern and Southern Objectives. The area is bounded by high mountains on the east and west (not shown). The Northern and Southern boundaries are the ridge of large hills that contains the Northern objective, and the Southern objective.

Target position location is greatly complicated by several rather deep and tortuous creek beds. The problem is further compounded by the narrow but dense forests that border all the creeks. The area outside of the creek bed borders is devoid of

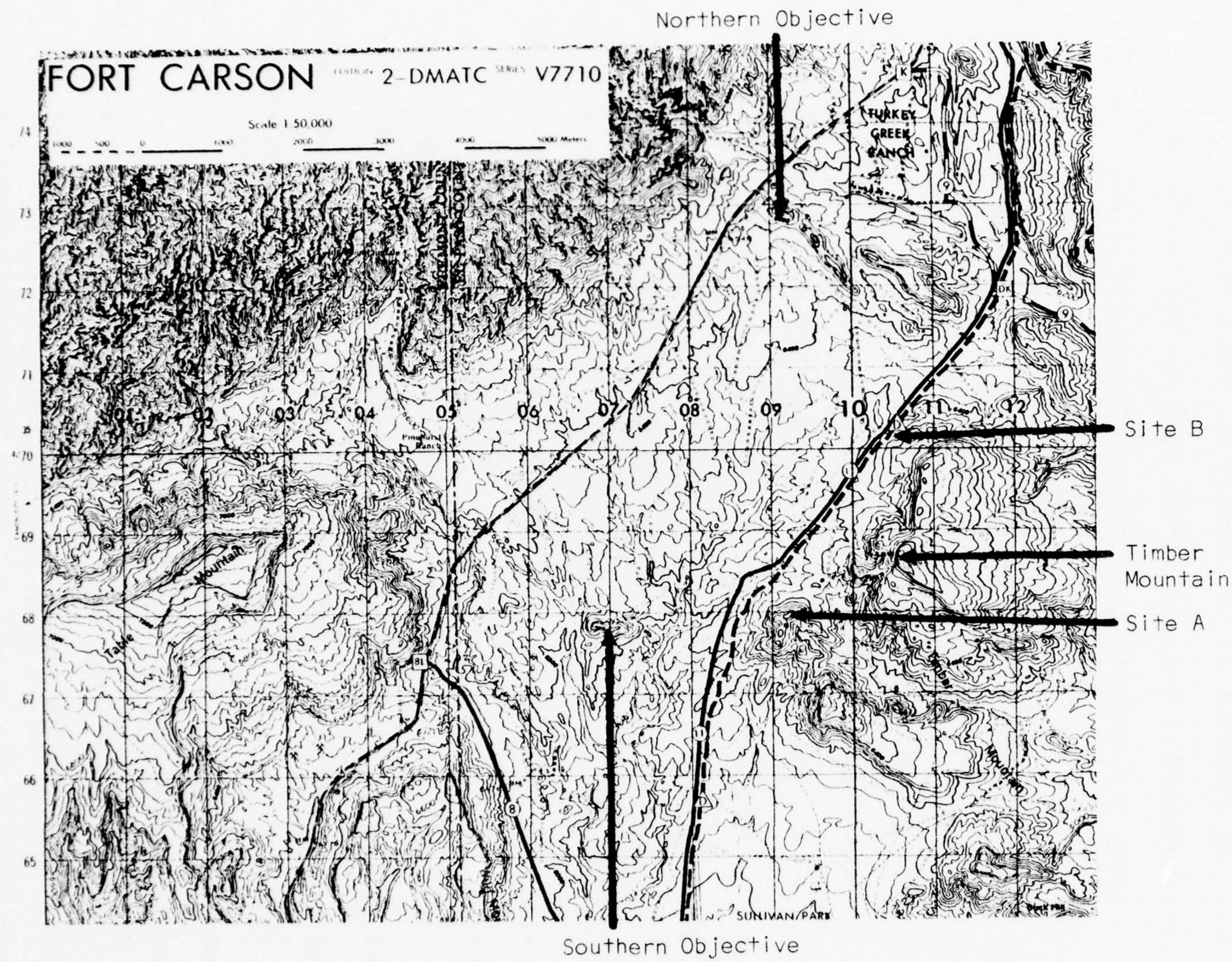

Figure I. Fort Carson Engagement Simulation Area Map

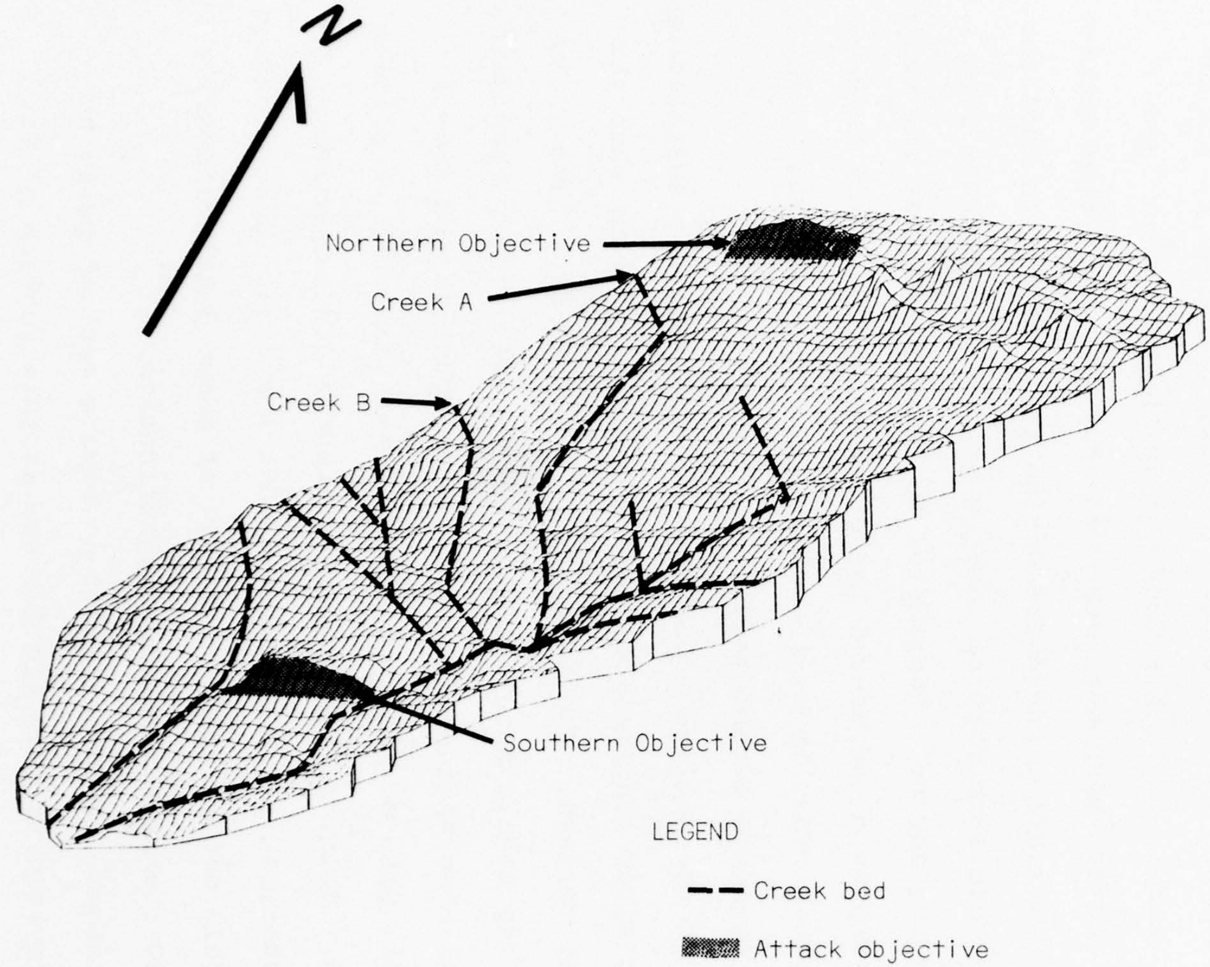

Figure 2. Fort Carson Engagement Simulation Area Surface

any significant ground cover.

Therefore, it is quite likely that armor vehicles attacking the southern objective will travel the creek beds. These creek beds provide the only areas consistently invisible to the objectives, and to any other location in the vicinity. However, Ft. Carson personnel observed that the creek beds become unsuitable for armor maneuvers during the winter. In addition, the creek beds appear to be ideally suited for ambushes from the defending forces. Therefore, it is possible that the vehicles may risk exposure and travel the outside of the forest bordering the creek beds. In this case, visual line-of-sight to the vehicles could be established.

Due to the rolling nature of the land, optical position determining sites must be located significantly higher than the engagement terrain. The alternative would be many observation sites in the area. This is costly. The most likely candidates for visual observation sites are Timber Mountain and Site A (Figure 1), Site B (Figure 1) is an alternative but at a lower elevation. However, the ranging distances are excessive -- 2 to 4 kilometers. It was observed that Realtrain identification plates could not be read, reliably, at about 3 kilometers, using a 23 diameter telescope magnification.

Therefore, it appears that no remote optical position locating system is feasible for use at this portion of Ft. Carson. Radio ranging techniques cannot maintain constant electronic line-of-sight into the creek beds. In some places, the bed is deeper than 20 feet. However, this is not common and radio ranging could be used if infrequent gaps in the data are acceptable. Table 9 summarizes the requirements for ARI's data collection at Ft. Carson together with the most likely system for satisfying these demands. This system is the Motorola, Miniranger. Unfortunately, the Miniranger III radio ranging system is hardly a low-cost item.

COSTS

ARI is searching for a low-cost remote date collection system to use as a temporary measure until a more suitable technique can be implemented. Unfortunately, the Miniranger III system costs approximately $100,000 when tailored to ARI's purposes.

PORTABILITY

All the currently available position determining systems require a line-of-sight to the target. Since the engagement simulation area is laced with rather deep creek beds, the observation sites must be located as high as possible above the area to maximize the available line-of-sight area. The most likely observation post -- Timber Mountain (Figure 2) -- is accessible by road. The most likely secondary OP -- Site A (Figure 1) -- is approachable only on foot. Data collection equipment must be backpack portable. The slave tracking station of the Miniranger III system fulfills this requirement.

Table 9

FORT CARSON DATA COLLECTION REQUIREMENTS*

	Fort Carson Requirements	Miniranger III ** Motorola
COSTS	3	5, 9
PORTABILITY	1	1, 2
TERRAIN APPLICABILITY	3	3
AVAILABILITY/ DELIVERY	1	1
POSITIONING ACCURACY	2	4
INVASIVE CONSTRAINTS	3	4
SYSTEM USABILITY	2, 4, 6, 8	2, 4, 6, 8
RELIABILITY/ MAINTAINABILITY	1, 3, 6, 8, 10, 11, 13	1, 3, 6, 8, 11, 13
DATA ACCESSIBILITY	2, 4	3, 4
OPERATING CONDITIONS	1, 4, 6	2, 5, 6

* Reference indicators described in Appendix D.

** The system that matches the requirements the closest, data from Table 5.

TERRAIN APPLICABILITY

The peculiar nature of the Ft. Carson area places heavy requirements upon the abilities of any data collection system used. The most likely target routes are in the deep creek beds with steep walls and bordered by dense foliage. A useful data collection system must not be overcome by these obstacles. The Miniranger III system is not useful if uninterrupted data is required. However, the Armor Command at Ft. Knox has found that the Miniranger system exhibits a terrain performance similar to commercial television. Optical systems are useless in this environment.

AVAILABILITY/DELIVERY

ARI is scheduled to start collecting data during January, 1978. Therefore, it is necessary that equipment used be currently in production and field tested. Thirty-day delivery is preferred. The Miniranger III fulfills this requirement and is in field use, mounted on tanks at Ft. Knox.

POSITIONING ACCURACY

About 25-meter accuracy is required of the position data. This requirement is well met by the Miniranger which achieves 2-3 meter accuracy over large areas. The Ft. Carson area size -- approximately 3 km x 6 km -- indicates the need for such a wide-ranging system. The alternative of many limited range systems presents serious problems of manpower, requirements, interteam coordination, large number of precisely surveyed OPs etc.

INVASIVE CONSTRAINTS

Since it is the intention of engagement simulation to present a realistic combat environment*, data collection techniques and equipment must not alter the normal operations of the conbanants. The use of optical techniques, for instance, would require that targets remain visible for at least a large portion of the exercise. The Miniranger systems require electronic visibility which is generally available. A temporarily mounted transponder functions independently from the target.

SYSTEM USABILITY

Regular Army enlisted personnel will be collecting the data. Therefore, the data system cannot require intensive training, nor a large number of personnel, and must be able to collect data rapidly. The Miniranger generally realizes these requirements. However, at least one trained person must set up the equipment and be available to correct malfunctions.

RELIABILITY/MAINTAINABILITY

Since the data collection system will probably be located at remote sites, the equipment must function in a highly reliable manner, be ruggedly constructed and easy to repair. The Miniranger does satisfy these requirements.

DATA ACCESSIBILITY

Ideally, a data collection system would be able to obtain

*Tactical Training for Combined Arms Elements, REALTRAIN, U.S. Army Armor School, TC-71-5 (1975).

position and behavorial data. The data should be stored in digital form for later analysis. The Miniranger meets these needs with the exception of recording behavorial data.

OPERATING CONDITIONS

The exercises at Ft. Carson during the early months of CY 1978 will require a data collection system to perform under potentially adverse weather conditions. That the equipment must be battery operated is taken for granted. The Miniranger is well protected from the elements and requires low voltage DC power.

CONCLUSIONS

From the preceding analysis, it can be seen that no position locating system available today can satisfy all the requirements for the Ft. Carson area. More typical terrains present much less of a problem. The combination of:

- Long distances
- Deep creek beds
- Dense ground cover
- Relatively untrained personnel
- Possible adverse weather

place heavy constrains upon the selection of any data collection system. Of all the systems reviewed, the Miniranger III satisfies the most constraints. However, even this system does not seem entirely adequate for ARI's short-term needs.

FIELD STUDIES OF DATA COLLECTION TECHNIQUES

Two possible methods for collecting target location data were evaluated at Ft. Carson, Colorado, and Ft. Belvoir, Virginia. The two techniques evaluated:

- Optical ranging and
- Optical triangulation

were selected as being the most likely candidates for use in the January, 1978, engagement simulation exercises. Both these systems are low cost and use easily obtainable, commercial equipment. Most of the equipment was supplied by ARI. A small amount of the money was allocated for contractor procurement of supplementary instrumentation. One week was reserved for the study at Ft. Carson.

During the preparation for the field studies, it soon became evident that optical ranging was not adequate for use over the long distances at Ft. Carson. However, the technique may have future potential for use by ARI at other sites and, therefore, remained part of the study.

OBJECTIVES

Due to a limited budget, the optimal equipment was not available for this study. Therefore, it was decided, with the concurrence of the COTR, to study the important parameters of the two techniques. The results of the parameter studies would provide the data upon which to base recommendations for more optimal future systems. The parameters studied are summarized in Table 10.

Table 10

FIELD STUDY PARAMETERS SUMMARY

Preparation

- Identification of the Target

  Time to locate a target

  Accuracy of target identification

- Target Alignment

  Time to center target on telescope crosshairs

- Range Alignment

  Time to adjust target image to range stadia

- Target Tracking

  Track target at speeds up to 25 mph

  Tracking distance limitation of a transit

Data Recording

- Triangulation Data

  Time to record azimuth and elevation angles

  Accuracy of azimuth and elevation angles

- Ranging Data

  Accuracy of ranging data

Coordination Dialogue

- Triangulation System

  Dialogue structure required

- Ranging Systems

  Dialogue structure required

The operation of optically collecting location data can be considered as two independent, but sequential, tasks. The "preparation" task involves searching for and identifying the proper target. The target is then aligned on the crosshairs of the telescope. The "data recording" task is concerned with reading the angular and ranging (if required) data from the instrument. Coordination is required to specify the proper target and indicate the point in time when data are to be recorded.

PROCEDURES

Since the tasks are independent, each task's parameter can be studied separately from the other task. Formal studies were used to evaluate the tasks. The "coordination dialogue" structure requirements were defined through informal observations during the formal studies.

Preparation Study and Ranging Data

A total of eight levels were designed into this study

- Observational conditions
  - Target initially in observer's field of vision
  - Target must be searched for
- Target speeds:
  - 0 mph - immobile target
  - 7 mph
  - 15 mph
  - 25 mph

The total of eight levels result from the four target speeds at each of the two observational conditions.

The study was designed to collect 160 observations. The experimental conditions were selected for each observation using a random number table*. In addition, one of four locations, at different distances, was randomly selected for the immobile target. Since target identification was treated as orthogonal to the other variable conditions, selection of which target number to be displayed was randomly added to each observation. Each observation was randomly assigned a direction of travel -- to the observer's right or left. The first 15 observation conditions are listed in Table 11.

The study was conducted on a dirt road in the engagement simulation area at Ft. Carson (Figure 3). The section of road used was continuously visible from a military tripod benchmark located about 570 meters west for about 1300 meters (Figure 4). The road was fairly level and allowed a target jeep to travel the required speeds. Four immobile sites were selected on the road and marked with metal surveyor's stakes. The terminal locations were also marked with red surveyor's tripod targets. The locations were surveyed using optical triangulation from the tripod benchmark and a windmill tower located about halfway down the road. The distance between the windmill and the tripod was measured with a 300-foot fiber glass surveyor's tape. Since

*Fisher, R.A. and Yates, F., Statistical Tables, Hafner Publishing Co., New York, 6th ed. (1967).

