APPLICATION OF MENSURATION TECHNOLOGY TO IMPROVE THE ACCURACY OF FIELD ARTILLERY FIRING UNIT LOCATION

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

APPLICATION OF MENSURATE TECHNOLOGY TO IMPROVE THE ACCURACY OF FIELD ARTILLERY FIRING UNIT LOCATION, by Matthew J. Day, 67 pages.

Target coordinate mensuration technology has improved the accuracy of the target location requirement of the five requirements for accurate predicted fire. The use of mensuration technology to improve the firing unit location requirement provides a degree of accuracy that can potentially refine firing unit occupation procedures. Restructuring of the field artillery military occupational specialties and associated equipment leaves a capability gap in firing unit location procedures that can be resolved by mensuration technology. Certification of Target Mensuration Only operators can be achieved at officer and non-commissioned officer professional development at Fort Sill, Oklahoma. The benefit of mass certification of field artillery leadership warrants the cost of training.

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ACRONYMS

CEP	Circular Error Probability
DAGR	Defense Advanced GPS Receiver
DFCS	Digital Fire Control System
DPPDB	Digital Precise Point Database
FDC	Fire Direction Center
FM	Field Manual
GLPS	Gun Laying and Positioning System
GPS	Global Positioning System
INU	Internal Navigation Unit
IPADS	Improved Position and Azimuth Direction System
NGA	National Geospatial-Intelligence Agency
SOP	Standard Operating Procedure
TLE	Target Location Error
TMO	Target Mensuration Only
TTP	Techniques, Tactics and Procedures

CHAPTER 1

INTRODUCTION

Overview

Efforts to improve the lethality of the field artillery is important in the fires community and spans many aspects of the delivery of fires. Advancements in technology that allow for greater accuracy in the refinement of geospatial positioning have made significant enhancements in the application of indirect fires. The ability of the field artillery to deliver accurate lethal fires has been critical to the success of the United States (U.S.) Army's history of land based warfare. One of these advancements has been the development and use of mensuration. Mensuration is a process used to refine and decrease the amount of error associated with a location. Mensuration capability has primarily been used in processes to refine grid coordinates that have been nominated as targets.

Accurately designating a target location is only one of five requirements for predicted fires. Firing unit location, weapon and ammunition characteristics, meteorological data, and computational procedures make up the remaining four requirements. Effectively accounting for these five requirements can allow a field artillery unit to achieve desired effects on target without significant round impact location error. This thesis explores the feasibility of the use of mensuration technology to further refine the requirements for predicted fire by increasing the accuracy of firing unit location.

Target coordinate mensuration is a process that uses a variety of sophisticated techniques to determine an extremely precise location on the earth's surface. The tools that allow this technology are ever changing and tailored to the output and specific capability required by the user. Capabilities of mensuration software are tiered by levels of classification and the requirements of accuracy for the supported activity. The specialized nature and the magnitude of the importance of quality trained mensuration operators demand a regulated certification process. Experts in this field of study have a full working knowledge of geodesy and the theory that allows mensuration to surpass the level of accuracy achieved by Global Positioning Systems (GPS).

The technology that allows the accuracy of target mensuration may expand to include refinements in target location requirement for accurate predicted fire. This capability should be explored to weigh the feasibility of use for the remaining requirements that have surface location input requirements, specifically firing unit location. Light towed field artillery units use GPS technology in conjunction with specialized survey equipment to determine firing unit location. The use of mensuration technology to further refine the firing unit location has the potential to improve on the accuracy provided by the GPS that is currently used. Aside from the accuracy improvements that can potentially improve firing unit location, the application of this technology may allow savings of funds and resources by replacing old technology and methods.

The importance of mensuration capability encompasses more than just the ability to provide a more accurate target location; it also allows a lower probability of collateral damage to unintended targets. The application of mensuration technology for the firing unit can potentially add a degree of safety that is not commonly considered. Commanders base decisions on the engagement of target sets by risk communicated by target location error, collateral damage estimate and circular error. Friendly troops, personnel, and infrastructure pose a collateral damage risk based on their location in respect to that of the target. Further refinement of the five requirements for accurate predicted fires will allow less probability for unwanted collateral and battlefield damage.

Primary Research Question

Is the application of mensuration technology a feasible method to provide improved location accuracy capabilities to light towed artillery firing unit occupation procedures?

Secondary Research Questions

Can technological advances in geospatial locating systems supplement the five requirements of predicted fires to provide an additional degree of accuracy when computing a ballistic firing solution?

Will the refinements in firing unit location affect additional numerical outputs used for calculations that are relevant to safety variables used for collateral damage mitigation?

Will the benefit of a mensurated firing unit location warrant the cost of dedicating assets to conduct the analysis?

Assumptions

This research will use techniques, tactics, and procedures developed for the M119A2 light towed howitzer firing platoon. Environmental considerations considered during the research process focused on firebase operations with static, fortified howitzer locations. Discussion of recommendations for additional areas of research to expand upon the scope project is in chapter 5.

Definitions

Certification: "A comprehensive evaluation of both an individual and a process that established compliance with a set of standards."[1]

Collateral Damage: "Unintentional or incidental injury or damage to persons or objects that would not be lawful military targets in the circumstances ruling at the time."[2]

Common Grid (Survey): "Accomplishment of the battalion survey mission provides a common grid for firing units and target-locating systems within prescribed accuracies. A common grid allows the cannon battalion to do the procedures below."[3]

Deflection: "1) The setting on the scale of a weapon sight to place the line of fire in the desired direction. (2) The horizontal clockwise angle between the axis of the tube and the line of sight."[4]

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[1]Chairman of the Joint Chiefs of Staff (CJCS), CJCS Instruction (CJCSI) 3505.01B, *Target Coordinate Mensuration Certification and Program Accreditation*, 10 January 2013, http://www.dtic.mil/cjcs_directives/cdata/unlimit/3505_01.pdf (accessed 6 July 2013), GL-2.

[2]Department of Defense, Joint Publication 3-60, *Joint Targeting* (Washington, DC: Government Printing Office, 2013), D-5.

[3]Headquarters, Department of the Army (HQDA), Field Manual (FM) 6-2, *Artillery Survey* (Washington, DC: Government Printing Office, 12 August 1965), 14-1.

[4]Headquarters, Department of the Army (HQDA), Field Manual (FM) 6-40, *Field Artillery Manual Cannon Gunnery* (Washington, DC: Government Printing Office, 1996), G4.

Digital Point Positioning Database Imagery (DPPDB): "A stereo image based product developed and introduced in the 1990s used for precise coordinate derivation to support the targeting and mission planning requirements."[5]

Fire For Effect: "1) A command to indicate that fire for effect is desired. (2) Fire that is intended to achieve the desired result on target."[6]

Geodesy: "that branch of applied mathematics which determines by observation and measurement the exact positions of points and the figures and areas of large portions of the earth's surface, the shape and size of the earth, and the variations of terrestrial gravity."[7]

Range: "1) The distance between any given point and an object or target. (2) The extent or distance limiting the operation of the gun."[8]

Standard Conditions: "Firing tables are based on actual firings of a piece and its ammunition correlated to a set of standard conditions. Actual firing conditions, however, will never equate to standard conditions."[9]

Target Coordinate Mensuration: "The process of measurement of a feature or location on Earth to determine an absolute latitude, longitude, and height. For targeting

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[5]U.S. Army Chief Warrant Officer Field Artillery School, "Precision Targeting Class" (Field Artillery Targeting Technician School Curriculum, Ft. Sill, OK, DVD from Center for Army Lessons Learned, Ft. Leavenworth, KS, 25 May 2013), 38.

[6]HQDA, FM 6-40, G5.

[7]The Defense Mapping Agency, Technical Report 80-003, *Geodesy for the Layman,* National Geospatial Intelligence Agency, http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003A.HTM (accessed 12 July 2013), 3.

[8]HQDA, FM 6-40, G10.

[9]Ibid., 3-17.

applications, the errors inherent in both the source for measurement and the measurement processes must be understood and reported. Mensuration tools can employ a variety of techniques to derive coordinates. These may include, but are not limited to, direct read from DPPDB stereo-pairs in stereo or dual mono mode, multi-image geo-positioning or indirect imagery correlation to DPPDB."[10]

Target Location Error (TLE): "TLE is the difference between the coordinates generated for a target and the actual location of that target. This is a sensor intrinsic error with sources likely from: survey, human error, atmospherics, terrain and training. TLE is expressed primarily in terms of circular and vertical errors, or infrequently, as spherical error."[11]

Limitations

Due to the limitations of time and an effort to maintain an unclassified research project, no classified sources were used during the conduct of research for this project. The span of unclassified sources available provides ample data to research and answer the primary research question.

The existing reference material concerning target mensuration and the technology that makes it possible is generally not found at an institution such as a library. Technical manuals, Standard Operating Procedures (SOPs), and training curriculums are examples of sources for the majority of this research. Institutions such as the Center for Army

[10]CJCS, CJCSI 3505.01B, GL-1.

[11]Department of Defense, Air Land Sea Application Center, Field Manual 3-09.32, *JFIRE Multi-Service Tactics, Techniques, and Procedures for the Joint Application of Firepower* (Washington, DC: Government Printing Office, 2007), 11.

Lessons Learned, The National Geospatial-Intelligence Agency and the Fires Center of Excellence contributed a significant amount of information and raw data.

Conclusion

This research explored the feasibility and the cost benefit of applying coordinate target mensuration to firing unit location to further refine the five requirements for accurate predicted fire. The systems used to compute a ballistic firing solution for field artillery systems were analyzed for compatibility with systems that provide mensurated locations. The existing studies, capabilities and standard operation procedures were reviewed and extrapolated for relevance in the literature review. The methodology review included the methods that this study used to analyze the collected data and the justification for use. Chapter 4 discusses the findings produced from this study and chapter 5 provides recommendations and conclusions.