Table 11

PREPARATION STUDY OBSERVATION CONDITIONS*

Observation	Initial Target Location	Travel Direction	Speed	Immobile Location	Identification Number
1	Out of sight	left	25 mph		21
2	in sight	right	0 mph	4	39
3	Out of sight	right	25 mph		39
4	in sight	left	0 mph	1	36
5	in sight	right	0 mph	4	39
6	Out of sight	right	0 mph	2	39
7	in sight	left	0 mph	1	21
8	in sight	right	15 mph		39
9	Out of sight	right	25 mph		39
10	in sight	left	25 mph		39
11	Out of sight	left	0 mph	1	21
12	in sight	right	7 mph		21
13	Out of sight	right	25 mph		39
14	in sight	left	25 mph		39
15	Out of sight	left	0 mph	2	21

* This list contains the conditions under which the first fifteen observations were collected.

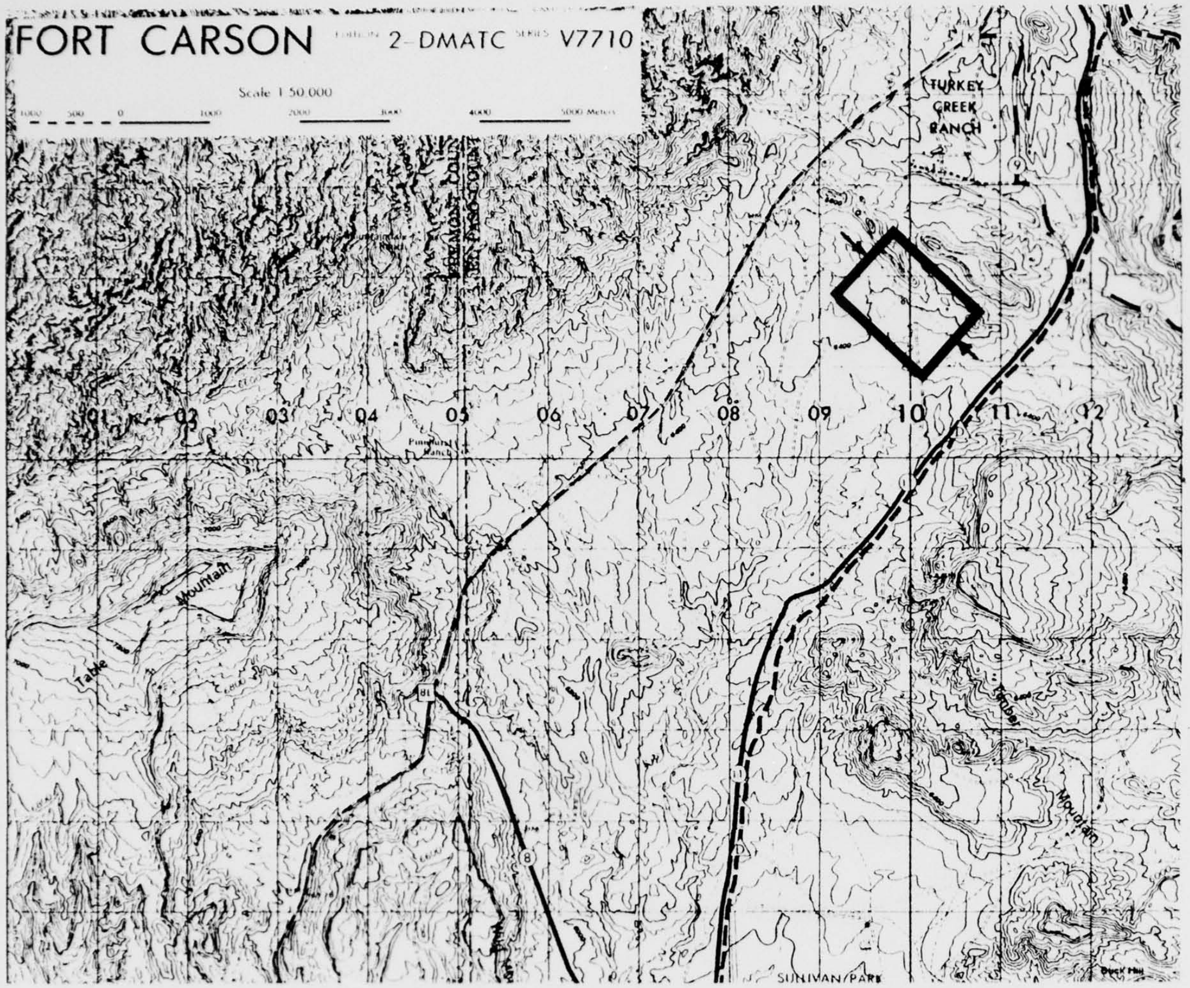

Figure 3. Preparation Study Area Location

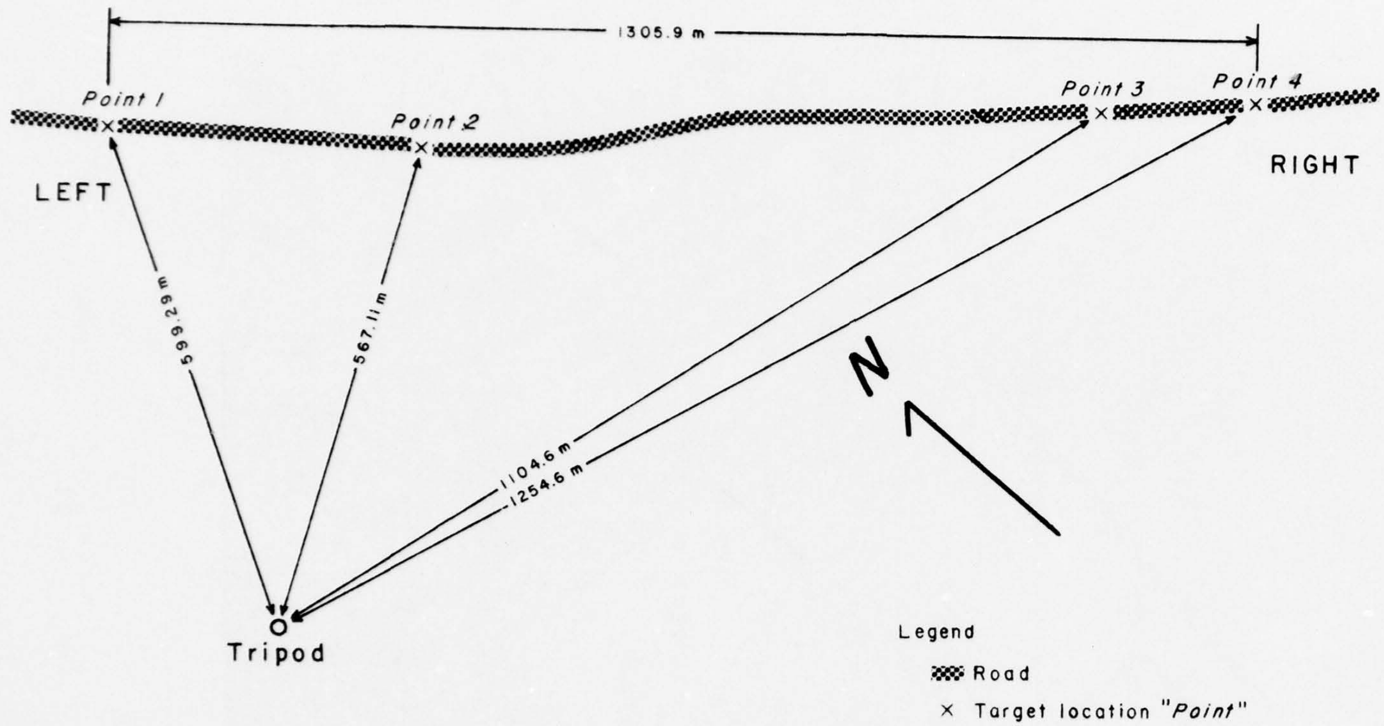

Figure 4. Preparation Study Area Details

benchmark location data could not be obtained from Ft. Carson, the exact location of the tripod is not known. The study observations were collected at the tripod benchmark.

The observation team consisted of three persons:

- Study controller
- Instrument man
- Data recorder

Both the study controller and the instrument man had prior surveying experience and were generally familiar with the equipment. The study controller gave instructions and operated the timer. The instrument man's sole function was to operate the observing instrument.

The equipment used in the study is listed in Table 12. The Accu-Range telescope was fastened to the camera tripod with a modified rifle bridge mount. The tripod orientation handle was located on the opposite side from the observer. This forced the observer to operate the telescope/tripod in a manner similar to a transit.

The REALTRAIN targets were constructed from tempered Masonite to conform to REALTRAIN specifications*. The boards were cut to 20" square and painted green. 18" high white numerals made of 2" lines were glued to the boards. The passenger in the jeep selected the proper sign and held it up for the observer to view.

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*Tactical Training for Combined Arms Elements, REALTRAIN. U. S. Army Armor School, TC 71-5 (1975)

Table 12

EQUIPMENT USED IN PREPARATION STUDY

Data Collecting

- Redfield Accu-Range telescopic rifle right 4x - 12x
- Camera tripod
- U.S. Army jeep
- 2 - REALTRAIN targets
- Microma electronic stopwatch
- 2 - Surveyor's tripod targets
- 4 - Metal surveyor's stakes
- 2 - 16 oz. plumb bobs
- 2 - Gammon surveyor's reels
- 2 - Red plastic signal flags
- White flagging tape
- 2 - U.S. Army two-way radios

Site Surveying

- Schneider BD-5 one minute transit
- 16 oz. plumb bob
- Gammon surveyor's reel
- 300' fiber glass surveyor's tape

The study was conducted using the following dialogue:

STEP NO. x

(Study Controller) The target vehicle operator and the data controller check to confirm the number of the next step. The target vehicle then either starts traveling to the opposite end of the road at the requested speed or drives to the specified target location.

TARGET x DEGREES (RIGHT or LEFT)

(Study Controller) this was announced as soon as the target passed a tripod target (moving target) or reached a specified target location (immobile target). The instrument man started searching for the target using the study controller's estimated angular distance as a location aid. The study controller starts the stopwatch.

VALID or INVALID

(Instrument Man) The target has been seen and the REALTRAIN number read. 21 identified a valid target and 39 an invalid one. The study controller calls out TIME and the stopwatch reading. The stopwatch is read by freezing the time display. Since it is a laps timer, timing still proceeds anyway. The data recorder records both the target number interpretation and the time.

FOUND

(Instrument Man) The telescope crosshairs are centered squarely on the REALTRAIN target. The controller again calls out TIME and the new stopwatch time for the data recorder.

RANGE

(Instrument Man) Using the zoom control, the instrument man has altered the virtual image size of the REALTRAIN target to fit between the ranging stadia. The study controller again announces the new stopwatch time.

X METERS

(Instrument Man) The target has been tracked while maintaining the virtual image in the stadia until a tripod target is reached. The range is read from the scale seen through the telescope.

Data Recording Study

This study was designed to determine the degree to which two independent observers could track a moving target with a transit telescope and then simultaneously stop tracking upon a command. This is a necessary operation for optical triangulation. A secondary objective was to assess the time required to read the angular data from a transit.

The observation posts were located on Timber Mountain and Site A (Figure 5). The dirt road used by the target vehicle was located about 2.6 km. from both locations. The further distance was about 2.9 km. The road section was about 1 km. long. The road and observation posts were selected to be approximately the locations that might be used during the January, 1978, exercises.

The same personnel were used except that each of the surveying experienced persons operated transits. One transit was located at each observation post. A new person was used as the study controller.

The equipment used was basically the same as the previous study (Table 12). The telescope and tripod were replaced by two transits and another radio was added. The jeep radio failed to operate and had to be replaced by one of the portable radios.

The study was conducted using the following dialogue:

STEP NO. x

> (Study Controller) The target vehicle operator and the data controller check to confirm the number of the next step. The target vehicle starts traveling to the opposite end of the road at the

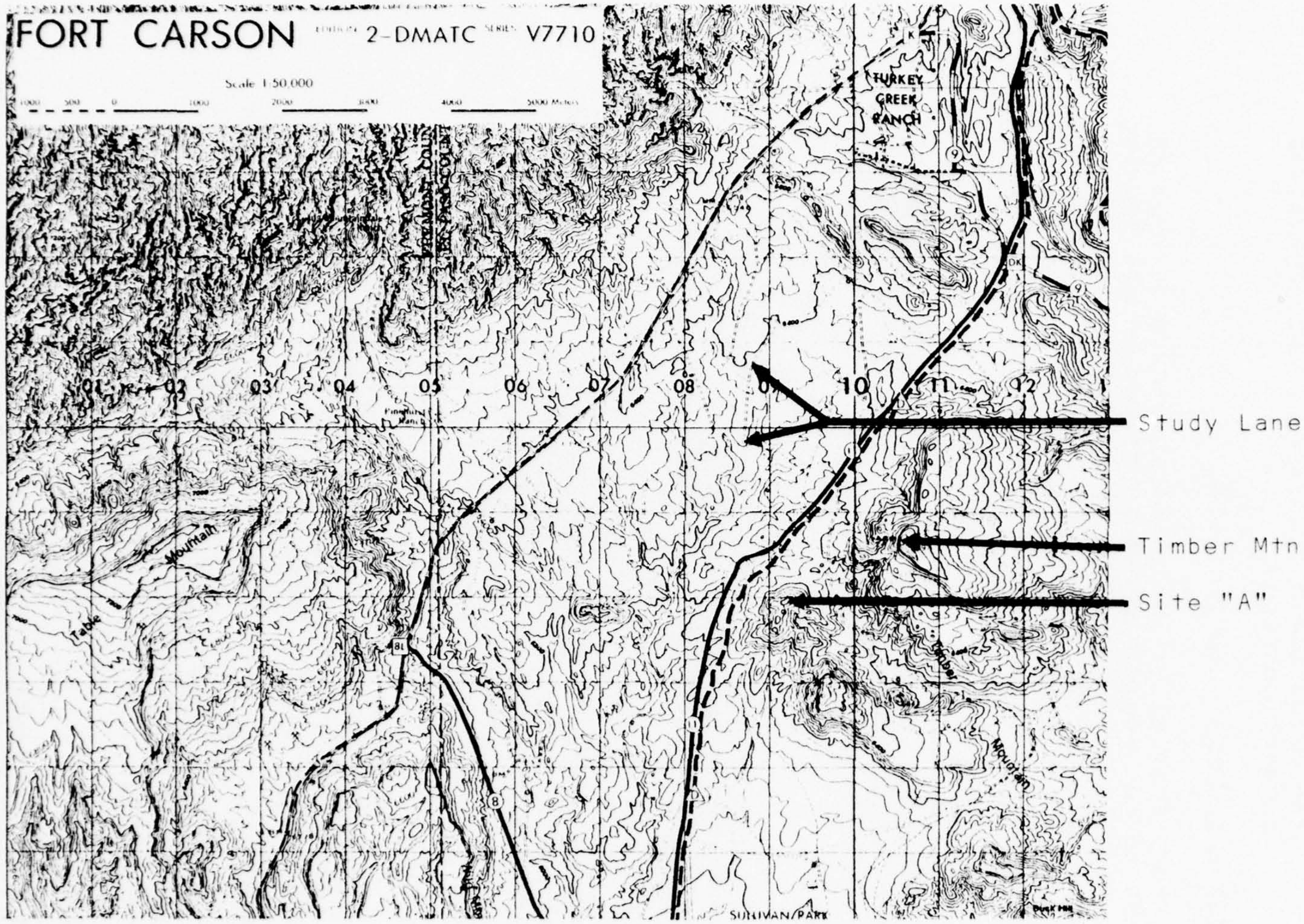

Figure 5. Data Recording Study Area

requested speed or drives to the specified target location

TARGET x DEGREES (RIGHT or LEFT)

(Study Controller) This was announced as soon as the target vehicle passed a tripod target (moving target) or reached a specified target location (immobile target). The instrument man started searching for the target using the study controller's estimated angular distance as a location aid.

VALID or INVALID

(Instrument Men) The target has been seen and the REALTRAIN number read. 21 identified a valid target and 39 an invalid one.

FOUND

(Instrument Men) The telescope crosshairs are centered on the REALTRAIN target. The target is tracked using the orientation fine adjustment screws.

ANGLE

(Study Controller) After the second FOUND command is heard, ANGLE is announced and the stopwatch started. The instrument men stop tracking immediately, and simultaneously, and start reading the angular data -- azimuth first.

FINISHED

(Study Controller) The target vehicle proceeds directly to the designated point of entry into the study lane for the next step.

AZIMUTH x

(Instrument Men) The azimuth is announced as a series of five digits, leading zeros used where necessary. The angle is recorded.

TIME x

(Study Controller) The time display is frozen and the time announced for the data recorder.

ELEVATION

(Instrument Men) The elevation is announced as a series of five digits, leading zeros used where necessary. The angle is recorded. The instrument men then align the telescope on the tripod target at the end of the lane, in the direction that they had been tracking.

TIME x

(Study Controller) The time display is frozen and time announced for the data recorder.

Due to the late start in performing the study, the limited availiability of a jeep and inclement weather (a lightning storm), the study was cancelled at Ft. Carson. Arrangements were then made for the study to be performed in area T-15 at Ft. Belvoir, Virginia. The entire schedule had been delayed by the late arrival of radios earlier in the week and by jeep drivers unfamiliar with the terrain during OP site selection.