CHAPTER 2

LITERATURE REVIEW

Introduction

The content of this chapter is organized by specific efforts within the fires community. The sources during this research were reviewed and studied in terms of firing unit mensuration applicability. The sections of this chapter include: U.S. Army field artillery operations, geodesy, mensuration, equipment technical manuals, and other sources. A variety of source types presented a challenge to differentiate between doctrine, Techniques, Tactics and Procedures (TTP) and individual assessments. Given the technical nature of this research, curriculums from training institutions and technical manuals were extensively reviewed to collect pertinent information.

U.S. Army Field Artillery Operations

Artillery specific Army publications used for this research included: Field Manuals (FM), Army Techniques, Tactics, and Procedures, Army Training and Evaluation Programs, Army Doctrine Publications, and Army Doctrine Reference Publications. The U.S. Army FMs reviewed were all field artillery and fires specific. The doctrine and TTPs published in each manual discussed the different aspects of field artillery operations. The core of the field artillery FMs have been updated throughout the last 10 years to stay current with Army doctrine progression. The most recent and the older versions of FMs were reviewed to understand the evolution and transformation of doctrine and TTPs.

FM 3-09.8, *Field Artillery Gunnery* provides the standards, principles and techniques for field artillery gunnery. It states its purpose as "a design standardizing gunnery training for the FA [field artillery] force in the midst of changes brought on by the contemporary operational environment." It focuses on the training and safety aspects for all field artillery organizations. This FM provides the framework for artillery gunnery programs and certifications, but does not replace FM 6-40, *Field Artillery Manual Cannon Gunnery* or FM 6-50, *Tactics, Techniques and Procedures for Field Artillery Manual Cannon Gunnery*. These FMs describe the theory behind field artillery gunnery, specific TTPs, and step action drills for use in training and combat situations. These three manuals emphasize the importance of the five requirements for accurate predicted fire and direct methods to ensure their achievement.

Other FMs reviewed during this research were specific to particular aspects of field artillery operations. FM 6-2, *Tactics, Techniques, and Procedures for Field Artillery Survey* provides the doctrinal framework as well as TTPs for field artillery survey operations. Though the concepts presented in this manual are still applicable, changes to the survey equipment that emplaces cannon field artillery units will soon render this publication obsolete. Chapter 4 discusses in depth the implication of the loss of the Position and Azimuth Determining System (IPADS).

Fire Support FMs focused on the doctrine and TTPs to provide an accurate target location, battlefield geometries and command relationships. FM 3-09, *Fire Support* is the Army's capstone fire support document and describes its purpose "to provide keystone fire support doctrine for United States (U.S.) Army forces. It provides guidance for planning, preparation, execution and assessment of fire support in decisive action." In addition to fire support, this grouping of FMs describes the targeting process in conjunction with FM 3-60, *The Targeting Process* in great length. Targeting consists of deciding, detecting, delivering and assessing the service of and the effects on a target. The research presented in this study aligns with the deliver phase of the targeting cycle.

The last group of FMs reviewed describes the doctrine for target acquisition, meteorology, multiple launch rocket systems, Paladin operations, and tactics for the field artillery battalion (FM 3-09.15, *Tactics, Techniques and Procedure for Field Artillery Meteorology,* FM 3-09.60, *Multiple Launch Rocket System Operations,* FM 3-09.70, *Tactics, Techniques, and Procedures for M109A6 Howitzer (Paladin) Operations* and FM 3-09.12, *Tactics, Techniques, and Procedures for FM Target Acquisition).* These references helped to understand the overall scope of field artillery operations. Each FM has a distinct relationship to circumstances that can affect the five requirements for accurate predicted fire. The assets discussed in these FMs are units and capabilities that were occupied in similar fashion as light towed howitzers during the Global War on Terror.

The recent Army Doctrine Publication, 3-09 and Army Doctrine Reference Publication 3-09, *Fires* provide the foundations and principles of the fires war-fighting function and its role in unified land operations. The Army Doctrine Publication and Army Doctrine Reference Publication series describe doctrine and the collective knowledge necessary to plan in the operations process. Little information from these publications pertained to this study.

Geodesy

The Defense Mapping Agency produced a series of technical manuals and publications that describe geodesy and the organization of the associated mapping systems. Specifically, these publications describe the theories of global mapping and the fundamentals necessary to understand the grid reference system. In combination with National Imaging and Mapping Agency Technical Report 8350.2, *World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems,* the details of how progression in global mapping can affect the operation and accuracy of GPS are provided. These publications were reviewed for concepts and working knowledge of geodesy and its linkage to this research.

Geodesy for the Layman presented a general overview of the principles of geodesy and the challenges that are associated with the science. This publication describes the importance of research and continued development in these scientific fields. "Geodetic Datum Overview" by Peter Dana also presented the fundamentals of geodesy, as well as practical uses and theory application for GPS.

The basics of ellipsoids and their use in global mapping and positioning were adequately discussed in the field artillery targeting and technician course curriculum taught at Fort Sill, Oklahoma (OK). "Mean Sea Level, GPS and the Geoid" by Witold Fraczek suggests errors in GPS accuracy are due to the sea level measurements used as a constant in GPS time calculations. Though this issue was not specifically a topic of research for this thesis, it describes error that plagues GPS and its overall reliability. GPS accuracy is a significant contributor to the problem of firing unit location accuracy.

Mensuration

The National Geospatial-Intelligence Agency (NGA) establishes the accreditation standards for target mensuration operators. *Target Coordinate Mensuration Certification and Program Accreditation* is a by the Chairman of the Joint Chiefs of Staff Instruction that outlines the standards and expectations for mensuration training programs. This document states, "NGA will review all documentation of accredited Service, CSA, and Combatant Command programs every two years, to ensure no changes detrimental to quality production have been made to training, certification and proficiency processes. NGA will re-accredit these programs every 4 years or sooner if warranted by mensuration program changes or other circumstances."

Department of Defense Directive Number 5105.60 directs "the mission, organization and management, responsibilities and functions, relationships, authorities, and administration of NGA [National Geospatial-Initelligence Agency]." The NGA is instructed in this document to consolidate geospatial- intelligence requirements and execute analysis and production. Command relationships and structures are described in this document, but no specifics for mensuration.

Training Circular 3-09.61, *Target Coordinate Mensuration* is in draft form and yet to be released for use. This publication is expected to be directive in nature focusing on mensuration practices, certifications and standardizations. Air Force Instruction 14-126, *Target Coordinate Mensuration, Training, Qualification and Certification* is the governing regulation the Air Force uses to mandate mensuration procedures.

The Field Artillery Targeting Technician course at Fort Sill, OK focuses portions of their curriculum on mensuration and the effects accuracy can have on precision guided munitions. Much of this content is For Official Use Only and cannot be summarized for this research. This course training products and documents instruct the fundamentals of geodesy, importance of accuracy and precision, types and uses of precision guided munitions, mensuration software and capabilities, and managing error. The reduction of target location error through the targeting process is the resounding theme through the majority of the course content.

Target coordinate mensuration is a specific TTP designed to improve the target location error. The fire support FM grouping does not describe this process in any form of detail as they focus on integration of fire support into the planning process. These FMs provide adequate information on the importance of fires, capabilities, coordination and the integration into the maneuver plan.

The 1st Armored Division published a target mensuration SOP in 2013. This document governs the internal certifications and focus of target mensuration training. The division precision fires program manager is the position within the division that is responsible for this effort. Unique to this procedure is the allocation of target mensuration trained personnel and their location within the division. This program calls for 10 target mensuration certified leaders at the Fires battalion. This research additionally reviewed J. Lindquist and S. McMeen mensuration methods in *Draft Target Mensuration Procedure* and the practicability of implementation as a unit level mensuration drill.

Accounts suggesting the importance of mensuration and reduction of target location error from combat provided first hand mensuration related challenges. A document in after action review format titled, “Target Location Errors in the MEB-Afghanistan Area of Operations” by Lieutenant Colonel Todd Finely emphasized the importance of accurate target location. Unit level mensuration procedures were discussed and explored for relevance.

Occupation SOPs, Tactical SOPs, After Action Reviews

Firing units at the battalion level publish requirements for section certifications in the form of battalion standardization memorandums. These memorandums are also formally known as a unit “Redbook.” The 2-*320 Field Artillery Regiment Balls of the Eagle* and 1-*320 FAR Tops Guns* Standardization Memorandums provide training and certification standards including detailed procedures for firing unit occupation. Gun section emplacement, as well as support functions such as survey and metrological standards, are depicted. These memorandums also provide certification guidance for the fire direction centers and the importance of digital fire mission over voice.

Technical Manuals

The technical manual for the Howitzer LT Towed 105mm M119A2 provides the equipment specifications for capabilities and maintenance. This document instructs step actions drills for occupation, routine upkeep and operation of the howitzer. Gunnery fundamentals as they pertain to improving accuracy and their relationship to the five requirements for accurate predicted fires are not discussed.

Other technical manuals reviewed include the Defense Advanced GPS Receiver (DAGR), Digital Fire Control System with the Internal Navigation Unit (DFCS/INU) and the Position and Azimuth Determining System (IPADS). Similar to the M119A2, these documents do not review survey or GPS theory; only the information necessary to operate the equipment. SOPs for emplacement and use for all the equipment with associated technical manuals reviewed are the responsibility of the firing unit.

Other Sources

The joint publications applicable to this study predominately concentrated on targeting and the associated inter-service considerations. Joint Publication 3-60, *Joint Targeting* and Joint Publication 3-09, *Joint Fire Support* provided doctrine on the importance of the joint targeting cycle and the relationship of the types of targets to the phases of the cycle. These publications stress the importance of dynamic targeting and the ability to react to a time sensitive target. Though the concepts and importance of the targeting cycles are discussed in detail, detection and delivery methods and the technology that drives it are not.