Problems at Ft. Belvoir forced further modifications to the design. The only area available and useful to the study, T-15, had very short distances (Figure 6). As a consequence, target tracking as speeds above 5 mph was impossible by relatively untrained instrument men, using the former 24x transit scope. The instrument men had been replaced. The requested jeep turned out to be a pick-up truck that could not idle slowly enough. The problem was further complicated since the study lane was shared with student drivers learning to drive 5-ton trucks. The traffic moved about 10 mph in one direction only. A violent rain storm precluded any work on the final afternoon after the students had left. Unavailability of radios the first day and a half of the

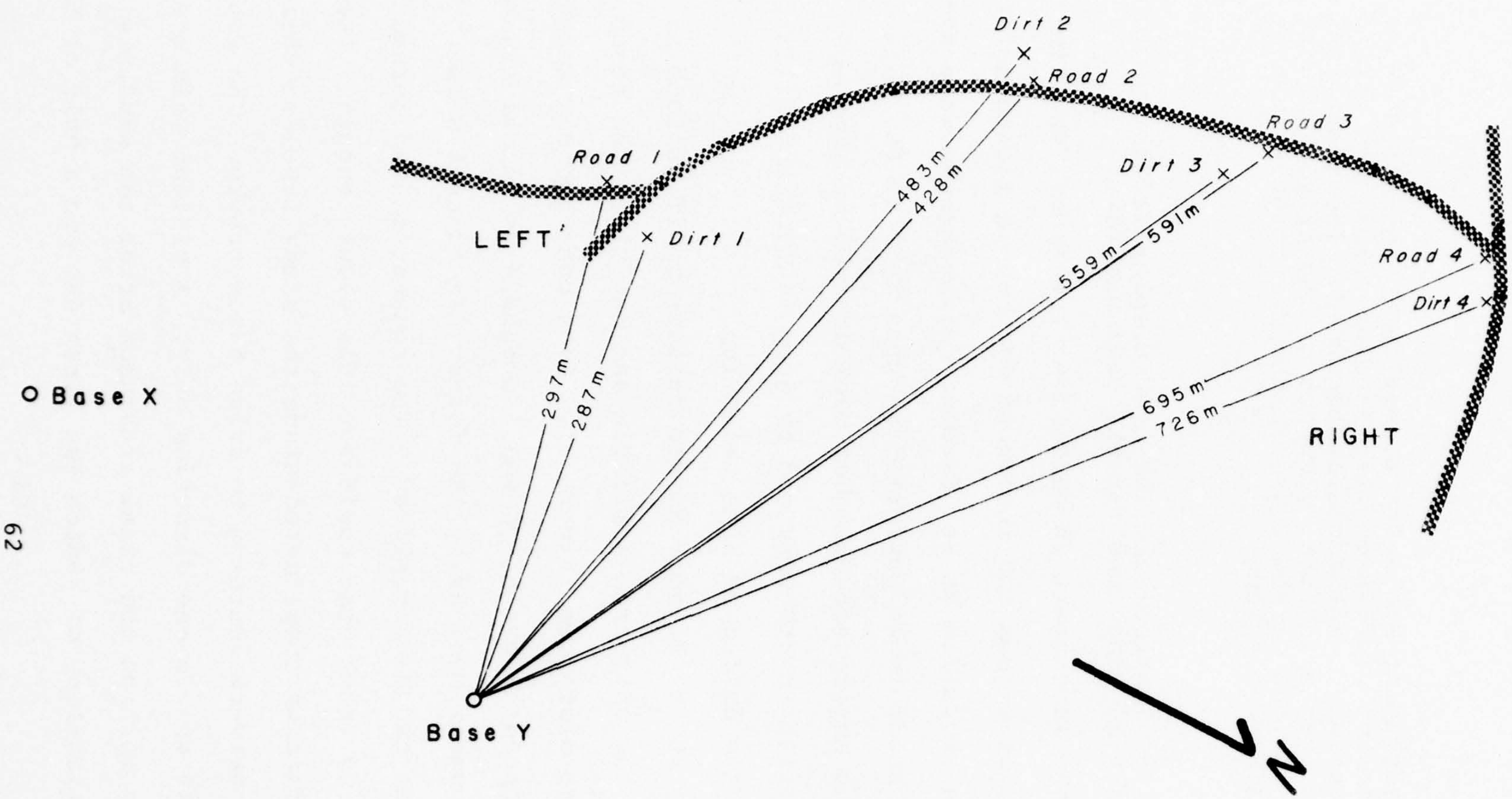

Figure 6. Ft. Belvoir Study Area

budgeted three days slowed up the site preparation.

As a result, moving targets could not be used. The study was reduced to 33 observations on immobile targets.

RESULTS

Preparation and Ranging Study

Since access to an Army jeep -- the target vehicle -- was limited, only 50 of the originally scheduled 160 observations were collected. However, the observational conditions were assigned in random order. As a result, the truncation of the data should not introduce a bias. It means that only general conclusions should be drawn.

Target Identification

As shown in Figure 7, the REALTRAIN identification numbers were consistently interpreted correctly. Three errors were made out of 41 valid observations. Since one of the errors was made with an immobile target, it seems reasonable to assume human communication or recording error.

Target Alignment Time

Figure 8 shows the time required to locate a target in a tripod-mounted telescope and to align the target in the telescope crosshairs. The average alignment time when a target is initially in the telescope's field of vision is about 4 seconds. When the target has to be searched for, the average time increases to about 10 seconds. Figure 9 demonstrates that the search

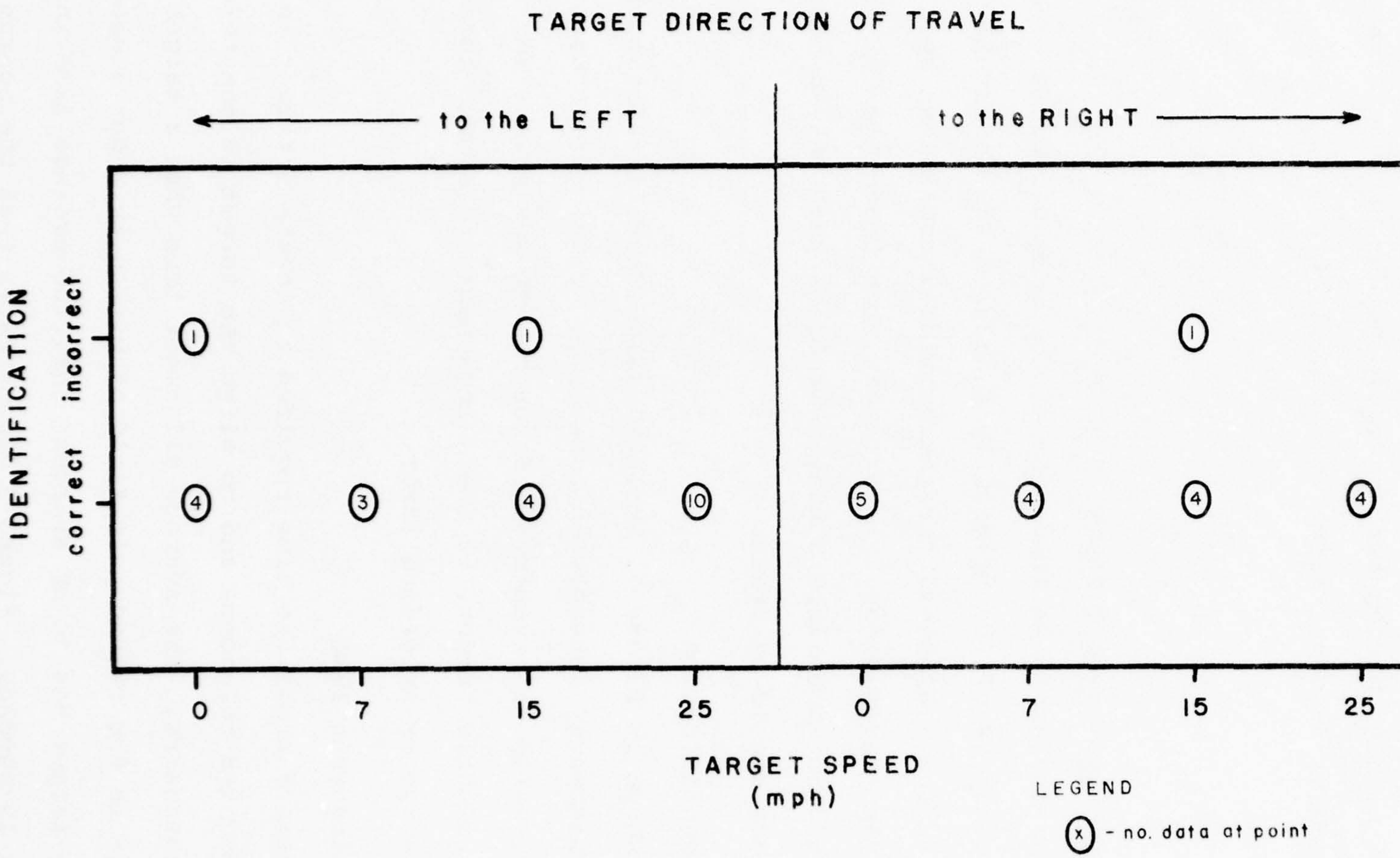

Figure 7. Target Identification

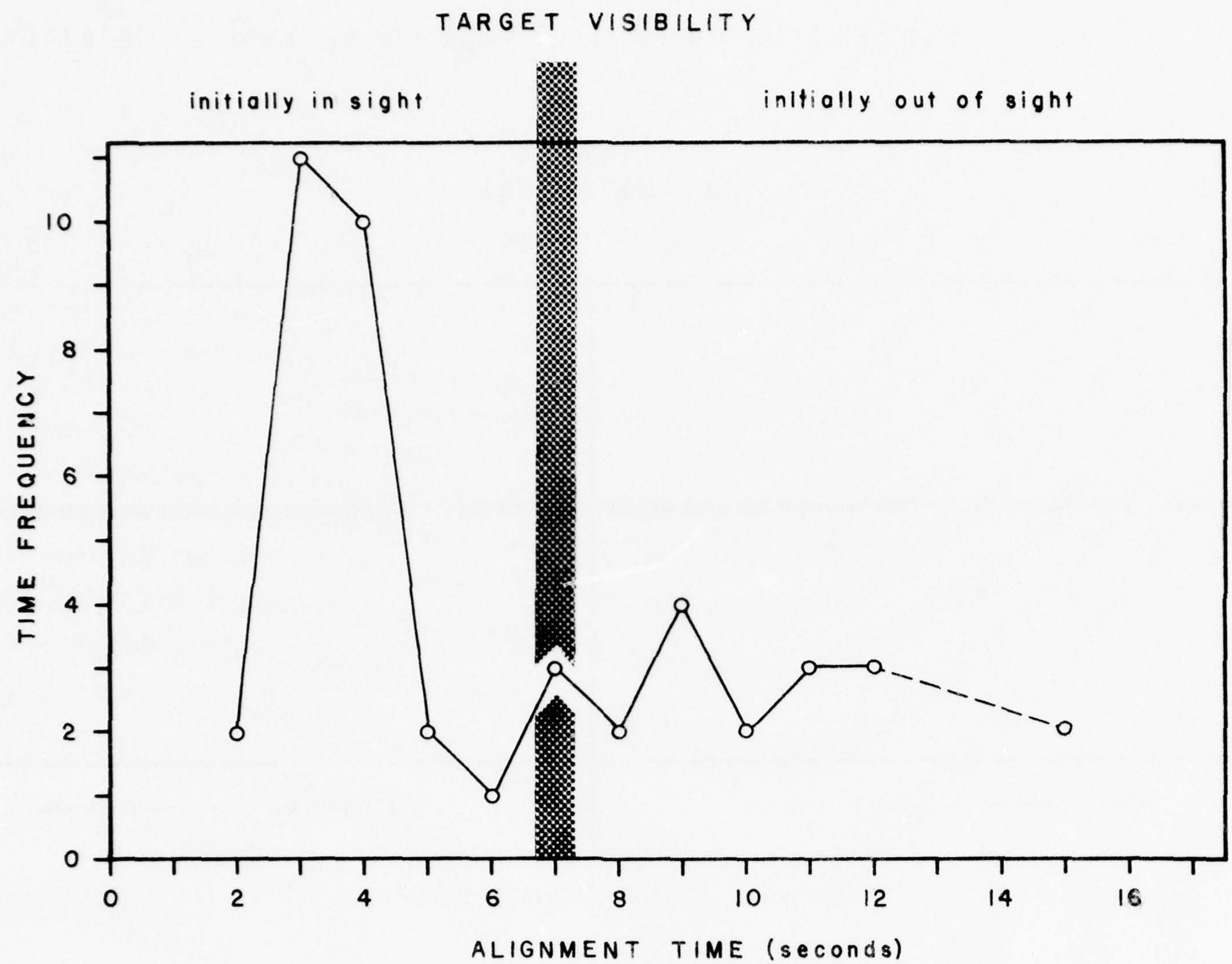

Figure 8. Frequencies of Times to Locate and Align a Target

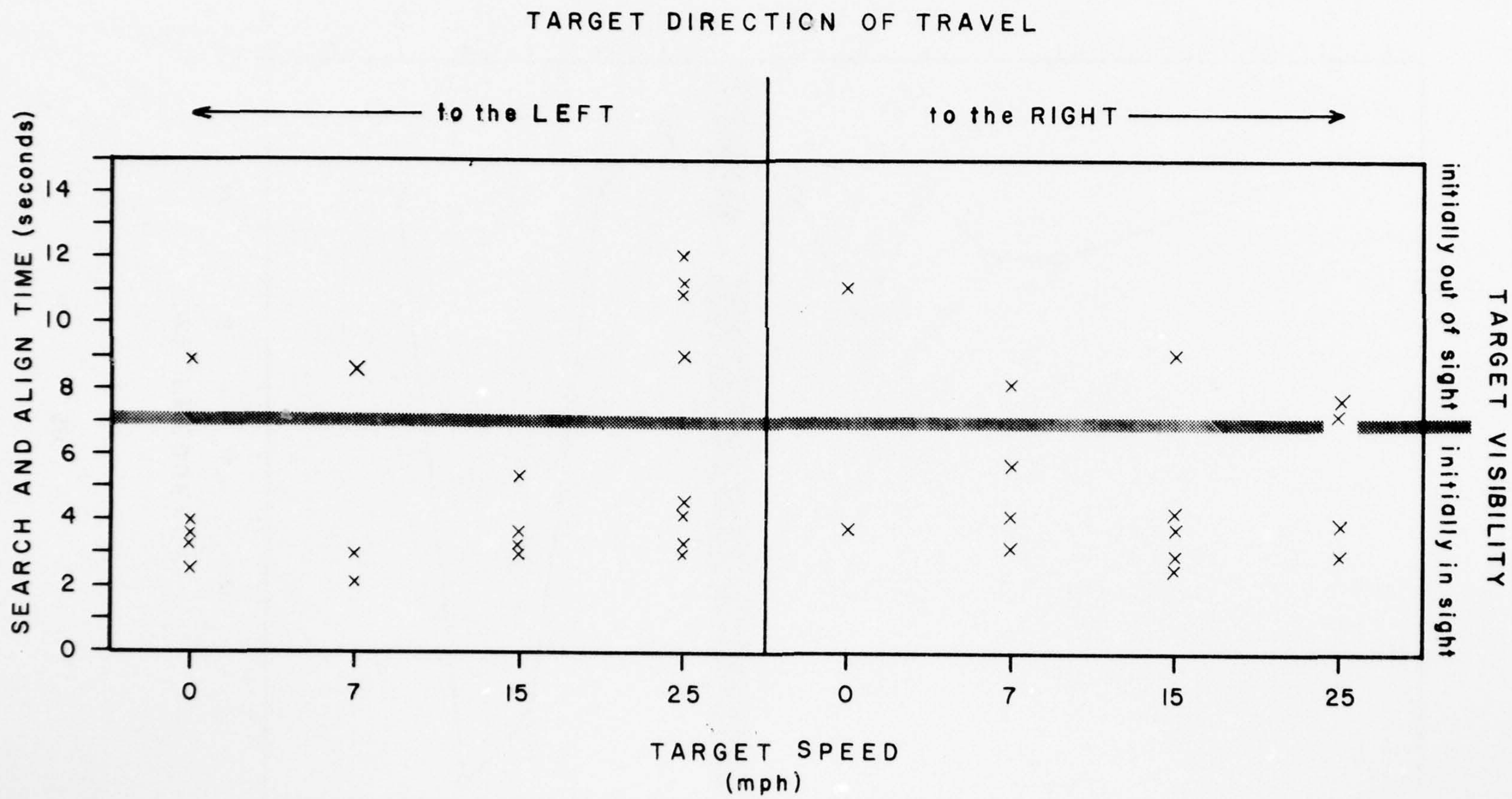

Figure 9. Times to Locate and Align a Target

and align times seem to be independent from the target's speed and direction of travel. The difference between the times -- 6 seconds -- can be assumed to be the target search interval.

Optical Ranging Study

Figure 10 illustrates the total length of time required to align a REALTRAIN identification plate in the ranging stadia of a Redfield Accu-Range telescope. The actual time seems to be independent of target speed and direction. These times represent the total search and alignment time.

The difference between search and align time and range align time is generally less than a second, 57 percent of the observations. The maximum difference is about 5 seconds. These data demonstrate that the stadia ranging can be performed quickly.

The estimated ranges fell within a 100-yard range. This represents the limitations of the commercial grade telescope used -- 50-yard graduations. A more finely graduated range scale will undoubtedly decrease the variation. Actual range determination accuracy could not be performed since the instrument was calibrated for deer and not REALTRAIN targets.

Data Recording Study

Due to the limited number of observations, the entire set of data are shown in Table 13. As is evident, the date easily meet the 25-meter accuracy requirement. During the study, data transmission was hampered by faulty radios. As a result, the data contain several outliers.

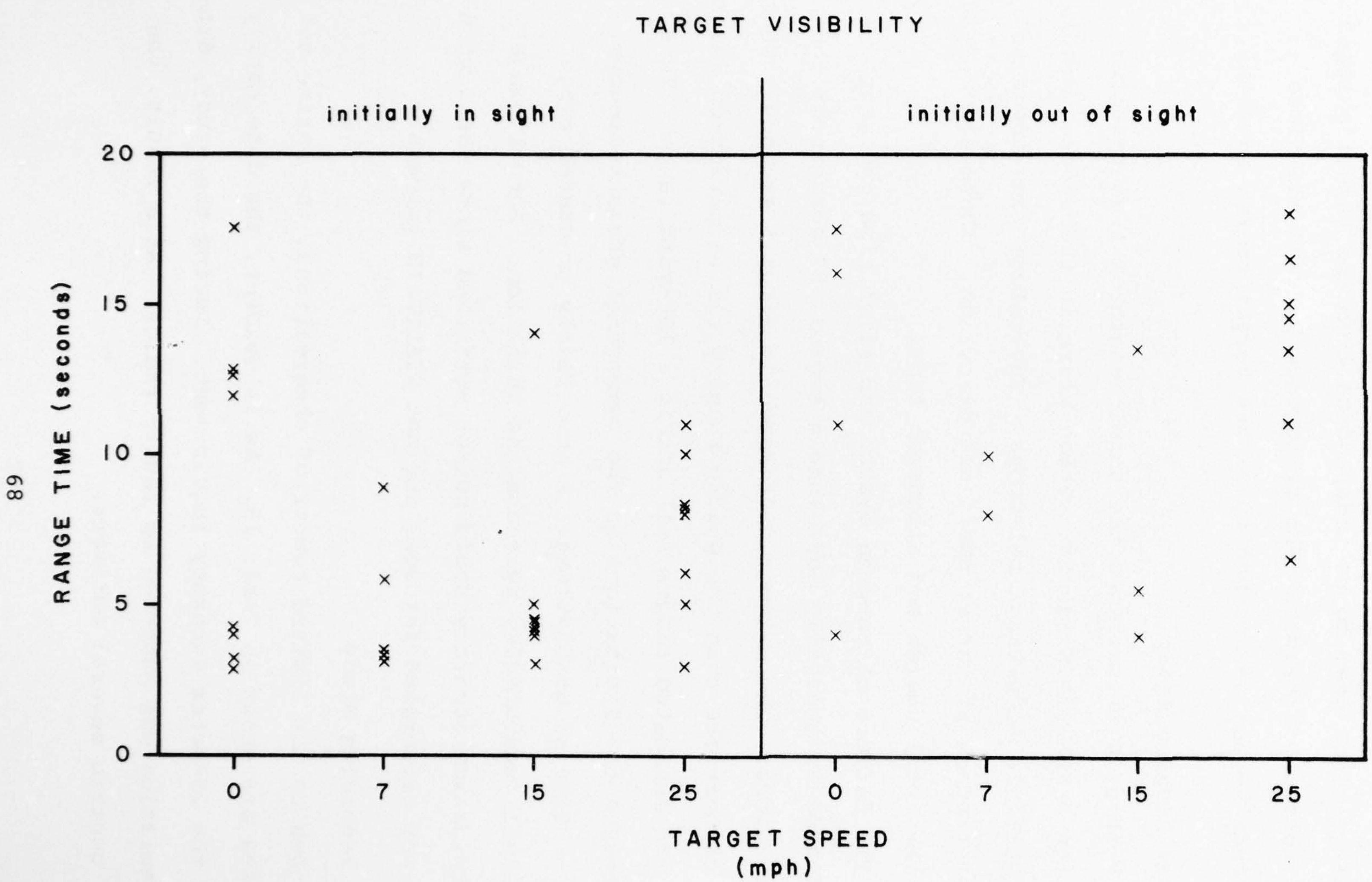

Figure 10. Optical Ranging (Cumulative) Times

Table 13

FORT BELVOIR DATA*

Target Location	Distance from Base Y	Triangulation Estimates					
R 1	297	285	290	<u>246</u>	290	<u>80</u>	
D 1	287	293	289	292	292	288	<u>261</u>
		291	<u>29</u>	<u>242</u>	291		
R 2	428	484	<u>41</u>	468	488		
D 2	483	493	504	491			
R 3	591	582	586				
D 3	559	no data					
R 4	695	666	<u>847</u>	632			
D 4	726	683	<u>265</u>	729	<u>105</u>	688	

* All underlined data are considered to be outliers. All distances are in meters.

The observed data do not coincide with the surveyed distances. This is due to the influence of road traffic during the study. The target vehicle attempted to halt as close to the target location benchmark as traffic would allow.

The average time required to read an azimuth angle was 19 seconds (8 seconds standard deviation). This was computed for 58 valid readings, including both observers. The average time for one observer was 20 seconds and the other was 18 seconds. Since the individual averages lie well within the overall standard deviation, they can be considered to be the same, exhibiting a stochastic deviation.

CONCLUSIONS

Both optical ranging and triangulation techniques appear potentially useful for position data acquisition. However, the techniques impose serious constraints on both the data and the environment being observed. Visual line of sight is needed in all cases. The ranging technique is useful only for distances less than 1 km. The triangulation techniques are useful on immobile targets within any likely engagement simulation area. The location of moving targets can be determined in the range of 1 to more than 3 km. This conclusion is not based upon actual data, but imformal observations made during the training sessions. Intensive staff training sessions are required. Equipment modifications are necessary.

The results showed that 7 to 15 seconds were necessary to search for and align a target. About one third of that time was required when the target search time was eliminated. Since it can be assumed that targets will have to be searched for, about 20 seconds per observation should be budgeted for search and alignment.

During the brief triangulation study, angular scale reading varied from less than 10 seconds to over a minute. However, additional staff training should reduce the time to about 30 seconds, maximum. The use of a direct reading theodolite will remove the vernier scales interpretation and the reading time required accordingly. About 10 seconds (time) reading should be expected. Therefore, with proper instrumentation (an appropriate theodolite) and staff training, a time budget of 30 seconds for observation seems reasonable.

Optical Ranging

In spite of the deficiencies of the commercial grade instruments used, the Redfield Accu-Range telescopic rifle sight -- with modifications -- appears adequate for collecting position data. The Redfield Company suggests that a new ranging scale be graduated from 330 meters to 1 km. A 6x to 18x variable power telescope should be used. Additional stadia in the telescope will increase the range from less than 100m to 1 km (Figure 11). The variable power adjustment ring should be loosened; rifle recoil is not a problem with a transit.

The rifle scope should be mounted onto a theodolite telescope using a dismountable electronic distance measuring fitting.

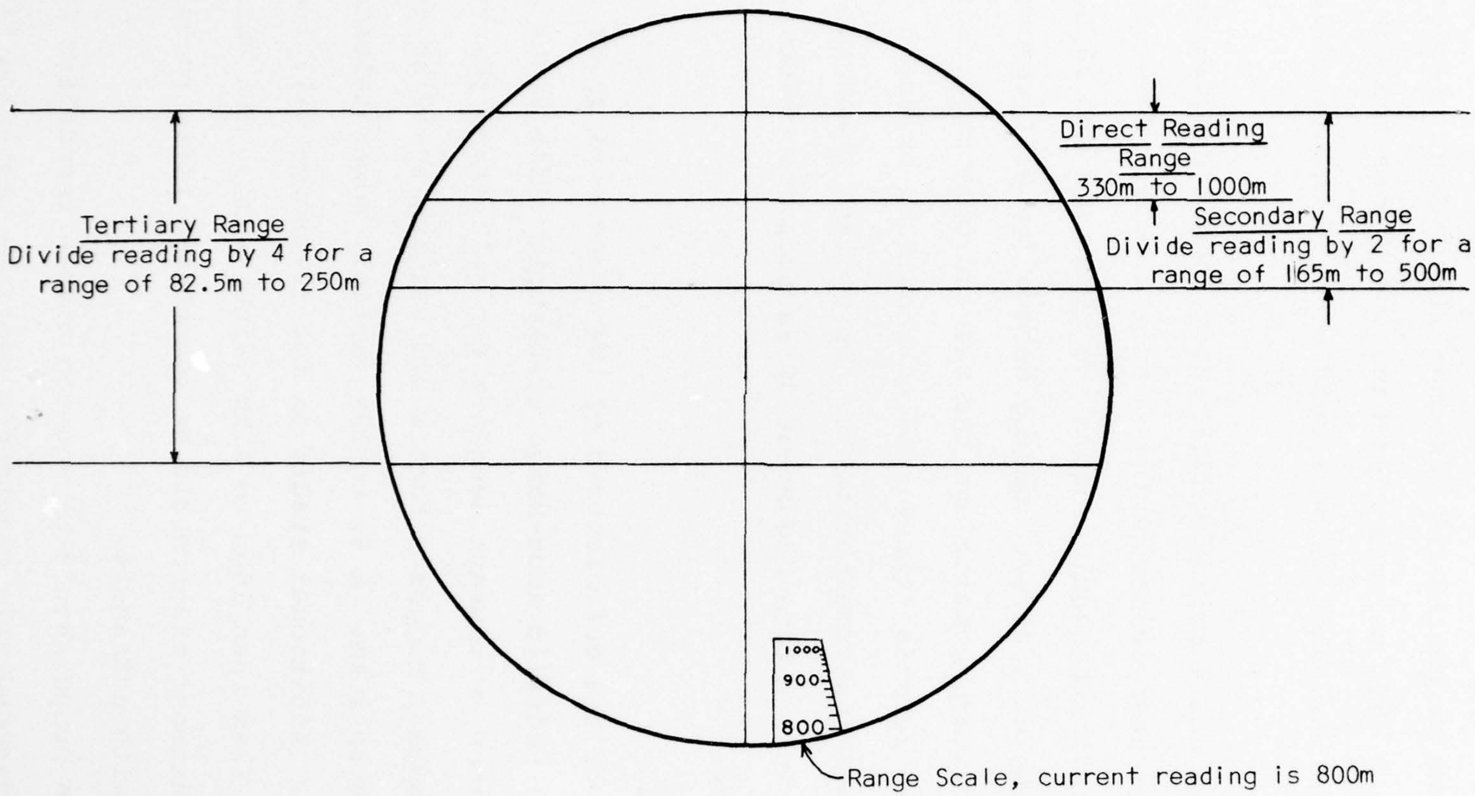

Figure II. Multirange Stadia Reticle

Up to 4 pounds can be supported by the telescope.

However, the stadia method of ranging is heavily dependent upon two target constraints. The target must be a known size. If multiple targets are used, they must all be the same size. The Accu-Range telescope must be individually calibrated to the target size.

The target must be oriented on a vertical line, perpendicular to the observer's line-of-sight. If the target is as little as 12.5^{o} of arc out of line-of-sight perpendicular, serious ranging errors will result. In order to minimize the orientation errors, a target is ranged on the vertical dimension only.

Because of the orientation problem, the long distances and line-of-sight constraints, optical ranging seems inappropriate for use at Ft. Carson. However, the technique might prove useful in small exercise areas in flat or gently rolling terrain with light or sparse ground cover.

Optical Triangulation

The data for triangulation position determinations (Table 13) appear surprisingly accurate given the level of staff training and inadequacy of the equipment. These data should be considered as illustrating the worst case. Unfortunately, the distances are short. However, considering the small errors at these distances, the data indicate that the required accuracy of ± 25 meters might be obtainable to 3 km. With the proper staff training and equipment, the requisite accuracy may be obtainable beyond 4 km.

Unfortunately, no data of any kind are available to assess the accuracy of triangulating a moving target. This should be studied further if the technique comes under consideration. The equipment recommended for use in this technique is the same as for the optical ranging, discussed above.

Coordination Dialogue

The coordination dialogue must be kept to brief one-word commands. Violations of the communications protocol during the study produced considerable confusion. In addition, the frequency of radio communications required for the triangulation technique will cause long messages to be lost.

Numeric data should be reported and recorded as a string of digits, without units designations. This method generally ensures that lost data elements -- digits -- will become obvious. Due to the high frequency of communications, data confirmation is not practical. Therefore, any data in doubt must be discarded.

The communications protocol used in these studies proved useful. It is suggested that these protocols be used as the basis for later ones. The need for communications protocol training cannot be stressed enough. Most of the problems during training sessions can be traced to protocol misunderstandings and violations.

The staff must respond quickly and accurately to the various commands. During actual data collection, time is not available for explanations and repeated messages.

Due to the intermitent radio transmitters, it was found that repeated single word commands -- from the study controller only -- greatly reduced confusion. Since, in some cases, the study controller counts responses, the instrument men should never repeat their commands or messages.

GLOSSARY

GLOSSARY

Azimuth - The horizontal angle between two points.

Digital Recording - Recording data in a form directly sensible by digital computing equipment. A portable tape recorder, capable of recording data in digital form, is generally used for field data.

Doppler Effect - An apparent change in the frequency waves, as of sound or light, occurring when the source and observer are in motion relative to one another, the frequency increasing when the source and observer approach one another and decreasing when they move apart.

Elevation Angle - The angle to a target from the horizontal plane.

EMF Spectrum - Electromagnetic force (radio and light) spectrums.

Impedence - A measure to the total opposition to current flow in an alternating-current circuit equal to the ratio of the rms electromotive force in the circuit to the rms current produced by it.

Interferometry - The technique that employs phase interference to measure distance.

LEAA - Law Enforcement Assistance Administration

LOP - Line of Position

LORAN C & D - A low frequency radio navigation system.

Optical Bearing - A measured angle.

Phase Interference - A new frequency created by combining two signals of the same frequency but out of phase.

Phase Lock - One or more signals at a given frequency transmitted in phase.

Pulse Lock - Two or more pulsed transmissions in which the pulses occur simultaneously across transmissions.

Pulse Trilateration - The method of determining the location of a target using pulsed transmissions to determine the distance between two observers and a target.

RDF - Radio direction finding

Reticle - A grid or pattern used to establish scale or position in the eyepiece of an optical instrument, typically a telescope.

RF - Radio Frequency transmissions

RMS - Root Mean Square

Stadia - Horizontal crosshairs in a telescope

Transponders - Units that receive and retransmit a signal.

Tribrach - A detachable base for a theodolite that fastens securely to a surveyor's tripod.

UMT - Universal Military coordinates

APPENDIX A

OPTICAL TRIANGULATION

APPENDIX A
Optical Triangulation

Triangulation is a method for determining a target's location as a vertex of a triangle consisting of two observation posts and the target. The distance between the two observation posts is known and only the angles between the target and the opposite observer need to be determined. The angles are measured with theodolites or transits. In addition to the azimuth, horizontal angles, the elevation, vertical or stadia angle, will be required if horizontal target distances from the observers are required. For horizontal plotting purposes, the azimuth angle will suffice.

Theodolites and transits comprise a class of instruments that accurately measure both azimuth and elevation angles. A wide variation of resolutions, from 0.2 second to 1 minute of arc, are available.* The methods of reading the angles vary from external vernier scales and internally viewed direct reading scales to digital displays. The costs of these instruments also varies widely -- from about $300 to about $20,000. The instruments generally weigh less than 20 pounds and are easily portable. In fact, special backpacks are available** for transporting the instruments over rugged terrain.

*Brinkler, R.C. Elementary Surveying. International Textbook Company, New York (1969). 620 p.

**Surveying Equipment and Supplies, Catalog 3. Dietzgen Corporation. Catalog No. C-9000-CAT3A.

These instruments consist of a telescope mounted so that it can be rotated 360°, in two-dimensions. The vertical travel is about an axis perpendicular to the telescope axis. Horizontal rotation is accomplished by rotating the instrument on its base. Scales for measuring angles are mounted on the rotational axes.

Transits differ from theodolites by being less expensive and more prone to angle reading errors. The angle reading scales are located on the outside of the instrument, are very finely graduated and use vernier scales to achieve their angular resolution. The fine graduations often require handheld magnifying lens to perform the reading. Settling dust and sun glare can be an annoyance.

Theodolites differ from transits in both appearance and design. They are more compact and streamlined and may weigh less*. The telescopes are usually shorter and contain glass reticles. Metal aiming sights are usually supplied. The angular reading system consists of an internal optical system that displays both the azimuth and elevation scales in the same field of vision through a built-in microscope. Many of these instruments provide a direct angular reading system in place of the transits' vernier scales. Theodolites are available with a detachable base, tribrack. The tribrack allows the theodolite to be removed from its tripod and later replaced without altering its alignment to a reference point. They may also have an optical system for precisely locating the instrument over a ground reference or benchmark. At the extreme resolution,

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* Brinkler, R. C. Elementary Surveying. International Textbook Company, New York (1969) 620 p.

these instruments theoretically measure the angle between two points 1 inch apart and 50 miles away.*

CONSTRUCTION

The transit consists of a leveling head, a standard and a telescope. The leveling head is threaded to screw onto a surveyor's tripod. A chain extends below the head, through a hold in the tripod head, for attaching a plumb bob, for centering the transit over the ground reference or benchmark. The main purpose of the leveling head is to align the transit in a horizontal plane. This is required to measure angles reproducibly.*

Above the leveling head are two concentric, independently rotating plates. The lower plate is seen as a ring finely graduated into degrees of arc to measure an azimuth angle. The upper plate contains a vernier scale to interpolate fractions of a degree on the lower plate, as minutes of arc. Each plate is controlled by a lock screw (clamp) and a tangent screw (fine adjustment).

A bracket, the standard to support the telescope, is an integral part of the upper plate. The elevation scale rotates with the telescope and also uses a vernier scale to interpolate elevation angles to minutes of arc.

The optical system of a transit is very simple -- a telescope (Figure A-1). The telescope magnification is fixed between 18 and 28 diameters. The stadia, crosshairs, in the telescope

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*Brinkler, R. C., Elementary Surveying. International Textbook Company, New York (1969). 620 p.