The relationship of risk and composite risk management to this study specifically focused on safety by means of distance to artillery impacts and collateral damage concerns. Army techniques, Tactics and Procedures 3-37.31, *Civilian Casualty Mitigation* and FM 5-19, *Composite Risk Management* depicts the controls to address hazards when mitigating risk. Specific to collateral damage and civilian casualties are mitigation efforts that drive an output of a collateral damage estimate. This estimate assigns a risk value to assist a commander’s decision on delivery assets when servicing a target. Though these publications do not delve into the detail of computation of collateral damage estimates, the importance of conformity is emphasized.

Conclusion

This review of literature provided a baseline understanding of the procedures and capabilities associated with basic field artillery operations. Important to the conduct of this research is the ability to understand the relationships between the topics reviewed. Technological advancements or retirement of capabilities can have a resounding effect in adjacent field artillery efforts. This review found such trends specifically with the retirement of the IPADS survey equipment and the accuracy of the replacement technology. Chapter 4 will discuss the impact of these trends on firing unit occupation accuracy.

CHAPTER 3

RESEARCH METHODOLOGY

Introduction

The purpose of this chapter is to explain and set the framework for this research. The objective of this research was to provide analysis necessary to aid in the understanding of how advancements in mensuration technology can benefit the fires community. The data analysis points were selected and compared with the intent of application of the findings by a field artillery organization. The implications of the findings based on the data analysis points will require further research and validation prior to field employment. Research and analysis of these data points remained unclassified in nature, though a significant amount of information exists in a classified format and is recommended for action in areas for further study.

Data Collection Method

The data collection methods selected for this research include both document review and case study approach. Collection and review will focus on requirements for accurate predicted fire, geodesy, GPS technology, firing unit occupation, targeting, and weapon safety considerations. Formats of the documents and publications analyzed varied according to the purpose of the document and intended audiences. The advancement of technology in these general areas has provided opportunity for accuracy and first round effects in the field artillery community; however, the lack of understanding the relationships between the groupings presents the potential for error.

Procedures units have successfully used to mensurate a location for precision guided weapon targeting techniques have been analyzed for similar use to mensurate firing unit location. Safety considerations of the weapon and delivery system must be understood and the impacts of location refinement considered on the accuracy of the weapon. The applicability of the research is aided by the comparison of these operating procedures to notional procedures for location mensuration of templated firing unit locations.

A document review and case study approach were selected as the data collection and review model for this research because of the technical nature of the resources available. These methods provide the best manner to organize the current trends, evaluate credibility of the source, and investigate different interpretations of the problem. The organization of the literature review was a comparison and contrast of works by topic of discussion. Data analysis points are organized in a different manner but build upon the organization of chapter 2. The particular advantages and disadvantages of these data collection methods will be explored in detail during data analysis discussion.

Data Analysis Method

Three analysis points were selected for research. These points focused on identifying location error and the effects of mensuration technology on a firing platoon. The points were: error inherent to current occupation methods, feasibility of firing unit level mensuration technology, and advantages and disadvantages.

The first analysis point in this methodology was to examine the doctrinal methods, and the TTPs used during firing position occupation of howitzer units. This thesis focused on light, towed artillery pieces, but the concept of occupation and the laying of guns remain constant regardless of the caliber of the howitzer. Location errors common during occupation have been reviewed and compared to the potential output of the weapon system if the error was negated. Sources of error can include the howitzer, elements of the basic initial issue, survey equipment, and human error. GPS characteristics and their common sources of error were examined and compared to that of mensuration. Additional factors, such as time to emplace and common survey considerations, that affect an artillery unit's effectiveness were explored.

The second point analyzed was the availability and feasibility of firing unit level mensuration capabilities. The types of software and their roles and functions in the mensuration process will be explored. User certification considerations along with current availability of automation at the battalion level were reviewed.

The third analysis point explored the advantages and disadvantages, particularly in accuracy, gained by unit location with mensuration technology. This analysis was difficult to complete at the unclassified level due to the sensitive nature of the mensuration software capabilities. The fundamentals of geodesy discussed during the literature review was built upon and applied to the problem set of achieving the desired firing unit location. Comparison of the accuracy of a mensurated grid was conducted with that of a traditional occupation of a firing unit, the inherent error and tolerances, and the potential decrease of target location error (due to refined firing unit location).

This thesis included the research and exploration the implications that a fully mensurated firing unit location can have on the different classifications of safety. The mathematical models that define industry accepted tolerances for safety and collateral damage calculations were defined and explained. Factors such as TLE, Circular Error

Probability (CEP) and Collateral Damage Estimation was analyzed and compared based on accuracy improvements of firing unit location.

The advantages and disadvantages data point also examined the cost versus benefit considerations that can be accrued from the application of mensuration technology to firing unit location. The lifespan of the current survey systems and the projected cost and savings of fielding field artillery units with mensuration technology was explored. Analysis of the Army's projected cuts to the field artillery survey technician (military occupation specialty 13T) and the proposed solution to the capability gap was compared to the benefits of replacement with mensuration technology.

Advantages and Disadvantages

The primary advantage to this combination of research methodologies was that it allowed the researcher to better sort through the overwhelming amount of data available from technical manuals, information papers, and After Action Reviews. Resources available through the combination of the National Geospatial Agency and Fort Sill Fires Center of Excellence are sufficient for analysis of the topic. Specific works that focus on the feasibility of the mensuration of firing unit have not been developed, adding validity to this study and follow on research.

Another advantage to this approach to research methodology was the exposure to SOPs and battle drills for an abundance of fires related tasks. Research, findings and recommendations were written in a manner that will allow a unit to expand upon this research to form a firing unit mensuration step action drill. The ability to use the industry standard format to publish findings and recommendations will encourage further exploration of this topic within the fires community.

The primary disadvantage to this research is the possibility that the available resources may not be the most current based on the evolution of technology. In addition, the quantity of work available that is classified secret or above is noteworthy, and not an available pool of data for this study.

Conclusion

Chapter 3 provided the research methodology used to conduct this study. The data analysis points selected for research have been summarized and linked back to the chapter 2 literature review. The majority of information available for analysis was in the form of industry specific formats tailored for the experienced technicians in the associated fields of study. Advantages include the amount of information available with a technical focus while the disadvantages related to the unavailability of the most current research in an unclassified format.

CHAPTER 4

ANALYSIS

Introduction

This chapter provides the analysis and findings achieved using the data points that were discussed in chapter 3. The findings presented are comparisons and exploration of methods to improve the firing unit location requirement imposed by the five requirements for accurate predicted fire. The researched data points include: (1) firing unit occupation sources of error; (2) firing unit mensuration capability; and (3) advantages and limitations. Chapter 5 explores the recommendations deduced from the findings and includes additional related topics suggested for further research.

These findings present accuracy benefits for the use of mensuration technology to provide a firing unit location. The evolution of field artillery equipment continues to dictate necessary changes in occupation methods used by firing units. Mensuration is a process that can improve the accuracy of firing unit location in comparison to standard methods currently in use. Topics in this chapter provide background and supporting data as to how and why mensuration use will improve firing accuracy in field artillery units. An understanding of the five requirements for accurate predicted fire and the advantages mensuration can provide is critical to grasp the concepts of this research.

Five Requirements for Accurate Predicted Fire

Field artillery gunnery doctrine describes five requirements necessary to achieve first-round Fire For Effect on a target. These requirements account for standard conditions and provisions for non-standard conditions that are inherent to all fire missions. These requirements are: (1) target location and size; (2) firing unit location; (3) weapon and ammunition information; (4) meteorological information; and (5) computational procedures. Once these requirements are accounted for, the firing unit can provide timely and accurate fires for the supported unit. Unaccounted for requirements or errors in calculations will affect the accuracy of the mission and adjustments may be required to bracket the target prior to a Fire For Effect engagement.[12] A firing unit strives to achieve first round Fire For Effect as it allows more responsive accurate fires and affects the number of targets that can be serviced in a given amount of time.

Accurate target location and size refers to specific ground location, as well as timely detection and identification of target type. An accurate target location allows the firing unit adequate data to determine a distance and direction from the howitzer location. A ballistic firing solution is calculated in the Fire Direction Center (FDC) to engage the target. The skill sets required to observe and designate targets are the specialty of the fire support specialist (Military Occupation Specialty 13F) or Forward Observer, and are often taught as common skill sets for all soldiers.[13]

Mensuration technology is currently used to improve the target location requirement. It is a requirement for most precision guided weapons and collateral damage

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[12]HQDA, FM 6-40, 1-3.

[13]Headquarters, Department of the Army, Field Manual 3-09, *Fire Support,* 2011, http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013), 2-1 -2-25.

mitigation efforts.[14] Use of this technology to improve the remaining requirements has minimal accuracy improvement potential, but worth research for implementation.

Accurate firing unit location is a requirement to identify the exact location of each weapon system in the firing unit. Cannon artillery engages with an elevation of the tube and a deflection from an aiming reference. An accurate firing unit location must be applied to ensure the mathematically calculated ballistic firing solution represents the actual location of the unit in comparison to the target location. Field artillery survey units and GPS devices are the current methods a firing unit uses to determine firing unit location. The field artillery surveyor is the Military Occupational Specialty (13T) that is responsible for survey operations.[15]

This research explores the feasibility of mensuration technology application to improve the firing unit requirement for accurate predicted fire. It is not currently used as an occupation method and potentially faces material and training challenges. The degree of accuracy improvement mensuration provides, coupled with the relative ease of mensuration when the proper equipment is available, supplements the feasibility of this concept.