FIGURE A-1. LIETZ UTILITY TRANSIT 115

may be fine wires, spider webs or a scribed glass reticle. The telescope is a simple straight tube type with an erecting eyepiece. Both the stadia and the target image can be focused independently.

The problems arising from the use of the transit are largly due to its elegantly simple design, quite similar to the "diopter" described about 120 B.C.* In order to achieve an angular resolution of one minute of arc or less, the scales are very finely and closely ruled. It is difficult for the relatively inexperienced occasional user to make consistent, error-free readings. The travel controls -- plate locks and tangent screws -- seem to be located for constructional simplicity and rotate with the plates. As a result, when the upper plate controls move into the vicinity of the lower plate controls, the instrument person may inadvertantly manipulate the wrong controls and misalign the transit.

The transit is frequently being replaced by the theodolite*. This instrument is similar in principle to the transit, but different in design (Figure A-2). The leveling head, tribrach, is generally detachable from the rest of the theodolite. This is a keyed arrangement so that the theodolite can be removed and replaced without disturbing its original reference alignments. It is assumed that the theodolite controls and the tripod were not disturbed. However, good practice requires alignment checking.

Theodolites contain a rather complex but rugged optical system. In order to achieve their improved angular resolution of 0.1

* Brinkler, R. C., Elementary Surveying. International Textbook Company, New York. (1969) 620 p.

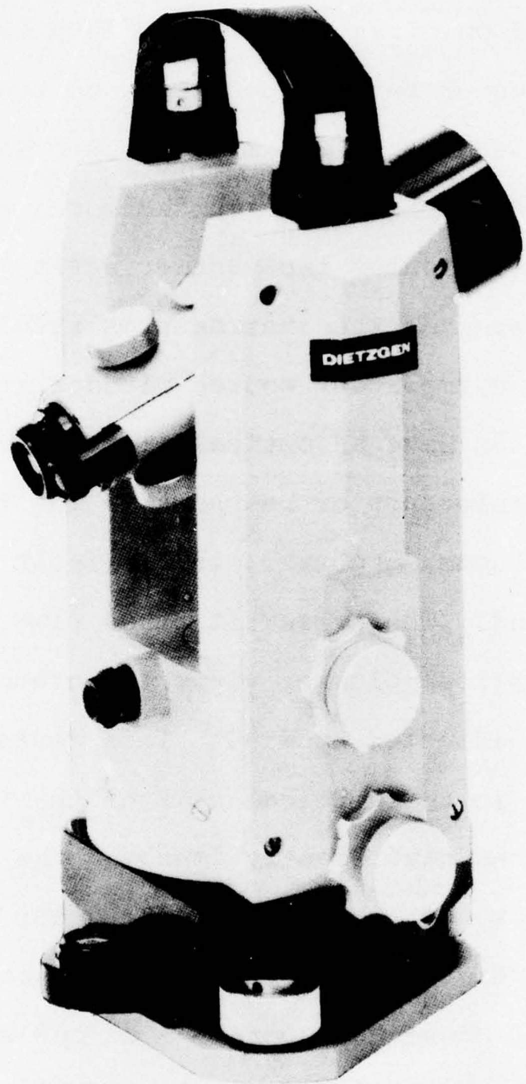

FIGURE A-2. DIETZGEN ONE MINUTE THEODOLITE, 6020-A6E seconds to 1 minute of arc, theodolite scales must be read with a microscope, which is an integral part of the instrument. The scales are scribed on glass. The optical systems use external illumination -- sun or battery powered -- to transmit an image of a portion of both scales to the microscope. Thus, both scales can be easily read at one time. Furthermore, the angular reading system often eliminates the vernier scales in favor of a direct reading system at the instrument's resolution. This greatly reduces one important source of data error.

Most theodolites have an optical plummet for ease of alignment to a ground reference or benchmark. The traditional pendulum plumb bob, although accurate, is difficult to keep still in an appreciable wind. Therefore, it takes time to recheck ground alignment. The optical plummet views the ground from the theodolite and is not affected by wind. This devise is a low-power telescope mounted in the vertical axis of the instrument.

Some theodolites have greatly improved the placement of the controls. For instance, the instruments described in the reference* have the vertical and horizontal scale controls placed together -- vertical above horizontal -- on one side of the instrument. The scale reading microscope is placed adjacent to the telescope, on the same side as the scale controls. This design should greatly increase the speed with which angular determinations can be made and reduce the error frequency.

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* Surveying Equipment and Supplies, Catalog 3. Dietzgen Corporation. Catalog No. C-9000-CAT3A.

Operation Notes

The method of operation for both transits and theodolites is the same in a triangulation study. Angles are determined with a transit by operating the lock (clamp) and fine adjustment or tangent screws. The telescope lock and tangent screws are controlled to located the target in the center of the field of view -- central crosshairs.

The first operation involves setting up the tripod. Only adjustable leg, wide frame, aluminum or wooden tripods should be used for engagement simulation data collecting. Extend the legs and set the tripod roughly over the ground reference point. Place the legs far enough apart so that the tips of the curved tripod feet can be pressed into the gound vertically.

Remove the protective instrument mount ring from the tripod head. The ring will loosely fit over one of the leg adjustment screws for temporary storage. The ring is important and must not be lost. If the tripod head threads, protected by the ring, become damaged, the damage may be transferred to instruments using the tripod.

Mount the instrument and attach the plumb bob, unless an optical plumb is used. The plumb bob should be mounted on a Gammon Surveyor's reel (Lietz No. 8124-50*) for ease of vertical adjustment. Adjust the bob to about 1/4" to 3/8" above the refer-

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* Surveying Equipment and Supplies, Catalog 3. Dietzgen Corporation. Catalog No. C-9000-CAT3A.

ence point. The tripod legs can be adjusted vertically and moved horizontally to center the bob on the reference and leave the transit head roughly level. Leave the bob attached for rechecking the alignment later. Inexperienced persons may find it helpful to remember the following rules for the use of the upper and lower transit horizontal controls*:

A. The lower controls are used for reference alignment only.

B. The upper controls are used for setting the horizontal plates to zero, to a given angle, and for target alignment.

The upper controls are used to set the azimuth scale to zero degrees prior to sighting along a reference line, and to obtain a differential movement between the plates when target sighting. The stepwise procedure for determining a direct or interior angle ABC (Figure A-3) is presented to illustrate the use of these controls.

1. Set up the instrument over point B and level the leveling head (or tribrach). Loosen both lock screws. Estimate the size of the angle to be determined for a rough check on the angle to be read.
2. Set the plates to approximately zero degrees by holding the upper plate while turning the lower plate by tangential

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* Portions of this section were taken in part and paraphrased from: Brinkler, R.C., Elementary Surveying. International Textbook Company, New York (1969). 620 p.

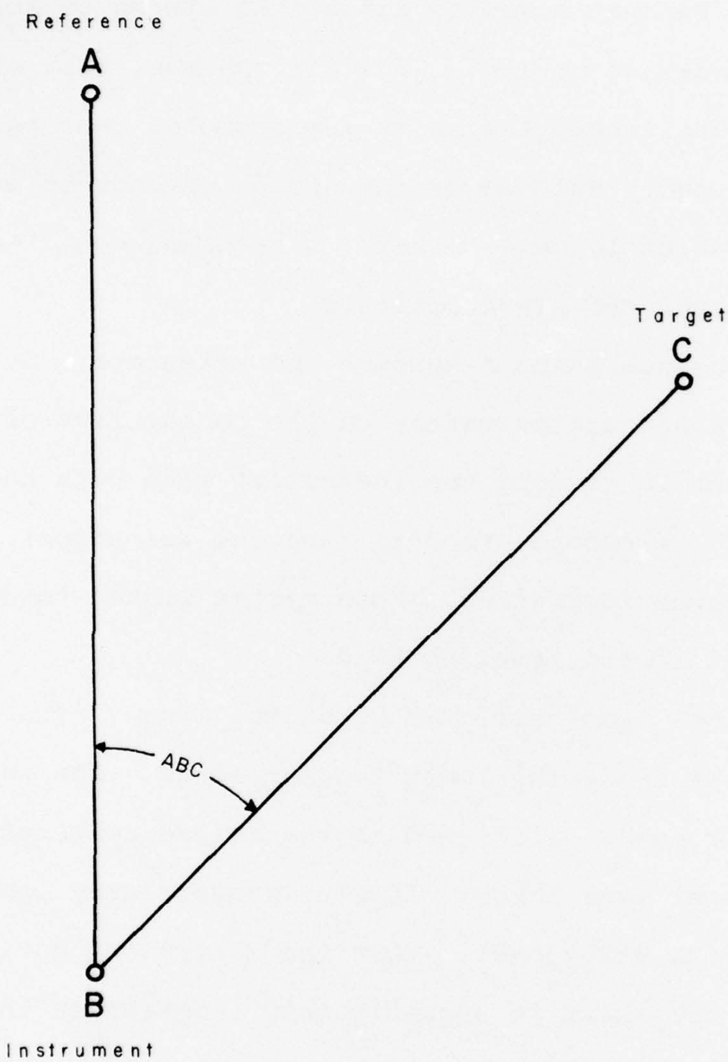

Figure A-3. Measuring an Angle

pressure on its underside. Tighten the upper lock screw snugly but not wrench tight. The plates are now locked together.

3. Use the upper tangent screw to adjust the plates to absolutely 0°. Use a clockwise motion. If 0° is overrun, back off and try again. (The tangent screw is a micrometer that pushes against a spring.) Release of the spring may not be even during reversal of the micrometer. A backlash would occur which might alter the plate position.
4. Sight the reference point A through the telescope. Set the vertical crosshair approximately on the center line of the reference point by turning the instrument with both hands on the standards, telescope brackets (not the telescope).
5. Tighten the lower lock screw. Both plates locked together are now locked to the leveling head.
6. Set the vertical crosshair exactly on the center line of the reference point using the lower tangent screw. The instrument is now oriented or aligned to the reference point.
7. Loosen the upper lock screw. If you inadvertantly loosen the bottom lock, start over. Turn the instrument until the vertical crosshair is approximately centered on the target. Snugly tighten the lock screw and complete the target alignment with the upper (not the lower) tangent screw.
8. Repeat Step 7 using the elevation controls and the <u>central</u> horizontal crosshair.
9. The angles can now be read.

Traditional surveying procedures recommend a more complicated and time-consuming technique. However, the above procedure will probably suffice for engagement simulation surveying, using experienced personnel. If the personnel are not experienced, then surveying by repetition is recommended.* About four repetitions would seem sufficient.

The above procedure should only be used for surveying purposes. The data collection procedures will be described shortly.

ACCURACY

An instrument capable of resolving 1 minute of arc can determine an angle between two points less than 1.5 meters, 5 kilometers away. Since this represents about 6 percent of the desired 25 meters accuracy, a 1 second of arc instrument should be sufficient. Of course, the instrument accuracy greatly improves at shorter ranges.

The greatest source of error lies in the human observer. The following sources of errors should be considered:

a. Misinterpretation of the vernier scales. This is eliminated in direct reading or digital instruments.

b. Improper use of the lock and tangent screws such as use of the wrong controls and not tightening a lock screw before adjusting the tangent screw.

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* Brinkler, R.C., Elementary Surveying. International Textbook Company, New York (1969). 620 p.

c. Unsteady tripod. The tripod leg bolts must be tight to prevent slippage. If the terrain permits, the tripod legs must be forced into the ground to prevent settling.

d. Reading the wrong scales such as reading the elevation first, when the field procedures specify the azimuth first. This is reduced in direct reading theodolites and eliminated in digital theodolites.

e. Using the wrong target.

f. Instrument not level.

g. Horizontal reference point not properly aligned.

DIGITAL DEVICES

Several digital, angular recording systems, are available. Typically labelled "digital theodolites," these systems electronically measure azimuth and elevation. The advantages over manual transits and theodolites are largely the speed and accuracy with which angular data can be obtained. The systems are composed of a pseudo transit or theodolite and a small computer. Accuracies range from 3 seconds of arc to 0.1 degree. Some of the characteristics of these systems are presented in Table A-1.

<u>Digital Theodolite</u>

At the present time, the only commercially available digital

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* Surveying Equipment & Supplies, Catalog 3. Deitzgen Corp. Catalog No. C-900-CAT3A.

Table A-1

EVALUATION OF DIGITAL ANGULAR MEASURING DEVICES*

	Lietz DT-3 Electronic Theodolite	Universal Data** Platform (current)	Universal Data** Platform (modified)
COSTS	4	no data	no data
PORTABILITY	1	2***	1
TERRAIN APPLICABILITY	1, 2	1, 2	1, 2
AVAILABILITY/ DELIVERY	1	1	---
POSITIONING ACCURACY	1	1	2
INVASIVE CONSTRAINTS	1	1	1
SYSTEM USEABILITY	2, 4, 7	2, 4, 6, 7	2, 4, 7
RELIABILITY/ MAINTAINABILITY	1, 4, 6, 8, 11, 14	1, 4, 5, 6?, 11	1, 4, 5, 6?, 11
DATA ACCESSABILITY	2. 4	2	2, 4
OPERATING CONDITIONS	1, 3, 4, 6	2, 3, 4, 7	2, 3, 4, 6

*Reference indicators described in Appendix D.

**The evaluation is concerned only with the Universal Data Platform instrument as might be set up on a hill or mountain.

***Portability restricted by land line communications.

theodolite is Leitz model DT-3*. Keuffel and Esser Company is scheduled to announce their version toward the end of calendar year 1977. The Lietz system is designed to operationally resemble standard, manual theodolites. Therefore, it is small, light and easily portable. The instrument contains an optical plummet and mounts on a familiar surveyor's tripod.

A magnetic encoding technique is needed to determine angles. The associated, portable computer then computes and displays the angles. The angular data are derived from magnetic drums prerecorded with a square wave. Two read heads are used to insure accuracy of 0.2 seconds of arc.

The system is well designed for ease of usage. Operator training requirements are minimal. In fact, reference alignment drift -- frequent source of inexperienced operator errors -- has been greatly reduced. The reference point is set electronically. The data can be digitally recorded to eliminate data transcription errors. This instrument costs about $18,000.

Universal Data Platform

The Army Reasearch Institute at Fort Ord, California, has constructed a digital angular measuring system*. This instrument measures azimuth and elevation angles with 0.1 degree of arc resolution. The accuracy is unknown. The system is composed of the angular measuring device and associated computing equipment. The cost is unknown.

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* Instrumentation for Field Experimentation. U.S. Army Research Institute for the Behavioral and Social Sciences (unpublished).

The angular measuring unit uses a magnetic technique to generate electrical pulses, 0.1 degree of arc apart. The orientation of the instrument is determined by dead reckoning counting of pulses. The data can be displayed in angular form or digitally recorded. A variety of optical spotting equipment can be attached to the unit.

The unit appears to be fastened to a heavy-duty camera tripod. A precise leveling arrangement appears to be lacking. In addition, the unit cannot be accurately aligned with a ground reference.

The computing equipment is contained in two "semi-trailer vans." The equipment provides considerable flexibility for processing the data as they are acquired, at the expense of portability. Since the computer is general purpose and programmable, the use can transform, display and record the data in any appropriate manner.

Even though this system currently has some serious deficiencies, it could be improved to become a potentially very useful data acquisition system (see Table A-2). However, it remains an optical device and is hence limited to visual line-of-sight. In addition, it is necessarily a single target at a time data device. Multiple targets introduce the same search, identify and align problems and time delays found in other optical instruments.

Since it is restricted to visual line-of-sight, the Universal Data Platform is not recommended for use in the Fort Carson

Table A-2

UNIVERSAL DATA PLATFORM, SUGGESTED IMPROVEMENTS

Current Operation	Alternative Operation
1. A camera-like tripod is used which lacks proper stability	1. Use a surveyor's wide-frame tripod, or alternatively, an Army artillery tripod.
2. Precise instrument leveling seems inadequate.	2. Adopt the instrument to a theodolite leveling base, such as Lietz 7311-35 Tribrach.
3. Precise alignment with ground reference -- benchmark -- is not possible for repeatable setups.	3. The tribrach mentioned above contains an optical plummet.
4. It is assumed that the instrument has an elevation level.	
5. The instrument transmits raw data to the "vans". This limits portability and increases the data error potential.	5. Construct a battery powered micro computer to transform the data into angles and then transmit to the "vans". Optionally provide for digital data recording directly from the micro computer. The instrument will then be capable of independent operation, and the system will be portable.
6. Digital data cassette tapes are being used to record the data. These tapes are notoriously unreliable.	6. Use the 3-M data cartridge, or the micro version. This is a tape cassette designed for digital data and has proven to be reliable.
7. Moving targets must be tracked in two dimensions, by hand.	7. Provide servo azimuth and elevation controls, directed by a single, proportional joystick.
8. Data are transmitted to the "vans" using a wire link. This requires that the "vans" be relatively close to the instrument -- not practical at Ft. Carson.	8. Use a radio or laser communication system.

Table A-2 (Continued)

UNIVERSAL DATA PLATFORM, SUGGESTED IMPROVEMENTS

Current Operation	Alternative Operation
9. Reference zeroing does not seem to be present.	9. Add a switch for automatically resetting angle counters when a reference point is aligned in the optics.
10. Azimuth travel stops can result in lost data when the instrument is improperly set up and large angle travel is required.	10. Eliminate the azimuth travel stop.

APPENDIX B

POSITIONING SYSTEMS

SPECIFICATIONS

APPENDIX B

POSITIONING SYSTEMS

SPECIFICATIONS

Table B-2 presents a comparison chart of specifications. The chart is slightly modified from the original*, constructed in 1974. Most of the medium-range positioning systems known at that time are included. Currently, several more systems have entered the field. Several of these systems were discussed earlier and in Appendix C. The system costs have generally increased by approximately 30 percent during the past 4 years. Note that systems have been developed generally for marine rather than land use, but may be appropriate for such land use.

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* Munson, RA R.C. Positioning Systems, Report on the Work of WF4146. Presented at the XV International Congress of Surveyors, Stockholm, Sweden, June, 1977.

Table B-1

NOTES TO TABLE B-2

1. Nonambiguous

2. Indicates the number of mobile units which can jointly use the same shore stations.

3. Lists the accuracy calculated and/or verified by the manufacterer at the stated operating range of the system (e.g., 200 km).

4. The list is partial or incomplete.

5. Indicates the time necessary for the system to warm-up and stabilize.

6. The number indicates the individual components (without options) that comprise an installation, excluding cables, connectors, batteries, etc.

7. This category presents a relative size comparison for the combined volume of all components calculated entirely from physical dimensions without regard to shape or configuration (e.g., 1 $vol.^3$= 1 x1 x 1 or .5 x .5 x 4).

8. The weight totals are for all components of an installation (without options).

9. Shore components(16kg) are the number of components (excluding batteries and options) which may limit backpacking a shore installation into a remote area.

10. Fault isolation technique is the method of locating a malfunction.

11. Typical warranties cover defective materials and workmanship providing the failure is not a result of improper use, improper repair or alteration, neglect, accident, or operation outside specified environmental requirements, and exclude shipping costs.

12. The approximate cost is for a minimum configuration of shore stations (usually 2) and 1 mobile unit.

13. The user countries list in some cases the use of earlier system versions, such as HIFIX, and include both private and government organizations. The listing is incomplete.

Table B-1 (continued)

14. Information is not available or unknown at time of publication, (1977).

15. ARGO - The system meets vibration and shock specification (US) MIL-STD-167.

16. HIFIX/6 - System has a time multi-plexed carrier and uses time sharing; HIFIX is a previous generation to SEAFIX and SEAFIX is a previous generation of HIFIX/6 but without the sophistication and higher power.

17. HYDROTRAC - The system operates with a time shared, single frequency; 4range/ranger users is under development; manufacturer's tests verify ranges; the theoretical maximum range is 400 nm (740 km); the MTBF is 8000 hours/chain over 8 chair years.

18. LORAC - The digital processing system is a standard item with its own HP computer; lane identification (CW & AM signal) is time shared, cesium beam frequency standard is necessary for range/range LORAC; light-weight, low power version is available; documented system reliability is 99.6%.

19. MAXIRAN - The system uses a pseudo random coded pulse and time sharing.

20. OMI - The system is completely portable; shore station is environmentally controlled for cesium beam clock; double sideband, suppressed carrier, provides for non-ambiguity and synchronous A.G.C.

21. RAYDIST - Minimum range: It is possible to operate within 2 miles (4km) or less of the shore station providing the shipboard transmitter power is reduced. This distance may vary depending on the distance between the shore stations. In the area between the base lines, there is an area which extends out to a maximum of 0.18 base lines for minimum intersections of 30 degrees; RFI may be present from some seismic profiling equipment.

Table B-2

MEDIUM RANGE POSITIONING SYSTEMS

SYSTEM OPERATIONAL CAPABILITIES

SYSTEM AND MANUFACTURER	PRINCIPLE AND MODES OF OPERATION	NON-AMBIGUOUS LOPS (NOTE 1)	NUMBER OF USERS (NOTE 2)	OPERATING RANGE		
				DAY	NIGHT	MINIMUM
ARGO (Automatic Ranging Grid Overlay) Cubic Western Data Corp. San Diego, Calif., USA	Range/Range Hyperbolic (optional) (phase measurement)	Only if actual lane count ± 5 lanes	12 w/2 ranges 9 w/3 ranges 7 w/4 ranges unlimited hyperbolic	400 nm (740 km) (maximum)	220 nm (408 km) (maximum, depending on operating parameters)	1 km from shore station
HI-FIX/6 Decca Survey Systems, Inc. Houston, Texas, USA Decca Survey Limited Leatherhead, Surrey, England	Hyperbolic Range/Range Compound (Range/Range/Hyperbolic) (phase measurement) NOTE 16	Only with coarse lane (option)	4 range/range unlimited hyperbolic	200 nm (370 km)	200 nm (370 km)	None
HYDROTRAC The Hydrocarta Corp. Houston, Texas, USA	Hyperbolic Range/Range (phase measurement) NOTE 17	Only with multi-systems or an integrated system	Single range/range Unlimited hyperbolic NOTE 17	250 nm (460 km) NOTE 17	125 nm (230 km)	5–6 wavelengths from shore sta. ≈ 1/2 nm (.9 km) without loss of accuracy 100 ft (31 m) without loss of lane count
LORAC (Long Range Accuracy) LORAC Service Corporation Houston, Texas, USA	Hyperbolic Hyperbolic (w/lane ident) Range/Range (passive) (phase measurement)	Usually integrated with satellite or with option of coarse, medium and fine lanes	Unlimited	250 nm (460 km)	100 nm (185 km)	8 nm (15 km) from a shore station
MAXIRAN Navigation Management, Inc. Ocala, Florida, USA	Direct Ranging (P.M.R.–Precision Microwave Ranging)	Yes 3 sequential pulse measurements	6 practical 22 (theory) (will respond to several interrogations simultaneously)	350 nm (650 km)	350 nm (650 km)	None
OMI SYSTEM Ocean Measurements, Inc. West Palm Beach, Florida, USA	Range/Range/Hyperbolic (passive phase comparisons) (phase measurements with cesium beam clock)	Yes – coarse lane is standard	Unlimited All Modes	250 nm (460 km)	150 nm (280 km)	1200 ft (366 m) (near field)
RAYDIST Teledyne Hastings–Raydist Hampton, Virginia, USA	Range/Range Range/Range/Hyperbolic Hyperbolic (phase measurement)	Only with Raydist 76 multiple LOPS (2 R/R & 2 hyperbolic) and integrated navigation system	4 range/range Unlimited hyperbolic 4 range/range/hyperbolic (RAYDIST 76)	250^+ nm (460 km)	150 nm (280 km)	Near baseline .18 times baseline length from station NOTE 21
TORAN Sercel Nantes, France	Hyperbolic Only (phase measurement)	Only with optional multi-frequency and channel	Unlimited	300 nm (550 km)	135 nm (250 km)	1–2 km less than focus

Table B-2 (cont'd)

MEDIUM RANGE POSITIONING SYSTEMS (continued)

SYSTEM OPERATIONAL CAPABILITIES

SYSTEM	MEASUREMENT CHARACTERISTICS						
	LANE WIDTH	BASELINE ACCURACY	OPERATIONAL ACCURACY (NOTE 3)	REPEATABILITY	RESOLUTION	OPERATING FREQUENCIES	MAXIMUM PLATFORM SPEED
ARGO	75–94 m	± 1 m	± 1.4 m (theory) Average installation ± 10 m	± 1.4 m	.01 lane	1.6 – 2.0 MHZ Synthesized (channelized)	20 kts (37 km/h) 80 kts (148 km/h) with multiple time slots
HI–FIX/6	75 m @ 2 MHZ on baseline	± 1.5 m (optimum)	> 30° arcs better than ± 5 m	65% probability exactly same	.01 lane instrumental	1.6 – 5.0 MHZ synthesized	460 kts (864 km/h) along baseline (4 lanes/sec)
HYDROTRAC	50 – 93 m	± 2 m ± 1 m (ideal)	Note 14	± 0.8 m ± .01 lane	± 0.8 m .01 lane	1.6 – 3.0 MHZ synthesized	38 kts (70 km/h)
LORAC	83 m	± 3 m	± 15–23 m @ 100 nm (185 km) ± 40 m @ 200 nm (370 km)	Same as operating range accuracy ± .01 lane instrumental	.001 lane instrumental	1.6 – 2.5 MHZ rho/rho system synthesized from cesium clock	80 kts (148 km/h) along baseline
MAXIRAN	None	± 3 m	± 3 m to 100 nm (185 km)	± 1 m	± 1 m	420–450 MHZ Crystal	80 kts (148 km/h)
OMI	183 m	± 1 m	± 1 m @250 nm (460 km)	± 1 m	.001 lane instrumental ± .2 m	1.6–1.8 MHZ Crystal	80 kts (148 km/h) option to 160 kts (296 km/h)
RAYDIST	45 m	± 3 m	rho/rho > 30° arcs ± 3 m hyperbolic @ 35 nm (65 km) ± 3 m	± 2 m CEP of ± 1 m	.01 lane instrumental ± .5 m	Shore (SSB) 1.64 – 1.66 MHZ Mobile (CW) 3.28 – 3.32 MHZ Crystal (Synthesized soon)	No limit (theory) tested to MACH 2
TORAN	40–90 m	± 1.5 m	0.01 lane instrumental	.01 lane	.4 – .9 m .01 lane instrumental	1.6 – 3.0 MHZ Synthesized	270 kts (500 km/h)

Table B-2 (cont'd)

MEDIUM RANGE POSITIONING SYSTEMS (continued)

SYSTEM OPERATIONAL CAPABILITIES
OPERATING FEATURES

SYSTEM	DISPLAY	OUTPUT DATA FORMAT	OPTIONAL FEATURES/CAPABILITY (NOTE 4)
ARGO	• Power indicator lights • Digital display (dimmable) • Panel illumination • Rack mountable (option) • Alarm light • 24 hour clock (± 5 sec/day)	• G.P.I.B. to IEEE 488–1975 standard • Analog for strip chart • RS–232 data format (option) • Data smoothing – (operator selectable) • Rate – Once/2 sec	• Strip chart; digital printer; data multiplier; interface with plotter; computing and recording; Fail Safe AC power supply • Hyperbolic capability
HI–FIX/6	• Power indicator lights • Filament type numeric indicators (dimmable) • Front panel hinged • Rack mountable • Alarm lights	• Parallel BCD – 48 BCD digits and 6 byte address • Data rate – 2 ms data period followed by 2 ms interval repeated • Sequence content – 3 16 digit words (1 word/display) • Data byte period – 40 μsec • Data sense – logical "0" and "1"	• Interfaces with Autocarta and mini-computer; remote indicators; left–right indicators; Sea Track unit of DECCA steering system; data logger; digital/analog converter; track plotter • Range/range/hyperbolic capability
HYDROTRAC	• Power indicator lights • Digital display (dimmable) • Rack mountable • Data Hold/Slew • Alarm (audio and visual) • Display of selected slaves	• Serial BCD (standard) – compatible with all HYDROCARTA systems • METHOD: Serial, asynchronous, 8-bit data bytes transmitted via 20 ma. neutral current loop at 1200 baud • FORMAT: (Repetition rate 1, 2, 3, 4, 6, 12/sec) Pattern 1 | Pattern 2 [377. | Control Byte | LSD | | | MSD | LSD | | | MSD] • Analog for strip chart • Optional: parallel BCD, ASC II, incremental	• RS–232 interface; user equipment interface • Strip chart; printer; data processors (HP9800 series); digital processor; incremental plotter • 4 users for range/range under development
LORAC	• Power indicator lights • Panel illumination • Illuminated rotating drum display • Most components rack mountable • Digital display with lat/long directly	• Serial BCD • Analog • Various digital from mini-computer • Cassette tape recorder • 60 cycle synchro out for auxilliary devices	• Interface with data processor, i.e., Analog/digital converter; time base generator; clock, processor; terminal; CRT; recorder; zero header; plotter; digital recording; TTY; analog recorder; integrated navigation system • Hyperbolic w/lane identification • Satellite integration
MAXIRAN	• Gas discharge display • Rack mountable	• 2 serial (TTY) and parallel (2,4,6,8) BCD outputs (parallel for 21 column line printer) at TTL logic levels	• Printer; track plotter; directional indicator; interface to computer
OMI	• Power indicator lights • Panel illumination • Dimmable display intensity • Rack mountable • Front panels hinged	• Parallel BCD; 48 byte (option) • Data rate – .4 sec; 14 ms to dump • Serial BCD	• Interface to any computer • Strip chart • Range/range/hyperbolic
RAYDIST	• Power indicator lights • Rotating dials (no illumination)	• Incremental digital (quadrature, 2 bit binary gray code) • Analog for strip chart • Optional: pure binary; BCD; ASC II; incremental	• Strip chart; data printer; line follower; Halop converter; track plotter; remote with digital clock; calculator; tape punch and interface; incremental digital junction box • Raydist test equipment • Hyperbolic and range/range/hyperbolic
TORAN	• NIXIE tube display • Alarm lights • Display illumination • Rack mountable	• Analog • Digital – 12 figures (6 per pair) BCD 1–2–4–8 positive logic TTL (available in parallel)	• Track plotter; recorder; left–right indicator; digital clock; data acquisition system and interface; printer • Lane identification device; UHF converter for differential mode operations • Remote coupler

Table B-2 (cont'd)

MEDIUM RANGE POSITIONING SYSTEMS (continued)

ELECTRICAL CHARACTERISTICS

SYSTEM	SHORE STATION/TRANSMITTER: SUPPLY LINE VOLTAGE AND FREQUENCY	SHORE STATION/TRANSMITTER: SUPPLY CURRENT	SHORE STATION/TRANSMITTER: MAXIMUM RF OUTPUT	SHORE STATION/TRANSMITTER: LOW POWER MODE	MOBILE STATION/RECEIVER: SUPPLY LINE VOLTAGE AND FREQUENCY	MOBILE STATION/RECEIVER: SUPPLY CURRENT	MOBILE STATION/RECEIVER: RECEIVER BANDWIDTH	SYSTEM WARM-UP PERIOD (NOTE 5)
ARGO	22 – 32 v DC or 115/230 v AC 50 – 60 HZ (option)	4.5 – 19 a DC 2 a AC	100 W PEP	10 mW for antenna tuning only	24 v DC or 115/230 v AC 50 – 60 HZ	6.5 – 24 a DC 2 a AC	80 HZ at 3 dB points	5 minutes
HI-FIX/6	22 – 32 v DC	19.5 a DC max 8 a DC continuous	90 W PEP Variable	30 W	22 – 32 v DC	Max 32.5 a DC 15a continuous	90 HZ at 3 dB points	2 – 4 min
HYDROTRAC	22 – 30 v DC or 115/230 v AC ± 10% 43 – 63 HZ	3 – 10 a DC 1/4 – 4 a AC	150 W PEP Variable	20 W	22 – 30 v DC or 115/230 v AC ± 10% 43 – 63 HZ	3 a DC max 1/4 a AC	100 HZ at 3 dB points	15 min
LORAC	115 v AC ± 10% 50 – 60 HZ ± 5%	7 – 21 a AC	300 W	30 W	115 v AC ± 10% 60 – 400 HZ ± 5%	2 a AC (w/options 20 a AC)	500 HZ at 6 dB points Reference Receiver 3 KHZ at 6 dB points	(NOTE 14) (85°C Crystal oven)
MAXIRAN	12 v DC	2 a DC	200 W PEP Minimum 20 KW max	3 W – 22 W	12 v DC or 110 v AC 50 – 400 HZ	2 a DC 2a AC (average)	5.7 MHZ at 6 dB points	None
OMI	24 v DC or 115 v AC ± 10%	2.3 – 10 a DC (depends on transmit power)	0 – 150 W PEP Variable (option 500 W)	None	12 v DC or 24 v DC	6 – 10a DC	1 KHZ at 3dB points	60 min for cesium clock initial installation; zero thereafter
RAYDIST	24 v DC (115 v AC converted to 24 v DC)	2.5 a DC	70 W PEP Mobile 40 W	15 W Variable Mobile 4–8 W	24 v DC (115 v AC converted to 24 v DC)	7 a DC	2.1 KHZ at 6 dB points	30 min
TORAN	28 v DC	Max 15 a DC	60 – 100 W Variable Max possible 300 W	60 W	22 – 30 v DC or 110/220 v AC 50 – 400 HZ	3 a DC	Self Adjusting with speed of mobile and to handle multi shore units	2 min

Table B-2 (cont'd)

MEDIUM RANGE POSITIONING SYSTEMS (continued)