Accurate weapon and ammunition information refers to performance of the weapon system by specifically accounting for three variables: muzzle velocity variances, propellant temperature, and projectile weight. Differences in weight of ammunition, inconsistencies in lots of powder, howitzer cannon tube erosion, and powder temperature are never uniform and must have correction factors applied to ensure accuracy. The field

[14]U.S. Army Chief Warrant Officer Field Artillery School, 12.

[15]HQDA, FM 6-2, 1-2.

artillery automated tactical data specialist (Military Occupational Specialty 13D) and the Fire Direction Officer are responsible for the management of weapon and ammunition information.

Accurate meteorological information data points depict the effects that weather variables can have on the trajectory of a projectile in flight. Atmospheric conditions are captured by sensors and relayed to artillery units that then apply correction factors to the ballistic firing solution.[16] The field artillery surveyor is responsible for providing and managing meteorological data.

Accurate computational procedures account for the manual and automated requirement for correct application of the ballistic firing solution calculation. This requirement uses data provided by the other four requirements.[17] The fire artillery automated tactical data specialist and the Fire Direction Officer are responsible for the management of computational procedures.[18]

When the five requirements cannot be accounted for, a registration can be conducted to compensate for the error. Registrations account for the cumulative error of all unaccounted for standard and non-standard conditions.[19] A registration relies on an observer to bracket fires onto a known location that the FDC can use to determine and apply a correction factor.[20] Subsequent fire missions use the correction factor in the

[16]HQDA, FM 6-40, 1-3.

[17]Ibid., 1-4.

[18]Ibid., 10-4.

[19]Ibid., 10-1.

[20]Ibid., 11-70.

calculation of the ballistic firing solution. Registration is not the preferred method to achieve first round effects. Accounting for the five requirements for accurate predicted fire is the ideal method to attain first round effects.

The requirement that causes the most error to target engagements is target location and size. (TLE) accounts for over half of the of the overall error budget when analysis is conducted. Improvements specifically designed to correct for TLE include the development of more accurate target location devices and target mensuration procedures. The weapon and ammunition information requirement ranks second in error budget rankings, while firing unit location error ranks third with the variables consisting of methods used to occupy firing positions. Application of mensuration to firing unit location is not currently a method to improve this requirement.

Firing Unit Location

Firing unit location determination process varies according to mission type, terrain, weapon system, and unit competence. Limitations of this research as discussed in Chapter 1 narrow conditions of the firing unit to a static secure location for a prolonged period of time. These limitations provide a best case scenario for the feasibility of the use of mensuration technology for determining firing unit location.

Occupation is the process by which a firing unit uncoils from a tactical march posture to a formation suitable for the emplacement, laying and delivery of fires.[21] The

[21]Laying a firing unit is a process that orients the howitzers on a common firing line. The firing lines are commonly referred to as an azimuth of fire. There are several ways to lay howitzers with the most common being reciprocal laying using survey equipment. Once a howitzer is laid, precise angles can be measured and used as to offset the howitzer from the firing line in accordance ballistic firing solution data the fire direction center calculates. Headquarters, Department of the Army (HQDA), Field

three types of occupation methods are deliberate, hasty and emergency. Deliberate occupation is planned and includes an echeloned flow of personnel and equipment into the selected occupation site.[22] This is the most common occupation method and it allows for the consideration of multiple tactical variables.[23] The occupation method that fosters the most accurate firing unit location readings is the deliberate emplacement. The benefits of mensuration technology are only recommended for the deliberate occupation methods for limitations discussed later in this chapter.

Firing unit occupation methods employed during the Global War on Terror used Forward Operating Bases to provide secure terrain to emplace howitzers. These "hot guns" were typically in a static location and very rarely moved. Deliberate occupations were conducted on occasion, usually for named operations after which the firing unit returned to the Forward Operating Bases. The firing unit location that was determined during the emplacement of the hot gun section was a field artillery survey function or by use of GPS technology. The majority of the mission types that were conducted were a variant of counter-fire or terrain denial and did not require the shoot and move concept normal to maneuver warfare. Several different types of howitzers were used during

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Manual (FM) 6-50, *Tactics, Techniques, and Procedures for Field Artillery Manual Cannon Gunnery* (Washington, DC: Government Printing Office, 1996), 4-11.

[22]HQDA, FM 6-50, 2-33.

[23]Hasty occupation is similar to a deliberate occupation, but with extremely limited time. Several steps to include site reconnaissance are not conducted. Emergency occupations are strictly reactions to fire support while the firing unit is in movement formation. Minimal occupation steps are conducted to achieve the baseline firing capabilities. HQDA, FM 6-50, 2-33.

firebase operations during the Global War On Terror; however this research focuses on the M119 series howitzers.[24]

The M119A3 light towed howitzer is being fielded to replace the M119A2 model. The addition of the DFCS that provides the capability to communicate digitally with the FDC and self locate with an INU system. The DCFS/INU uses GPS technology with the commonly fielded DAGR to provide an individual howitzer location that can be sent digitally to the FDC. There remain challenges to the application and efficiency of the DFCS/INU and associated equipment on the M119A3 to the additional weight added to the howitzer and commonality with similar systems designed for other howitzer

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[24]The M119A2 105millimeter (mm) is the current light towed howitzer that primarily provides direct support fires to the Infantry Brigade Combat Team. It fires a semi-fixed propellant and projectile combination standard to North Atlantic Treaty Organization specifications. The howitzer weighs approximately 4,300 pounds which meets the weight specifications for air assault operations with the UH 60 or CH 47 rotary wing platforms, or airdropped by a fixed wing aircraft. The maximum range with conventional munitions is 14,000 meters (19,500 meters rocket assist) and can sustain six rounds per minute for the first two minutes of target engagement. The standard crew requirement is seven military occupational specialty 13B cannon crew members. The howitzer is of British design and provides increased range and firing rate over the predecessor M102 variant howitzers. The M119A2 howitzer firing units are typically arrayed in platoons of four guns, two firing platoons per battery, and two firing batteries per battalion. During firebase operations in the Global War on Terror two guns per firebase normally maintained a consistent firing capability. Joint Readiness Training Center, *Fire Direction Center Smart Book,* U.S. Army, https://www.us.army.mil/suite/designer (accessed 30 May 2013), 56.

models.[25] The DFCS/INU component that allows the howitzer to self locate is not a new concept; similar capabilities are common to the M777 and M109A6 howitzers.[26]

Determining Firing Unit Location

Several methods are currently in use to provide firing unit location. Varied degrees of accuracy are associated with each method. Much like selection of occupation method, each location method is used based on the tactical environment and mission set conditions.

Field artillery survey is the preferred method to establish firing unit location. "The primary mission of the surveyors in a cannon battalion is to provide timely and accurate survey control to the firing batteries and any other battalion assets as required. Survey control consists mainly of establishing a line of known direction and determining the locations, both horizontally and vertically, of the weapons and the target-locating systems. In addition, field artillery battalion survey must provide control for other weapons, instruments, and electronic equipment as required."[27]

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[25]Joseph Lipinski, "Commonality of Towed Artillery Digital Fire Control Systems (DFCS)," *Army AL&T* (July-September 2010), http://asc.army.mil/docs/pubs/alt/2010/3_JulAugSep/articles/21_Commonality_of_Towed_Artillery_Digital_Fire_Control_Systems_(DFCS)_201003.pdf (accessed 25 May 2013), 23.

[26]The U.S. Army employs several other field artillery weapon systems that are not used by the Infantry Brigade Combat Team. These systems are primarily 155 mm howitzers and Multiple Launch Rocket Systems that are organic to Armored Brigade Combat Teams and Fires Brigades. Though these larger caliber weapon systems can outrange and have more devastating effects than the 105 mm, they weigh more and cannot typically be used for forced entry operations.

[27]HQDA, FM 6-2, 14-1.

A critical function of field artillery survey is its ability to provide common survey. The achievement of common survey allows the capability of massing fires, the ability to deliver surprise observed and unobserved fires, and transfer target data between firing units. Common survey is promoted by a proper emplacement of an accurate starting location with coordinates, height, and orientation, or Orienting Station.[28] Common survey is achieved by emplacing the Orienting Station with similar survey methods to allow units or enablers to be relative to one another.[29]

Field artillery control surveys are performed to fourth and fifth order specifications to describe accuracy and maintain common survey. Fourth-order survey is performed to an accuracy of one unit of error in 3,000 similar units of survey. It is usually written 1:3,000. Fifth-order survey is performed to an accuracy of a maximum of one unit of error in 1,000 similar units of survey. It is usually written 1:1,000. Fourth-order survey is more accurate than fifth-order survey.[30] The survey equipment that provides the capability for field artillery units to occupy with fourth order survey is the IPADS.

"The Position and Azimuth Determining System (IPADS) is a self-contained inertial surveying system." It has the capability to provide location coordinates, height, and an azimuth for each Orienting Station. Field artillery organizations employ the

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[28]There are three elements of survey control: direction, location and altitude. Direction is the most critical element to common survey and is apparent if directional errors exist when laying the firing unit. Location of the firing unit in terms of field artillery survey is second in order of importance. Altitude of the firing unit is third and can be obtained by many means including survey outputs, GPS, or contour lines on a map. Survey teams provide the necessary information to maintain common survey when the Orienting Station is established. HQDA, FM 6-2, 14-1.

[29]HQDA, FM 6-2, 14-1-2.

[30]Ibid., app. B.

IPADS mounted in a tactical vehicle for mobility advantages. The field artillery surveyor is specially trained to operate the IPADS. IPADS survey technique has the capability to establish fourth or fifth order survey.[31] IPADS has some significant challenges that can limit its availability. There is typically only one IPADS authorized for each artillery battalion which can restrict availability to firing platoons. Additionally, the IPADS must calibrate with survey control points that contain higher level survey information that may not be available in all parts of the world.

Common survey is a critical component to the firing unit requirement for accurate and predicted fire. Starting control for accurate survey operations mandates that known coordinate, height and azimuth are available in order to maintain common survey to reduce the amount of error possible from that aspect of firing unit location.[32] IPADS can provide common survey due to the nature of one survey control point establishment and the subsequent laying of the howitzers from that point. Firing units that use DFCS/INU cannot achieve common survey because each howitzer has an individual DAGR. When multiple GPS receivers are used during the occupation of the firing unit, common survey is not achieved.

The Gun Laying and Positioning System (GLPS) is a laying and location system that is available at the platoon level. "When used in conjunction with GPS, the GLPS will determine grid location and establish directional control." It can be used to establish survey during conditions where a survey section is not available for support. In conjunction with the DAGR, it can lay the howitzer; provide a location, height, and a line

[31]Ibid., ch. 9.

[32]HQDA, FM 6-2, 14-1.

of known direction. The GLPS can be operated by the firing platoon gunnery sergeant, platoon sergeant and platoon leader during occupation and safety drills. The GLPS has the capability to establish fifth order survey.[33]

GPS was first introduced in the late 1970s when the first block of GPS specific satellites were launched into orbit. The purpose of GPS is to define geographic positions on and above the surface of the earth.[34] The satellites are in a semi-synchronous orbit that achieves one revolution every 12 hours to provide accuracy, survivability and coverage.[35] Dual use systems in terms of GPS refer to the use by civilian and military. Military uses include navigation, surveying, and target acquisition.[36]

There are several factors that can add error to the GPS location outputs. Ranging errors can be caused by malfunctions in the satellite's internal clock, miscalculated orbit, atmospheric conditions, and receiver malfunctions. Signal reflections can potentially interfere with the actual direct signal from the receiver to the satellite based on angles leading to error. Other signals such as radar, microwave and radio traffic can potentially interfere with GPS signals. Modernization efforts are underway to improve the military components of the GPS program. DAGRs are the most current GPS receivers, a newer military code within the direct signal is being fielded and the overall power to the system is being increased.[37]

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[33]HQDA, FM 6-50, 4-10.

[34]U.S. Army Chief Warrant Officer Field Artillery School, 52.

[35]Ibid., 53.

[36]Ibid., 56.

[37]Ibid., 68.

Firing Unit Location Sources of Error

The current systems used to provide location during the occupation of a firing unit have varied degrees of potential error. The total location error is a combination of several factors that each contribute to a cumulative amount of error. Each occupation method and associated emplacement equipment has set accuracy potential and industry understood capabilities that can be tailored for the mission criteria.

Light towed artillery firing units are held to strict standards for occupation of a selected firing point. These points are selected and unit leadership conducts reconnaissance, but the howitzers do not necessarily emplace in the exact location selected during the planning phase of the mission. Tactical level leaders must make the determination as to the suitability of a location based on cant of the ground, site to crest challenges, and the solidity of the terrain.[38] The leadership attempts to emplace the howitzer formation as close to the published plan as possible in order to retain ballistic field artillery safety calculations done prior to movement during the planning phase.

Orienting stations are established by the field artillery survey team with the IPADS survey equipment that can emplace locations to the degree of fourth order survey. The field artillery leadership will then use the established Orienting Station as a base point for the M2 aiming circle or the GLPS. These specific survey pieces of equipment allow the turning of angles to lay the guns along the azimuth of fire, and can be used to derive a location of each gun based on the distance and direction from the laying piece.

[38]Headquarters, Department of the Army, U.S. Army Field Artillery School, Student Text 6-50-20, *Battery Executive Officer's/Platoon Leader's Handbook* (Washington, DC: Government Printing Office, 1986), 10-1.

This allows the firing unit to remain on common survey.[39] Occupation standards for firing capability for the M119 series howitzer section is less than five minutes with additional time standards for position improvement. Many field artillery units use the IPADS at each howitzer location to provide the most accurate location within the realm of the unit for each howitzer.[40] Error common to emplacement and laying of the howitzers is collective, from inaccurate orienting stations and inability to maintain fourth order survey.

Light artillery strives to conduct fully digital fire mission processing specifically from the FDC to the gun-line. There must be a location entered for each gun to process digital missions because each howitzer will receive a slightly different ballistic firing solution to engage the target. The differences in the ballistic firing solution are due to the many gun locations engaging a single target with a fixed location. When fire missions are conducted by voice, the FDC cannot transmit several sets of firing data within fire mission time standards. The ballistic firing solution data is calculated for the base piece and then corrected using Terrain Gun Position Corrections for the rest of the howitzers in the formation.[41] The Terrain Gun Position Corrections are calculated for each gun based

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[39]HQDA, FM 6-50, 4-15.

[40]Field artillery units occupy with GLPS when IPADS support is not available. The GLPS can also self-locate and has the ability to establish an Orienting Station based on GPS location. Thus, establishment of a survey control point by the survey team is not necessary; however, the accuracy of the Orienting Station is degraded. The accuracy of the order of survey that the GLPS can provide is less than that of the capability of the IPADS. HQDA, FM 6-50, 4-8.

[41]The FDC has the option to calculate ballistic firing solution computations on the location of the base piece and associated Terrain Gun Position Corrections for the adjusting pieces. Terrain Gun Position Corrections are only to be applied if the control method for fire missions is voice. When digital fire missions are conducted, each

on the location of the base piece compared to the locations of each howitzer. Terrain Gun Position Corrections are then calculated by mils of adjustment both in elevation and deflection. Error common to the conduct of voice missions over digital is the calculation of Terrain Gun Position Corrections.

The findings for firing unit occupation sources of error do not differ greatly from those of the accuracy of each location providing system. The accuracy of each location system is discussed later in this chapter. Errors associated with the occupation of a firing unit are a function of the technology used, type of operation conducted, and competence of the personnel. Analysis of the probable sources of error that are inherent to occupation procedures must be focused on the tolerances in the emplacement equipment and the human error associated with its operation.[42] Human error must be taken into consideration during the occupation drills and procedures to assign a firing unit location.

Mensuration Requirements

Mensuration, as discussed previously, is used most often to reduce target location error.[43] Ultimately, this is an effort to improve the target location requirement of the five

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howitzer receives individual firing data calculated for its exact location. Though not doctrinal, survey teams can provide a location for each howitzer by using the IPADS at gun locations. This method is more accurate and allows digital fire missions that provide a separate ballistic firing solution for each howitzer. HQDA, 6-40, 12-14.

[42]A variable that is often overlooked and the cause of firing incidents is the elevation used for ballistic firing solution calculation. Elevation errors have the capacity to be significant due to the effect it can have on range to target. Similar to the location aspect of GPS, the elevation output is susceptible to the same inherent error.

[43]Mensuration is defined as “the application of mathematical principles to a two dimensional surface in order to accurately determine the most accurate location of a target on all three planes of a Cartesian surface (X, Y, Z). The purpose of using mensuration techniques is to reduce the amount of location error associated with a

requirements for accurate predicted fire. Use of mensuration to improve the accuracy of the firing unit location requirement enhances the cannon field artillery goal of first round fire effects on target. Although the exact accuracy of mensuration is classified, and is not discussed in this research, the benefits it could provide to improve the five requirements are considerable.

DPPDB is a type of imagery that is required for mensuration software packages. "It allows users to derive precise coordinates of any identifiable target contained within the product area." It is stereo image based and was developed, tested, and introduced in the 1990s. This type of imagery is primarily used for coordinate specific targeting purposes by the military and other intelligence agencies. The databases that drive DPPDB imagery are primarily comprised of rectified aerial imagery and support data required to exploit the imagery.[44]

Mensuration in general terms differs from target coordinate mensuration. The NGA defines target coordinate mensuration as: "the process of measurement of a feature or location on Earth to determine an absolute latitude, longitude, and height. Fort targeting applications, the errors inherent in both the source for measurement and the

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location of interest." Target Location Error is most commonly reduced by using mensuration techniques. There are numerous requirements to conduct the mensuration that are standardized by the NGA. A point of interest must be selected to mensurate for a refined location. This is usually a target that requires a coordinate-seeking weapon to engage. The target grid is then associated with DPPDB imagery in mensuration software that averages a location grid coordinate. Known points depicted in the imagery assists the mensuration operator's refinements to the initial location of the desired target location. U.S. Army Chief Warrant Officer Field Artillery School, 12.

[44]"The imagery consists of parametric support data, compressed reference grids, and high resolution national imagery stereo pair sets." Each stereo pair set is typically a 60 x 60 nautical mile area. U.S. Army Chief Warrant Officer Field Artillery School, 38.

measurement processes must be understood and reported. Mensuration tools can employ a variety of techniques to derive coordinates. These may include, but are not limited to, direct read from DPPDB stereo-pairs in stereo or dual mono mode, multi-image geopositioning, or indirect imagery correlation to DPPDB."[45] The NGA is the governing body responsible for the standardization of Target Mensuration Only (TMO) certification requirements. The certification exists to maintain the reliability of TMOs that mensurate for purposes of coordinate seeking weapon systems. "This requirement maintains the integrity and reliability of: (1) coordinate data in targeting databases, (2) products generated using mensurated coordinates and (3) coordinate data used to support employment of coordinate-seeking weapons."[46]

Minimum topics for NGA target coordinate mensuration training and certification must include: (1) basic imagery familiarization and management (to include acquisition and updating); (2) DPPDB management (to include acquisition and updating); (3) basic geodesy; (4) mensuration tool capabilities, operations, and limitations; (5) precise point poisoning process techniques and limitations; and (6) database capabilities, requirements, and standards.[47]

The use of TMO-capable tools does not necessarily constitute target mensuration. Mensuration must be conducted by certified personnel, and not by computer operators that may happen to have the knowledge to operate the software. This has many risk and legal implications that commanding officers at each echelon must mitigate.