SYSTEM	ENVIRONMENTAL CHARACTERISTICS: OPERATIONAL	ENVIRONMENTAL CHARACTERISTICS: STORAGE AND TRANSPORT	SHORE STATION: NUMBER UNITS (NOTE 6)	SHORE STATION: VOLUME (NOTE 7)	SHORE STATION: WEIGHT (NOTE 8)	SHORE STATION: ANTENNA	MOBILE STATION: NUMBER UNITS	MOBILE STATION: VOLUME	MOBILE STATION: WEIGHT	MOBILE STATION: ANTENNA
ARGO	• -20° to $+55^{\circ}$C • 95% R.H. • Immersion with cases to 4 ft (1.2m) • Splash proof without covers • Altitude 10,000 ft (3050 m)	• -40° to $+75^{\circ}$C • 95% R.H. • Air transportable altitude 50,000 ft (15,240 m)	2	6 ft^3 (.2 m^3)	60 lbs (28 kg)	100 ft (31 m) Tower (portable as option)	3	8 ft^3 (.2 m^3)	90 lbs (41 kg)	25 – 35 ft (7–11 m) Center load whip or collapsable whip
HI–FIX/6	• -30° to $+60^{\circ}$ C • 95% R.H. • Splash proof – Creeth – style cases	• -50° to $+85^{\circ}$ C • 95% R.H. • Air transportable with vents open	4	11 ft^3 (.3 m^3)	112 lbs (51 kg)	30–100 ft (10–31 m) Tower	3-range/range 1-hyperbolic	13 ft^3 (.4 m^3)	158 lbs (72 kg)	5 ft (1.5 m) Fiberglass whip
HYDROTRAC	• 0° to 50° C • 20 – 98% R.H. • Immersion in cases • Splash proof out of cases	• -55° to $+75^{\circ}$ C • 20 – 98% R.H. • Air Transportable	3	5 ft^3 (.2 m^3)	Master 41 lbs (18 kg) Slave 48 lbs (22 kg)	36 – 100 ft (11 – 31 m) Tower Uniform cross-section vertically polarized 32 ground plane radials	1 hyperbolic 3 range/range	2 ft^3 (.06 m^3) 6 ft^3 (.2 m^3) range/range	29 lbs (13 kg) 70 lbs (32 kg) range/range	5 ft (1.5 m) Fiberglass whip 36 ft (11 m) for range/range
LORAC	• 0° to 50° C • 95% R.H. • Waterproof limited duration	• 0° to $+50^{\circ}$ C • 95 % R.H.	6	33 ft^3 (.9 m^3)	≈ 600 lbs (280 kg)	100 ft (31 m), 150 ft (46 m), or 1/2 wavelength Tower	3 Digital 4 units	9 ft^3 (.3 m^3) Digital 15 ft^3 (.4 m^3)	125 lbs (57 kg) Digital 325 lbs (147 kg)	8 ft (2.4 m) whip
MAXIRAN	• -10° to $+50^{\circ}$C • 95% R.H. • Transponder immersible • Splash proof units	• -35° to $+70^{\circ}$C • Clock above -7°C • 95% R.H. • Air Transportable	2	1 ft^3 (.03m^3)	40 lbs (18 kg)	Omnidirectional with 45° beamwidth Max height 80 ft (25 m) & dual antennas High gain directional 48° horizontal & vertical beamwidth Horizontally polarized	3	4 ft^3 (.1 m^3)	110 lbs (50 kg)	Omnidirection with 45° vertical beam width Vertically polarized
OMI	• 0° – 50° C • 95% R.H. @ 40°C • Splash proof case	• -40° to $+75^{\circ}$C • 95% R.H. • Air transportable	3	4 ft^3 (.1 m^3)	80 lbs (36 kg)	100 ft (31 m) Tower (portable)	3	5 ft^3 (.2 m^3)	98 lbs (44 kg)	30 ft (9 m) Sectionalized whip
RAYDIST	• +5 to $+65^{\circ}$ C • 95% R.H. • Splash proof case • Altitude – max used 50,000 ft (15,240 m)	• 5° to 65° C • 95% R.H • Air transportable	1	1.2 ft^3 (.03 m^3)	29 lbs (13 kg)	100 ft (31 m) Tower 16 ground plane radials	4	3 ft^3 (.1 m^3)	66 lbs (30 kg)	35 ft (10 m) whip in 6 sections
TORAN	• Receiver 0° to $+50^{\circ}$C transmitter -30° to $+70^{\circ}$C • 95% R.H. • Transmitter immersible to depth of 6 ft (2 m) for 1 hour • Splash & corrosive fog tested	• -30 to $+70^{\circ}$ C • Air transportable • Waterproof	3	5 ft^3 (.2 m^3)	140 lbs (64 kg)	80 ft (24m) tower with 15 ft (4.5 m) whip on top 48 ground plane radials	1	1 ft^3 (.03 m^3)	44 lbs (20 kg)	13 ft or 23 ft (4 m or 7 m) fiberglass whip in 2 sections

Table B-2 (cont'd)

MEDIUM RANGE POSITIONING SYSTEMS (continued)

	PHYSICAL CHARACTERISTICS AIDS TO SYSTEM PORTABILITY			INTEGRATED LOGISTICS SUPPORT DOCUMENTATION SUPPLIED BY MANUFACTURER					
SYSTEM	HANDLES	TRANSIT CASE	SHORE COMPONENTS > 16 KG (NOTE 9)	OPERATORS MANUAL	MAINTENANCE MANUAL	TROUBLE-SHOOTING PROCEDURES	SCHEMATICS	PARTS LIST	RECOMMENDED SPARES LIST
ARGO	Yes	Yes	None	Existing	Under Preparation	Under Preparation	Existing	Existing	Existing
HI-FIX/6	Yes	Yes	2-Control Unit 52.5 lb (23.8 kg) & Power Amplifier 49.5 lb (22.5 kg)	Existing	Existing	Existing	Existing	Existing	Existing
HYDROTRAC	Yes	Yes	1-Power Supply 65 lbs (29.5 kg)	Under Preparation	Existing	Existing	Existing	Existing	Existing
LORAC	Yes	Rack mounted unitized construction	2-Control Receiver 70 lbs (32 kg) & Transmitter 450 lbs (204 kg)	Existing	Existing	Existing	Existing	Existing	Existing
MAXIRAN	Yes	Yes - 1 airline case for each mobile and for each 3 shore stations	1-Linear Amplifier 46 lbs (21 kg)	Existing	Existing	Existing	Existing	Existing	Existing
OMI	Yes	Yes as Option	1-Cesium Beam Clock 60 lbs (27 kg)	Under Preparation	Under Preparation	Under Preparation	Existing	Existing	Existing
RAYDIST	Yes	Yes	None	Existing	Existing	None	Not Available to User	Existing	User Option
TORAN	Yes	Yes - Marine Plywood	1-Transmitter 77 lbs (35 kg)	Existing	Existing	Existing	Existing	Existing	Existing

Table B-2 (cont'd)

MEDIUM RANGE POSITIONING SYSTEMS (continued)

INTEGRATED LOGISTICS SUPPORT

SYSTEM	TRAINING PROVIDED BY MANUFACTURER	REPAIR PHILOSOPHY	FIELD CHECKS AND MAINTENANCE	FAULT ISOLATION TECHNIQUES (NOTE 10)	
				INTERNAL EXCITATION	EXTERNAL EXCITATION
ARGO	2 weeks at manufacturer (4 technicians) 1 week on site	• Circuit board exchange • Some interchangeable components	Self tests and housekeeping	Yes	Optional software
HI–FIX/6	Negotiable at manufacturer or on site	• Circuit board and subassembly exchange • 12 basic interchangeable cards • Diagnostic card for troubleshooting	Operator tests and housekeeping	Yes	Yes
HYDROTRAC	2 Weeks at manufacturer (informal)	• Circuit board exchange for minimum down time • Off–Shelf components to facilitate user technician *repairs*	Operator Tests Cleaning and check of plugs/connectors and air filter	Yes	
LORAC	Negotiable with user	• Circuit Board exchange • Operational functions on same board • MFR recommends 2 shore transmitters/station (1 as spare)	Operator Tests	Yes through computer	
MAXIRAN	On job training at assembly plant (informal)	• Circuit board exchange • Some interchangeable parts	None except operator checks	No	No
OMI	Yes	• Circuit board and module exchange • Some interchangeable modules • Duplicity of some components	Operator checks and cleaning	Yes	
RAYDIST	1 Week at manufacturer (2 technicians)	• Module and subassembly replacement • Defective unit repaired only by manufacturer • Potted units	None	No	Yes
TORAN	2 Weeks on site	• Solid state circuit board and component replacement (w/ troubleshooting flow charts)	Operator tests		Yes

MEDIUM RANGE POSITIONING SYSTEMS (continued)

INTEGRATED LOGISTICS SUPPORT

SYSTEM TEST, CALIBRATION AND PERFORMANCE MONITORING

SYSTEM	BUILT–IN TESTS	TEST POINTS/ JACKS	SPECIAL TEST EQUIPMENT AVAILABLE ONLY FROM MFR	FIELD ADJUSTMENTS	SYSTEM INITIALIZATION	SYSTEM OPERATIONAL MONITORING	ALARMS
ARGO	• System is self testing in operation • GO/NO GO; phase shifter synthesizer; display; RF closed loop; receiver; and transmitter tests (optional)	Yes	No	• Antenna tune only (remotely controlled)	• Remote antenna tuning • Calibration and smoothing factors set • Master signal acquisition (automatic)	• Monitor meters • Display test • 4 channel display • Alarms • Manual lane ident if error $\leq \pm 5$ lanes • Position update rate – 2 sec • Continuous self test	• Lane loss $\leq$ 5 lanes upon command • Antenna detune • Improper operation by operator • Over voltage/under voltage • Weak signal • Noisy signal
HI–FIX/6	• B.I.T.E. of both mobile and shore stations • Diagnostic boards • Simulator boards (Dummy phase memory, RF, & synthesizer)	Yes – test points on all cards	No		• Variable power output • Internal timer adjustment w/ initial trigger • Single button to lock signal • Receiver/transmitter parameters set	• Monitor meters (RF input; FWD & REF RF; Driver mA; battery check; power amplifier current) • 3 channel display • Alarms • Changeable receiver/transmitter parameters • Position update rate – 5/sec	• Parameters outside of limits set (audio and visual) • Timing synch discrepancy; trigger; reverse RF power level; low battery voltage; phase synthesizer error
HYDROTRAC	• Slave simulate	Yes – RF output, RF input trigger	No	• Slave simulate • RF input & output tests • Slave trigger output tests	• Cycle length set • Frequency adjustment • Power output adjustment • Max speed of vessel set • Propagation correction set	• Monitor meters (AGC; RF input & output; FWD & REF RF; voltages; status of locking oscillator; battery charge rate) • Alarms (audio & visual) • 2 channel display (updated 1 to 12/sec)	• Received signal; improper operation by operator; overheating; lane loss; skywave presence • Shore station malfunction
LORAC	• Signal simulate	YES – AGC	Yes – SWR indicator dummy load	• "Universal" calibration by MFR	• NET ON/OFF remotely (option) • Base station monitoring (option) • Fine, medium, coarse lane identification (lane ident signal transmitted each second during lane ident period) • Antenna tune	• Monitor meters • Alarms • Processed CRT display	• Shore station malfunction (transmitted) past & present • Digital system: system parameters outside of set limits
MAXIRAN	• System test and system calibrate	Yes – for oscilloscope	No		• Pulse code selection • Station selection • Processed signal initially displayed on oscilloscope for acquisition on scale	• Monitor meters (signal strengths; battery voltage; AGC/MGC; current) • 3 channel display • Data entries (time; line; date; and shot stations selection • Automatic or manual tracking	• System operation
OMI	• Internal calibration • Internally generated frequency verified by display	Yes	No	• Cesium clock – (No C Field Adjustment: employs Δf compensator)	• Manual lane set	• Monitor meters • 2 Channel display	• Invalid data lamps
RAYDIST	None	Yes	Yes – system simulator; frequency monitor (receiver); RF test oscillator; dummy load; wattmeter	• Antenna tune • System simulate (with special equipment) • Oscillator adjustment • Power output adjustment • Frequency adjustment	• High power/low power set • Manual lane set	• Monitor meters (AGC & PMA; power output) • 2 channel display	None
TORAN	• Test control to check calibration of fractional lane counters and proper operation of signal processing section of receiver	Yes	No	• Net calibration • Phase adjustment for pattern calibration	• Mode of operation selection • Chain switching • Initial lane count set	• Monitor meters • Alarms • 2 channel display	• Shore station main power loss (transmitted) • Data distortion – past and present possibly unnoticed

Table B-2 (cont'd)

MEDIUM RANGE POSITIONING SYSTEMS (continued)

SYSTEM	INTEGRATED LOGISTICS SUPPORT	MISCELLANEOUS			
	FAILURE MODE PROTECTION	WARRANTY (NOTE 11)	APPROXIMATE COST (NOTE 12)	USERS (NOTE 13)	NOTES
ARGO	• DC & AC circuit breakers • Transmitter open shore circuit protection • Over & reverse voltage and lightning • Alarm	1 year After date sent from factory	$140 K	U.K., U.S.	NOTE 15
HI–FIX/6	• Alarms • DC & AC fuses	6 months after installation	$80K	Australia, Canada, Finland, Germany, New Zealand, Norway, Poland, Sweden, U.K., U.S., U.S.S.R.	NOTE 16
HYDROTRAC	• Reverse polarity • Antenna mismatch • DC & AC fuses • Alarms • Automatic power shift to batteries if AC lost (transmitter will reduce power to save batteries)	1 year	$80 K (3 shore)	U.K., U.S.	NOTE 17
LORAC	• High voltage interlocks • Overload relays • fuses • Automatic (optional) transmitter shift if one fails • Alarm	90 days	$185 K (3 base & reference shore Base stations (4) ($150 K total) Standard Receiver – $20 Digital Receiving System – $35K	U.K., U.S.	NOTE 18
MAXIRAN	• Reverse and over voltage • Short protection	6 months	$76 K (3 shore)	U.S.	NOTE 19
OMI	• DC fuses • Open & short circuit • Reverse voltage	1 year	$150 K Mobile – $35K 3 Cesium Clocks – $20K (ea) 2 Shore Station – $27.5K (ea)	New System (entering introductory phase)	NOTE 20
RAYDIST	• DC fuses • Antenna mismatch and lightning (automatic shut down) • Automatic shift to batteries if AC Power lost • Reverse & over voltage	3 years for modules 6 months for remainder of components	$80 K (3 shore: RAYDIST 78) $60 K (2 shore: DRS–H)	Denmark, U.K., U.S.	NOTE 21
TORAN	• Alarm • Reverse voltage • Accidental grounding or breakage of antenna	6 months parts & labor no charge	$56 K – P10 chain $73 K – P100 chain	Denmark, France, Iceland, U.K.	

APPENDIX C

RADIO RANGING EQUIPMENT DESCRIPTIONS

APPENDIX C

RADIO RANGING EQUIPMENT DESCRIPTIONS

PASSIVE RANGING SYSTEMS

The Litton AN/PSN-6 Manpack is a Loran C/D system which is rugged, portable and field tested. The chief constraints are cost and accuracy and the lack of digital data recording facilities.

Litton System quotes cost at $35,000 per unit in quantities of 100. The very high cost derives from three factors: (1) expensive internal computer system to convert RF time delay readings to UMT grid coordinates for direct reading; (2) military specifications for impact, drop, environment resistance; (3) miniaturization of whole unit into 4" x 5" x 9", 8½-pound unit.

Accuracy is 100 meters for position prediction, allegedly 10-20 meter repeatable accuracy. Field testing indicates 47-meter CEP (Circular Error Probability, one standard deviation).

The ITT's model WN 2-876 is an automatic relatively low-cost unit with typical Loran C/D accuracy (±500 feet) for airborne navigation. It is not configured or ruggedized for ground use.

Sperry's AN/ARN-85 Loran C/D receiver is similarly a navigation system which receives Loran signals, and, in conjunction with a computer and vehicle information (speed, heading, etc.), can display past track and present position on a chart (display unit ID-1316/ARN-85). The overall system cost is appreciable, and accuracy is that common with Loran -- ±0.1 mile.

From both a cost, but primarily an accuracy standpoint, no commercially available Loran system is appropriate to ARI vehicle location objectives. However, for future use, the concept should not be discarded because of the advantages of passivity (any number of targets can be used simultaneously), range, all weather availability, and possible attainable accuracy. As reported by Aerospace*, accuracies of an RF time of arrival system can be improved considerably, and probably to within required limits by techniques such as time sequenced pulse modulation and construction of relatively small area RF phase grid pre-mapping so as to approach reported "repeatable" vice position prediction limits. These are still R&D efforts with costs not known, but undoubtedly appreciable. Costs of associated hardware and software for computerized conversion/display will also be appreciable. Such a passive system for ground vehicle location within 25 meters in all probability could be developed in 2-3 years, well before the global satelite navigational system (circular accuracy 10 meters) envisaged for circa 1985 or beyond, but R&D and probably acquisition costs would be considerable.

The Kaman system as prototype tested** is designed for remote control of an M47 tank rather than for position location. Because it is not in production, costs are undetermined. Three fixed

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* Automatic Vehicle Location Systems for Law Enforcement Applications. Volume I: Executive Summary. Aerospace Corporation, ATR-76 (7914-01)-1, Vol. I (1976).

** Pulsipher, J.A., A Study Directed Toward Applying Navigational Grid System Information to Remote Control Target Vehicles. TARADCOM R&D Laboratory Techinal Report No. 12298.

location transmitters are alternately pulse modulated for specified time intervals and operate on the same frequency with constant phase relation. The resulting RF phase grid system is highly discriminatory and achieves high position location accuracy (estimated 10 meters). Redesign and development of the receiver and display hardware for position location rather than vehicle remote control is essentially a matter of applied engineering as the technology is commercially widespread.

ACTIVE RANGING SYSTEMS

Active ranging systems require a response from the remote station or target. The response unit is a transponder that retransmits a signal from a master unit. Due to price considerations and current availability, only two systems appear suitable for ARI's position determination requirements.

Although the two systems are slightly different techniques, they have similar specifications and costs. However, the Motorola system package includes precoded computer software for processing the data -- a potentially significant advantage. Some of the specifications common to both systems are summarized in Table C-1.

Multitracker System

The Multitracker system, manufactured by Del Norte Technology Corporation, is one of the relatively moderate-priced X

Table C-1

SPECIFICATIONS COMMON TO DEL NORTE AND MOTOROLA SYSTEMS*

- Track 30 targets
- Track moving targets at any land speed
- Limited to electronic line of sight
- Range is greater than 30 km.
- Accuracy is about 3 meters
- Rapid data collection
- Battery powered remote stations (targets)
- Penetrate light foliage
- Small size for remote stations
- Real-time display monitor
- Digital data recording
- Capable of unattended operation
- GSA Availability
- Commercially used in land vehicles for several years

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* The specifications listed are those likely to be of paramount interest to ARI's position determination data requirements.

Band pulsed radar ranging systems. It has found wide use for several years in marine and land environments. The "Multi-tracker" is a Del Norte expansion of the time-proven trisponder system, which provides real-time continuous tracking of up to eight targets. The system is expandable up to 30 targets with added tracking stations at added cost.