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[45]CJCS, CJCSI 3505.01B, GL-3.

[46]CJCS, CJCSI 3505.01B, 2.

[47]Ibid.

The most common mensuration program available at the unit level is Precision Strike Suite for Special Operation Forces. The hardware capability to operate this program has historically been available at firing unit level especially when deployed. A Secret Internet Protocol Router Network is required because Precision Strike Suite for Special Operation Forces is a classified program. Strike Suite for Special Operation Forces is capable of mensuration at point of detection. These capabilities already exist at the brigade and higher echelon staff elements, specifically the Fires Support Element.[48]

Trained TMOs at the firing unit level is the dynamic that challenges integration of mensuration at the firing unit level. Ability to operate the mensuration software and derive a location without proper NGA accredited certifications does not meet the published standards for mensuration operations. Integration of TMO certification programs is needed during officer and non-commissioned officer professional development schools.

Firing Unit Mensuration Capability

The tools required to conduct mensuration specifically for firing unit location must be available at the firing unit. Minimum requirements include mensuration software, the associated hardware, and certified operators. Availability of these resources is limited, expensive and requires justification for fielding below the brigade level staff. DPPDB imagery must be available in conjunction with the software and hardware to process it. Mensuration of howitzer location must include DPPDB imagery that captures

[48]U.S. Army Chief Warrant Officer Field Artillery School, 53.

the howitzer in place. This imagery can be requested through intelligence channels if not current; however, operational priorities dictate the requests that will be serviced.

Critical to the application of mensuration technology to firing unit location determination is the availability of DPPDB imagery in the selected occupation area. This project specifically researches the feasibility of mensuration of firing unit location on an established firebase with DPPDB imagery that captures the emplaced howitzers. The procedure to mensurate the grid to the firing unit location would not be difficult in this situation. Networks in place and ample communications allow the transfer of the mensurated grid from the certified operator to the fire direction center.

The most available course to field artillery career field soldiers that certifies mensuration operators to NGA standards is the precision fires TMO resident course at Fort Sill, OK. "Individuals who mensurate coordinates used to support employment of coordinate-seeking weapons require certification by NGA or certification by an NGA-accredited Service, Combatant Command, or CSA program."[49] This course is a 40-hour course designed to train fire support and targeting personnel to conduct TMO for the effective employment of joint and organic fire support assets. Additionally, precision fires TMO mobile training team schedules courses at units to train operations at their home station. According to the precision fires department at Fort Sill, OK, in fiscal year 2011 the TMO course, both resident and mobile training, certified 224 operators. Trained operators more than tripled in fiscal year 2012 by training 867 operators.

Arguably the most significant challenge for TMO certification is the effort to maintain currency for certified operators. Proficiency must be maintained and evaluated

[49]CJCS, CJCSI 3505.01B, 2.

every six months to maintain currency. Of the over 1,100 operators trained by the precision fires TMO course, less than 25 percent remain current most commonly due to operational deployments or lack of funding for recertification. The use of the TMO mobile training team for recertification purposes only has the capability to significantly reduce the amount of TMO operators that lose currency. Only a tailored recertification process would be necessary for those seeking recertification.

Findings for the firing unit mensuration capability data point are as follows: (1) the tools necessary to mensurate are available to the firing unit. Mensuration software and the hardware to operate it are available at higher echelons; it can be disseminated for use at the firing unit; and (2) field artillery leaders are the primary audience for TMO certification and are co-located with an accredited course at Fort Sill, OK during officer and non-commissioned officer professional development.

Advantages and Limitations

The primary advantage of mensuration use to provide a firing unit location is accuracy. Mensuration use for purpose of determining a firing unit location has advantages primarily related the degree of location accuracy. Limitations that hinder the use of this technology are related to the equipment fielding and TMO certification process. Measures of accuracy are expressed in several different methods which must be placed in common terms to understand the overall impact it can provide.

Accuracy

Accuracy within field artillery is commonly described as the ability to engage the target and achieve first round effects. Feedback specifically for accuracy depends on the type weapon system that engages the target. Accuracy and its relationship to precision and precision fire weapons ultimately manage location error; both target and inherent weapon system errors.[50]

Error management is achieved by using statistics and understanding the purpose of the data. The variables used to describe these errors include standard deviations, circular errors probable and circular error. Proper error management can aid a commander with target engagement method decisions and the associated risk management.

CEP is the error that is associated with the weapon system. Sources for this error can originate from: atmospherics, the delivery system, system wear, terrain and user training. In the military science of ballistics, CEP is an intuitive measure of a weapon system's precision. It is defined as the radius of a circle, centered about the mean, whose boundary is expected to include the landing points of 50 percent of the rounds.[51] Circular

[50]Accuracy in terms of precise positioning refers to relative measurements to an absolute point in space. The five requirements for accurate predicted fires seek to reduce error in order to improve the accuracy of the artillery fires. Dispersion of the sheaf during a Fire For Effect mission set is directly related to the refinements of the five requirements and the competence of the computational procedures used to calculate the ballistic firing solution. Accuracy in terms of sheaf distribution refers to the center mass impact of the sheaf, and its location in comparison to the target. Precision as related to field artillery sheaf placement refers to the round dispersion within the pattern of bursts. This dispersion is not necessarily only a function of probable errors in range and deflection. The capability to refine and thus provide a more accurate individual howitzer location provides an additional degree of accuracy to the precision within the sheaf. Though the use of mensuration is not as accurate as convention survey with the IPADS, the ability to mensurate a point for each howitzer for use in digital fire mission processing can increase the accuracy of the inputted grid, thus improving the precision of the aim-points within the sheaf. HQDA, FM 6-40, 3-18.

[51]Air Force Operational Test and Evaluation Center, "Circular Error Probable (CEP)," Technical Paper 6, Version 2, July 1987, www.dtic.mil/dtic/tr/fulltext/u2/a205489.pdf (accessed 26 August 2013), 1.

Error is a similar variable as that of CEP with the difference being 90 percent of the rounds impacting within the mean circle.

Circular Error calculations are the standard for the NGA as they predict 90 percent of rounds will impact within the circular error value. CEP predicts 50 percent of rounds will impact within the circular error probable value. To convert from CEP to Circular Error, CEP must be multiplied by a conversion factor of 1.8227.[52]

Accuracy Advantage

Each of the location methods discussed has different accuracy capabilities. Reasons for use of each of the methods vary, but they can be ranked strictly in order of accuracy. These findings use the conversion factors described to rank order location assets by accuracy.

The accuracy of a fourth order survey control point established by IPADS is 1:3000 (1 unit of error for 3,000 similar units of survey).[53] Unclassified mensuration accuracy is less than 18 meters. The accuracy for the GLPS is contingent on the GPS DAGR that feeds it. GPS has the capability to establish a location point to the accuracy of 10-meter CEP. To remain consistent with terminology and statistics, the 10-meter CEP must be converted to Circular Error equivalent. The conversion factor to convert CEP to CE is 1.8227. Thus, GPS has an 18.2-meter Circular Error. The DFCS/INU component to

[52]Air Force Operational Test and Evaluation Center, 1.

[53]HQDA, FM 6-2, 14-1.

the M119A3 Light Towed Howitzer functions with the DAGR GPS receiver and cannot achieve a more accurate location than 18.2-meter Circular Error.[54]

A firing unit that uses the INU system does not meet the requirements to achieve common survey. An Orienting Station established by the IPADS or GLPS uses one DAGR to establish the point, and then derives a location for each howitzer. The introduction of the DFCS/INU system for each gun adds additional DAGRs to the system of which cannot meet the requirements for common survey. Common survey must use the same GPS to during the occupational procedures.[55]

The findings for the accuracy advantage provided by mensuration of firing unit location include: (1) the rank order of occupation methods in terms of accuracy is IPADS, Mensuration, GLPS, GPS, and DFCS/INU; and (2) DFCS/ INU does not provide common survey.

Limitations

Limitations of this research focus on the hazards associated with the use of mensuration technology to determine a firing unit location. To explore the limitations, risks and benefits were weighed against the complicated process of introducing new firing unit occupation methods and TTPs that would be necessary at the platoon level.

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[54]The DAGR as used for self-location as part of the DFCS/INU can be accurate to the degree of 18.2 meter Circular Error only if all of the prescribed conditions as per published step actions drills are met. Proper settings must be present in the menu function of the DAGR, and ample time must be allocated for the system to achieve the minimal amount of location readings. Additional inaccuracies can occur if the DAGR is not set to, averaging mode, and enough time allocated for 30 readings to average to a starting location. Only through correct initiation of the DAGR can an accuracy of 18.2 meter CE be achieved.

[55]HQDA, FM 6-2, 14-1.

Safety issues were taken into consideration as they are fundamentally linked to the inherent risk with artillery fires.

Impact on Safety

The importance of safety within an artillery organization is amongst the highest of priorities. Strict safety standards and leader certification programs are required in field artillery units and managed by the commander.[56] These standards and certifications are controls for the possible hazards inherent to artillery fires. Mitigation of the error that has the potential to cause hazards based on firing unit location must be considered as critical to risk management.

The Army defines risk management as, "the process of identifying, assessing, and controlling risks arising from operational factors and making decisions that balance risk cost with mission benefits."[57] Risk in relation to the five requirements for accurate predicted fire is associated with the amount of error, tolerance, or unaccounted for conditions that add to the uncertainty of where rounds will impact. Composite risk management directs the classification of risk both in probability and severity. Impact of error in firing unit location is not the predominate contributor to total error in fire missions, but does impacted overall accuracy. Target location is the source of error that contributes the most to total error. A firing incident is the most probable hazard

[56]HQDA, FM 6-40, 1-3.

[57]Headquarters, Department of the Army (HQDA), Field Manual (FM) 5-19, *Composite Risk Management,* U.S. Army Criminal Investigation Command, 2006, http://www.cid.army.mil/documents/Safety/Safety%20References/FM%205-19%20Composite%20Risk%20Management.pdf (accessed 6 July 2013), glossary 8.

associated with the risk of engaging with field artillery. The probability of a firing incident caused by firing unit location is low; however the severity can be catastrophic.[58]

The mensuration of a firing unit location ranks second to survey operations by use of the IPADS in order of accuracy. If IPADS is removed from firing units, mensuration methods will be the most accurate method. Though the exact numbers are classified, mensuration technology is significantly more accurate than occupation methods that use GPS.

Though the overall risk of firing unit location and its association with total error when engaging a target is low, mensuration has the ability to minimize it further. Adherence to the five requirements for accurate predicted fire provides burst radius accuracy at the target location.[59] Efforts to increase accuracy are accomplished in smaller technical steps.

Cost

Risk is not the only cost associated with this research. Monetary requirements for equipment fielding and training comprise the majority of the costs. The comparison of the cost to field new equipment and train certified operators cannot necessarily be made to the loss of the field artillery surveyor. The termination of that career field has undoubtedly saved the Army money; however the benefits from those savings have certainly been engulfed by competing programs. The costs of the fielding of the M119A3

[58]Ibid., 4-20.

[59]HQDA, FM 6-40, 1-3.

howitzer and the associated INU and DFCS self location systems were considered when terminating the 13T Military Occupational Specialty and the IPADS.

New equipment fielding would be necessary to operate the mensuration programs at the firing battalion, battery and platoon. This fielding is not necessarily a new cost. Computer fielding continues as a routine equipment issue in most units for both secret and unclassified computers. The software required to operate mensuration software can be driven by computers currently in firing units' allocation.

The integration of TMO certification at during field artillery basic officer leadership course is the most cost effective way to train TMO operators in the field artillery community. The applicability of mensuration certified lieutenants can affect both target location as well as firing unit location refinements. A field artillery lieutenant will typically perform company fire support officer duties as his first assignment after graduating this course. The importance associated with leadership in a company command post understanding mensuration and the impact it can have on precision fires is invaluable. The second job for a field artillery lieutenant is usually firing platoon leader or fire direction officer. The mensuration skills learned at Fort Sill and practiced as a fire support officer, would be sufficiently developed for use in a firing platoon for firing unit location mensuration.

The two predominate benefits of firing unit mensuration over the GPS are the accuracy advantage and ability to maintain common survey. The risk associated with error tolerances was assessed as low thus suggesting that benefits would also be minimal. The commitment to invest in technology and training of personnel provides influence for the future decisions made as technology continues to advance.

The findings associated with limitations specifically addressed the hazards probable to field artillery fires and the reduction of risk by reducing the error in firing unit location. The cost of new equipment fielding and use of existing hardware was analyzed as minimal. Cost of target mensuration certification for leaders within a firing unit below the echelon of brigade was discussed for the ideal training timeframe. Risk does not present a solid case to warrant the cost of training and hardware; however, the benefit of masses of certified target mensuration operators does.

Conclusion

This chapter presented findings on the advantages and disadvantages of the use of mensuration technology to provide a firing unit location. Organization of information analyzed was by data points consisting of: (1) firing unit occupation sources of error; (2) firing unit mensuration capability; and (3) advantages and limitations. Analysis presented in this chapter has described how mensuration can improve the accuracy of firing unit location and improve the five requirements for accurate predicted fire. Chapter 5 provides recommendations and areas for further study based on the presented findings.

The findings presented in this chapter are: (1) the tools necessary to mensurate are available to the firing unit; (2) field artillery leaders are the primary audience for TMO certification; (3) order of occupation methods by accuracy is IPADS, Mensuration, GLPS, GPS, and DFCS/INU; (4) The DFCS/INU does not provide common survey; (5) firing unit occupation errors are associated with the accuracy of the location technology; (6) firing unit location accuracy has minimal effect in the overall calculation of safety calculations; (7) risk does not present a solid case to warrant the cost of training and hardware; and (8) the benefits of masses of certified TMO warrants the cost of training.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The purpose of this chapter is to provide conclusions and recommendations based off the findings presented in chapter 4. This chapter includes discussion of the implications of the findings and explanations their meaning. Additionally, recommendations include areas for further study with a scope that includes classified information not researched in this study.

This thesis explored a primary research question of whether target mensuration technology is a feasible method to provide improved accuracy to light towed artillery to increase the probability of first round fire for effect results. In this chapter, recommendations will be made on the best use of mensuration technology to refine a firing unit location. Analysis was conducted by researching three distinct data points: (1) firing unit occupation sources of error; (2) firing unit mensuration capability; and (3) advantages and limitations.

The findings from chapter 4 were: (1) the tools necessary to mensurate are available to the firing unit; (2) field artillery leaders are the primary audience for TMO certification; (3) order of occupation methods by accuracy is IPADS, Mensuration, GLPS, GPS, and DFCS/INU; (4) the DFCS/INU does not provide common survey; (5) firing unit occupation errors are associated with the accuracy of the location technology; (6) firing unit location accuracy has minimal effect in the overall calculation of safety calculations; (7) risk does not present a solid case to warrant the cost of training and hardware; and (8) the benefits of masses of certified TMO warrants the cost of training.

Conclusions

These conclusions expand on the findings and suggest practical applications for use by operational artillery units. The loss of the field artillery surveyor and the IPADS survey equipment potentially causes a degradation of the accuracy achievable for firing unit location. Integration of mensuration as an option for use at the firing platoon level adds to the flexibility of field artillery emplacement techniques.

The conditions of a platoon of light towed howitzers on a fire base similar to that used in the Global War on Terror fosters an simplistic approach to the application of mensuration. DPPDB imagery exists depicting the howitzer location permitting certified individuals the ability to mensurate. In cases when the imagery does not exist, it can be requested. This type of imagery is prevalent in combat environments, though not as accessible in garrison and training environments. Efforts to migrate mensuration technology into standard procedures for field artillery operations have challenges that must incorporate the appropriate training and certifications.

The use of mensuration to provide a firing unit location provides an accuracy advantage and is an operation feasible at the firing unit level. Operator certifications and equipment fielding or reconstitution are challenges essential to this effort. Mensuration technology improves the accuracy of the target location factor in the five requirements for accurate predicted fire and can do the same for firing unit location. Future technological advances in cannon delivered precision guided weapons may demand improved accuracy for all variables that affect total error of the weapon system engagement, to include firing unit location.

The second conclusion describes the order of preference by degree of accuracy for establishment of firing unit location. IPADS remains the most accurate method to provide a firing unit location and should be first in priority. Mensuration ranks second strictly from data presented in this study without field testing. GLPS and its reliance on the DAGR ranks third over the stand alone DAGR because the GLPS is stationary and avoids error associated with movement. The DAGR ranks fourth over the DFCS/INU system. Both the DAGR and the DFCS/ INU use GPS technology; however, the DFCS/INU system introduces an additional DAGR for each howitzer which does not meet the requirements for common survey. A stand-alone DAGR could be transported to each gun location, provide a grid coordinate, and maintain common survey.

This study concludes that it is in the best interest of the U.S. Army, specifically the field artillery community, to train leaders as TMO certified operators. This research argues the benefits for TMO certification as part of institutionalized field artillery training at officer and non-commissioned officer professional development at Fort Sill, OK. Leader certification prior to arrival to a maneuver or firing unit saves the Army time and money that would be spent training these soldiers at a later date. Efforts are underway to develop a mensuration management program at the division level that monitors and manages the currency of all subordinate TMOs.

The option of training field artillery second lieutenants during the basic officer leader course should be explored as an option to save time and money. This course is an 18-week school at Fort Sill, OK that teaches the fundamentals of field artillery and fires.

It graduates over 400 field artillery officers each year. A significant percent of these second lieutenants will graduate and immediately assume platoon leader or Fire Direction Officer responsibilities in a light artillery unit. The precision fires TMO resident course is located at Fort Sill with a complete resident staff. Benefits of working target mensuration into the field artillery basic officer leader course curriculum would be a mass training of TMO certified leaders who will be operating in firing units prior to the expiration of the TMO certification. TMO mobile training teams could then focus strictly on recertification of noncurrent soldiers.[60]

Firing platoons in light artillery will generally co-locate the platoon operations center and the FDC. Platoon level leadership would have full access to the mensuration certified soldier and the hardware that drives the mensuration software. The 13D non-commissioned officers are excellent candidates to fulfill to the role of enlisted certified mensuration operators. They have the subject matter expertise and the opportunity to receive the TMO training while attended professional development courses at Fort Sill, OK.

This study concludes that effects of firing unit location refinement by mensuration have limited effect on safety estimates that commanders use to mitigate collateral damage. The common safety variable computations are minimally affected by a degree of improved firing unit location. Though a degree of additional accuracy is gained, it is unlikely that this would effect a decision to service a target with a particular weapon system.

[60]The Official Website of Fort Sill, Oklahoma, Field Artillery Basic Officer Leader Course–B (BOLC-B), “Course Overview & Requirements,” U.S. Army, http://sill-www.army.mil/BOLC-B_1/ (accessed 15 October 2013).

Recommendations for Further Study

Areas for further study to continue this research should focus on the exact amount of accuracy gained by using mensuration to provide a firing unit location. These types of studies would maintain a classification at the secret level due to the sensitivity of mensuration software. Data outputs from this further research could then supplement efforts to provide mensuration capability at the firing unit.

The introduction of scene matching software to the mensuration process has the potential to allow procedures to mensurate with imagery that does not depict howitzer location. This software merges imagery captured by an unmanned aerial system to existing DPPDB imagery. Photos of a firing unit location could potentially be captured by an unmanned drone or fixed wing aircraft, merged and then used for mensuration purposes.