There are basically two signal generators, one up to 5-mile range, one to 50 miles. Costs are similar, but the longer-range system provides more power and penetration of light covers, e.g., leaves, at an inconsequential sacrifice of accuracy, and is thus preferable.

Like other short-range high-frequency systems, Multitracker is limited by electronic line-of-sight, i.e., the tracking station (signal generator) must be able to electronically "see" the target transponder antenna. Resolution is advertised at 0.5 meters; test results show accuracy in the 2-3 meter range. The units are battery powered, field maintainable, rugged, portable and essentially interference immune.

Multitracker uses advanced microwave and digital technologies to measure line-of-sight distance from a master to two or more targets. Ranges are obtained in milliseconds, thus providing an accurate track of targets. Since the transponder operates in the X band, LF propagation problems are eliminated and no readjustment is needed after temporary power or signal loss. Ranging is feasible on targets moving at MACH 1.

Display is of the variable intensity numertron type. Warm-up time is about 15 minutes above 15^{o}C. The transponders are horizontally polarized. Tracking station has vertical beamwidth 5^{o}, mobile transponder 20^{o} Operators and maintenance manuals, troubleshooting procedures, schematics, parts and spares list are all existing. The manufacturer provides 2-3 day training course. Warranty is 1 year parts and labor. System is in use worldwide*.

System Operation

Accurate line-of-sight distance information from a master station to one or more stations is obtained by measuring the roundtrip time of radar signals transmitted between the two stations. Each distance displayed is an average of 10 to 100 measurements selected by digital filtering, which reduced statistical error and increases system accuracy and stability. Each measurement requires only about 1 ms, and the indicated average is updated once per second. Signals to and from each station are coded, and thus provide a means of station selection and outside rejection.

One master unit transmits the identifications code, for the target to be ranged, to the satellite master(s). The master units then transmit a train of pulses, preceded by the digital identification code, and only that target, retransmits the pulse train. The master units then determine the target's relative

* Munson, RA R.C. Positioning Systems, Report on the Work of WG4146. Presented at the XV International Congress of Surveyors, Stockholm, Sweeden, June, 1977.

range as a function of the travel time of the pulse train. The resulting data can be transmitted to the supervising master unit. The target's position can be determined by trilateration*, Figure C-1.

A Standard Trisponder System Consists Of:

1. A distance measuring unit
2. A master transmitter/receiver and omniantenna
3. Target remote transmitter/receiver and directional antennas
4. Multi-channel distance measuring unit to handle eight targets
5. Power and inter-connecting cables
6. Instruction and maintenance manuals

Distance Measuring Unit

The DMU controls all Multitracker functions and contains all operational controls and data readouts. The DMU provides signals to the Master Station for transmission to targets. Signals from targets are in turn received by the Master and returned to the DMU to determine distance. Accessory equipment such as printers can be connected.

Master Station

The Master interrogates target units upon command from

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* Multitracker, Del Norte Technology, Inc. (unpublished).

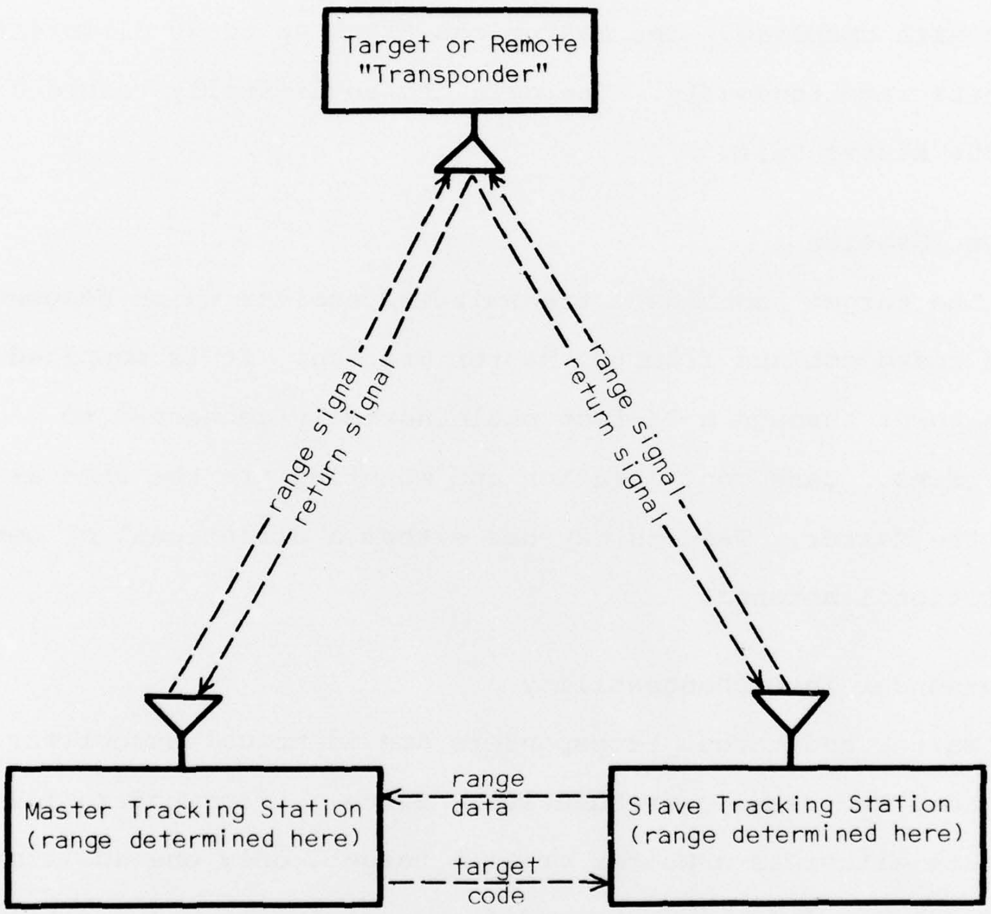

Figure C-1. Del Norte "Multitracker" Operation

the DMU. It is supplied with power and control through a 50-foot cable connected to the DMU. Master normally uses an omni-directional antenna. The entire device can be mounted on an American or European surveyor's tripod or on a length of 1-inch pipe with coupling. The Master can track up to 30 different targets simultaneously. The data can be digitally recorded at the Master Unit.

Target Station

The target contains a transmitter/receiver which responds to a coded command from the Master Station. It is supplied with power through a 25-foot cable normally connected to batteries. Case configuration and mounting are the same as for the Master. Targets may use either a directional or omni-directional antenna.

Transponder Interchangeability

Master and target transponders are identical except for transmit and receive frequencies. Since a transponder will operate either as a Master or as a target, only one additional station, a Master, is required for complete transponder backup.

Power Requirements

Power normally is obtained from two automotive batteries connected to provide 24 vdc. Supply voltage may vary over a range of 23 to 32 vdc., but must have a 4-ampere capacity to supply the peak current required during pulse transmission.

The standard power and signal cables may be coiled or shortened for a neater installation. Longer cables are available from the factory when required.

Maintenance

Design is such that performance can be checked in the field. If trouble is encountered, the unit or module at fault can be isolated quickly and replaced from recommended spare parts. All major units and component assemblies can be replaced in the field without the need to return the system to the factory for recalibration and adjustment. The DMU is waterproof and is splashproof with cover removed.

Accessories

Digital Printer: Provides permanent record with indentification and time.

Autoplot: Provides real-time conversion, and plotting of Range data in true x-y coordinates.

Techincal Specifications

System Capability:

Range:	50 miles (80 km.) electronic line-of-sight
Accuracy:	$\pm$10 feet ($\pm$3 meters)
Resolution:	1 foot, 1 meter, or 1 yard

Distance Measuring Unit:

Display:	up to 8 ranges simultaneously with multi-channel DMD
Units:	Feet, 6 digits; meters or yards, 5 digits
Output:	BCD 1-2-4-8mm TTL compatible
Voltage:	23 to 32 vdc
Current:	1.7 ampere
Size:	16 x 12 x 8½ in. (40 x 30 x 20 cm.)
Weight:	25 pounds (11 kg.)
Temperature:	$\pm 32^{\circ}F$ to $115^{\circ}F$ ($0^{\circ}C$ to $+67^{\circ}C$)
Housing:	Rugged, waterproof, aluminum case; unit floats with cover closed and is splashproof when open and operating

Master and Target Transponders:

Frequency:	Microwave
Mounting:	U.S. or European surveyor's tripod, or 1-inch NPT pipe
Voltage:	23 to 32 vdc
Current:	0.4 ampere standby, 0.7 ampere transmit
Size:	14 x 6 x 10½ in. (36 x 16 x 27 cm.)
Weight:	15 pounds (7 kg.)
Temperature:	$-22^{\circ}F$ to $+158^{\circ}F$ ($-30^{\circ}C$ to $+70^{\circ}C$)
Packaging:	Waterproof housing; unit floats
Antennas:	(Master) $360^{\circ} \times 30^{\circ}$
	(Target) $87^{\circ} \times 5^{\circ}$

Costs

NOAA estimated the cost of the Trisponder system in 1974 at basic $27,000 with multichannel UDM; i.e., two targets. Current information from the manufacturer is that commercial prices are of the order indicated (items indentified by a # are in GSA Catalog at slightly less cost).

Master tracking station (observation point)# 2 @ $15,000 each

Target (vehicle) transponders # $6,000 each

Control Display Unit (for direct reading) $9,300

Multi-channel VDM, Estimated $7,000

For eight targets, system cost should be $118,300.

<u>Miniranger III</u>

The Motorola Miniranger is similar to the Multitracker except that one unit provides a choice of C or X band (C band suffers less transmission loss, particularly in rain).

The Miniranger uses precision radar pulse measurement ranging, up to 30 targets with time sharing. The multi-target system uses coded pulses to identify targets. Whereas the Multitracker's target stations determine their own LOP's (Figure C-1), the Miniranger's master tracking station determines its distance and the distance for its slave station to a target, given a known distance between the two stations (Figure C-2). Range is 37 km., with accuracy ±3 meters, in

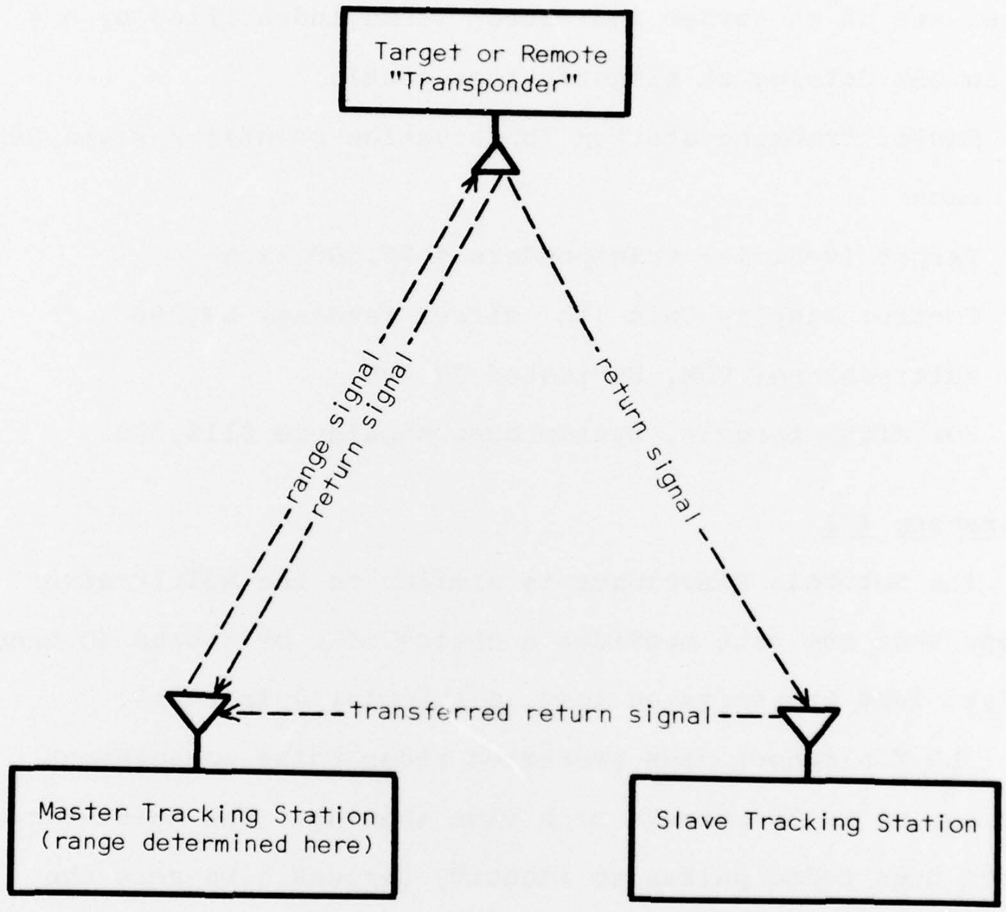

Figure C-2. Motorola "Miniranger III" Operation

the 5.47-5.6 GHz or 9.3-9.5 GHz range for target speeds up to MACH 1 plus. Display is LED and is rack mountable. Tracking station supply voltage needed is 24-30 vdc., 0.5 ampere maximum RF output 400w. Target supply current is 1.0 amp AC, with 115v/ 230 Vac or 3.0 amp DC, with 24-30 vdc. Warm-up time is 15 minutes. Display $0^{o}C$ to $50^{o}C$; tracking station transponder $-54^{o}C$ to $71^{o}C$; target transponder $-40^{o}C$ to $60^{o}C$. Transponders are sealed, splashproof and light (5 pounds). Tracking station units weigh 37 pounds. System units are backpack portable. Operators, maintenance manuals, schematics, troubleshooting routines, parts and spares list are all existing. Motorola offers operator and maintenance training.

Maintenance is relatively straightforward, with separate functions on modular circuit boards and circuit board exchange from established repair kit. There is a built-in test evaluation unit, with 3-month check measurement readings desirable. Warranty is 1 year parts and labor and shipping.

The system has been in use for several years, worldwide. There are at least 100 options available to the basic system, and Motorola can tailor the system to user's needs. This system can track up to 30 remote stations and will shortly be modified to track 48 remote stations.

The Miniranger III system has been in use, mounted on Army tanks, at Ft. Knox for two years. Experience has shown the system to be quite reliable. Two to three meter accuracy of location is attained. Multipath transmission errors were reduced using three repeaters (slave/Master units) and selecting those readings within a tolerance limit. Line-of-sight and foliage constraints appear to be similar to commercial television transmission.

Costs

NOAA* estimates 1974 cost of basic system at $27,000 for system with one target. August, 1977, information from Motorola indicates the basic system cost is $36,000 with $5,100 additional for each target over 1 up to 30. A $2,200 modification, 16-unit code/decode modification unit is necessary, plus $950 for each target over 4. The cost for a basic system with 12 targets, for example, would be:

$ 37,000	- basic
2,150	- printer time and loop range
15,300	- target units 2, 3 and 4
2,200	- modification for multiple targets
45,900	- target units 5 to 12
$102,550	

Computer analyses and other options would be additional. Software basically is included in any such computer costs, but software modification might be extra. A digital data recording tape costs $2,200 extra.

Delivery time is 30 days. Basic system units are in the GSA Catalog.

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* Munson, RA R.C. Positioning Systems, Report on the Work of WG4146. Presented at the XV International Congress of Surveyors, Stockholm, Sweeden, June 1977.

APPENDIX D

EXPANSION OF EVALUATIVE SCHEMA

APPENDIX D

EXPANSION OF EVALUATIVE SCHEMA

A general schema (Table D-1) for selection of position locating methods and techniques is presented. The ten variables can provide a basis for influencing method selection. Each of the variables is discussed earlier in this document in the section entitled "Schema for Method Selection."

Table D-1 is presented as a fold out. It is suggested that the table be unfolded prior to reviewing the document. In this manner, the evaluation tables can be studied without extensive page searching.

TABLE D-1

EXPANSION OF EVALUATIVE SCHEMA

Costs

Purchase price for basic system

1. $0.00
2. $1,000.00
3. $5,000.00
4. $20,000.00
5. $50,000.00
6. $100,000.00
7. over $100,000.00

Additional costs for receiver/ transmitter units

8. $0.00
9. $1,000.00
10. $5,000.00
11. $20,000.00
12. $100,000.00
13. over $100,000.00

Portability

1. Hand carried
2. Vehicle carried
3. Stationary system

Terrain Applicability

1. Line-of-sight limitation
2. Suitable for rolling terrain
3. Suitable for any terrain

Availability/Delivery

1. Commercially available
2. Available within 12 months
3. Available within 24 months
4. Prototype undergoing development

Position/Accuracy

1. 0 to 10 meters
2. 10 to 25 meters
3. 25 to 50 meters
4. 50 to 100 meters
5. 100 meters and above

Invasive Constraints

1. Requires visual line-of-sight
2. Requires electronic line-of-sight
3. Requires no contraints
4. Interference sensitive
5. Spectrum conflicts

System Usability

1. Requires highly trained staff
2. Minimal staff training
3. Long observation times
4. Short observation times
5. Capable of gap-free data
6. Gaps in data
7. Manpower intensive operation
8. Manpower independent operation

Reliability/Maintainability

1. High system reliability
2. Low system reliability
3. High observer reliability
4. Low observer reliability
5. Requires specialists for set up and maintenance
6. Parts available
7. Parts not available
8. Relatively maintenance free
9. Costly to maintain
10. Inexpensive to maintain
11. Rugged
12. Delicate
13. Rapidly repairable
14. Protracted repair time

Data Accessability

1. Provides behavioral data
2. Provides behavioral and position data
3. Provides position data only
4. Digital data recording

Operating Conditions

1. Daytime operation only
2. 24 hour operation
3. Weather dependent
4. Master station required only
5. Remote stations required
6. Battery powered
7. Line power required