Use of mensuration for forced entry operations specifically airborne and air assault/air insertion should improve accuracy for existing methods in place. The IPADS and GLPS are not typically used during forced entry operations. These types of operations rely on the handheld DAGR to provide location for the orienting stations and gun locations. Future technological advances may provide the technology for the unit involved in the forced entry operation to mensurate a location with a computer terminal and a network connection.

Recommendations for Action

The ideas presented in this thesis should be tested in a controlled training environment with a focus on accuracy, advantage gained and feasibility for routine use. A notional SOP that incorporates the use of mensuration to refine firing unit location is a recommendation described below that would allow the collection of baseline data to test this procedure. This notional procedure was discussed in cooperation with the precision fires department at Fort Sill, Oklahoma.

Once studies are completed on the feasibility of using DPPDB scene matching software in conjunction with mensuration, a SOP could be developed for the use of mensuration to improve firing unit location. Use of this procedure cannot provide an initial firing unit location with mensuration technology, but can provide data that improves the five requirements for accurate predicted fire as the fire position is improved. The following is a narrative of an example firing unit mensuration SOP.

A tactical firing unit plans as occupation point for emplacement of platoon. Platoon leadership conducts a reconnaissance of the terrain in order to template locations for individual howitzers, FDC, and platoon operation center. Coordination is conducted with the brigade military intelligence company for unmanned aerial surveillance of the planned firing point. The platoon conducts a deliberate occupation using the GLPS to lay the platoon and provide howitzer locations for each gun. Occupation procedures continue until the platoon achieves firing capability. The Unmanned Aerial System captures the formation of howitzers in suitable format for upload to the FDC. The FDC uses scene matching software to overlay the imagery depicting the firing platoon on DPPDB imagery of the firing point. A Secret Internet Protocol Router Network computer located in the platoon operations center or the FDC is necessary for this process. Mensuration conducted by a TMO certified leader would then allow a refined location for each howitzer thus improving the five requirements for accurate predicted fire. This process repeats as the firing unit relocates or moves for survivability purposes.

Conclusion

This thesis researched the possibility and practicality of mensuration at the firing unit level to improve and refine the firing unit variable in the five requirements for accurate predicted fire. Chapter 4 presented findings that suggest a higher degree of accuracy can be obtained by use of mensuration and the tools necessary to conduct this process are available. Certification of trained operators is a challenge the field artillery community must consider during curriculum design at the officer and non-commissioned officer professional development courses.

Conclusions and recommendations translated the findings into practical ideas that could be explored in line field artillery units. Recommendations for further study included discussion on potential for DPPDB scene matching technology integration into firing unit location mensuration, and a notional SOP for discussion purposes. Further study of the exact accuracy advantage mensuration provides was limited by classification levels and could be further studied in a classified research project.

BIBLIOGRAPHY

Government Documents

Air Force Operational Test and Evaluation Center. "Circular Error Probable (CEP)." Technical Paper 6, Version 2, July 1987. www.dtic.mil/dtic/tr/fulltext/u2/a205489.pdf (accessed 26 August 2013).

Chairman of the Joint Chiefs of Staff (CJCS). CJCS Instruction 3505.01B, *Target Coordinate Mensuration Certification and Program Accreditation*. 10 January 2013. http://www.dtic.mil/cjcs_directives/cdata/unlimit/3505_01.pdf (accessed 6 July 2013).

The Defense Mapping Agency. Technical Manual 8358.1, *Datums, Ellipsoids, and Grid Reference System.* National Geospatial Intelligence Agency, 1990. http://earth-info.nga.mil/GandG/publications/tm8358.1/tr83581a.html (accessed 6 July 2013).

______. Technical Manual 8358.2, *The Universal Grids: UTM and UPS.* National Geospatial Intelligence Agency, 1989. http://earth-info.nga.mil/GandG/publications/tm8358.2/TM8358_2.pdf (accessed 6 July 2013).

______. Technical Report 80-003, *Geodesy for the Layman*. National Geospatial Intelligence Agency. http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/TR80003A.HTM (accessed 12 July 2013).

Department of Defense. Air Land Sea Application Center. Field Manual 3-09.32, *JFIRE Multi-Service Tactics, Techniques, and Procedures for the Joint Application of Firepower*. Washington, DC: Government Printing Office, 2007.

______. Department of Defense Directive Number 5105.60, *National Geospatial-Intelligence Agency (NGA).* 2009. http://www.dtic.mil/whs/directives/corres/pdf/510560p.pdf (accessed 6 July 2013).

______. *Draft Target Mensuration Procedure.* Washington, DC: Government Printing Office, 2008.

______. Joint Publication 3-09, *Joint Fire Support*. Defense Technical Information Center, 2010. http://www.dtic.mil/doctrine/new_pubs/jp3_09.pdf (accessed 12 July 2013).

______. Joint Publication 3-09.3, *Close Air Support*. 2009. http://www.fas.org/irp/doddir/dod/jp3_09_3.pdf (accessed 12 July 2013).

______. Joint Publication 3-60, *Joint Targeting*. Washington, DC: Government Printing Office, 2013.

Department of the Navy. Marine Corps Warfighting Publication 3-16.7, *Marine Artillery Survey Operations.* 2002. http://community.marines.mil/news/publications/Documents/MCWP%203-16.7%20Marine%20Artillery%20Survey%20Operations.pdf (accessed 6 July 2013).

Field Artillery Branch Historian's Office. *U.S. Army Field Artillery School Annual History, 1 January 2012 through 31 December 2012.* U.S. Army. https://www.us.army.mil/suite/designer (accessed 22 November 2013).

Headquarters, Department of the Army. Army Doctrine Publication 3-09, *Fires.* 31 August 2012. http://armypubs.army.mil/doctrine/ADP_1.html (accessed 13 July 2013).

______. Army Field Artillery School ST 6-50-20, *Battery Executive Officer's/Platoon Leader's Handbook.* Washington, DC: Government Printing Office, 1986.

______. Army Technical Manual 5-6675-308-24P, *Position and Azimuth Determining System AN/USQ-70.* Washington, DC: Government Printing Office, 1992.

______. Army Technical Manual 9-1015-252-10P, *Technical Manual/Operator's Manual for Howitzer, Light, Towed, 105-MM, M119A2.* Washington, DC: Government Printing Office, 2006.

______. Army Technical Manual 9-6675-347-13&P, *Gun Laying and Positioning System (GLPS): M67.* Washington, DC: Government Printing Office, 2000.

______. Army Techniques Publication 3-09.3, *Techniques for Observed Fire.* 2013. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Army Techniques, Tactics and Procedures 3-37.31, *Civilian Casualty Mitigation*. 2012. http://armypubs.army.mil/doctrine/DR_pubs/dr_a/pdf/attp3_37x31.pdf (accessed 13 July 2013).

______. Army Training and Evaluation Program 6-037-30-MTP, *Field Artillery Consolidated Cannon Battery.* Washington, DC: Government Printing Office, 2012.

______. *DAGR Operator's Pocket Guide to 31R4-2PSN13-8-1.* Washington, DC: Government Printing Office, 2005.

______. Field Manual 3-09, *Fire Support.* http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July, 2013).

______. Field Manual 3-09.12, *Tactics, Techniques, and Procedures for Field Artillery Target Acquisition.* 2002. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Field Manual 3-09.15, *Tactics, Techniques, and Procedures for Field Artillery Meteorology*. 2007. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Field Manual 3-09.21 (FM 6-20-1), *Tactics, Techniques, and Procedures for Field Artillery Battalion.* 2001. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Field Manual 3-09.31 (FM 6-71), *Tactics, Techniques, and Procedures for Fire Support for the Combined Arms Commander.* 2002. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Field Manual 3-09.60 (FM 6-60), *Multiple Launch Rocket System (MLRS) Operations.* 2008. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Field Manual 3-09.70, *Tactics, Techniques, and Procedures for M109A6 Howitzer (Paladin) Operations.* 2000. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Field Manual 3-09.80, *Field Artillery Gunnery.* Washington, DC: Government Printing Office, 2006.

______. Field Manual 3-60, *The Targeting Process*. 2010. http://armypubs.army.mil/doctrine/6_Series_Collection_1.html (accessed 13 July 2013).

______. Field Manual 5-19, *Composite Risk Management.* U.S. Army Criminal Investigation Command, 2006. http://www.cid.army.mil/documents/Safety/Safety%20References/FM%205-19%20Composite%20Risk%20Management.pdf (accessed 6 July 2013).

______. Field Manual 6-2, *Artillery Survey*. Washington, DC: Government Printing Office, 12 August 1965.

______. Field Manual 6-20-20, *Tactics, Techniques, and Procedures for Fire Support at Battalion Task Force and Below*. Washington, DC: Government Printing Office, 1991.

______. Field Manual 6-40, *Field Artillery Manual Cannon Gunnery*. Washington, DC: Government Printing Office, 1996.

______. Field Manual 6-50, *Tactics, Techniques, and Procedures for Field Artillery Manual Cannon Gunnery*. Washington, DC: Government Printing Office, 1996.

______. U.S. Army Field Artillery School, Student Text 6-50-20, *Battery Executive Officer's/Platoon Leader's Handbook*. Washington, DC: Government Printing Office, 1986.

Joint Readiness Training Center. *Fire Direction Center Smart Book.* U.S. Army. https://www.us.army.mil/suite/designer (accessed 30 May 2013).

National Imagery and Mapping Agency (NIMA). NIMA Technical Report 8350.2, *World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems*, National Geospatial Intelligence Agency, 2000. http://earth-info.nga.mil/GandG/publications/tr8350.2/wgs84fin.pdf (accessed 12 July 2013).

The Official Website of Fort Sill, Oklahoma. Field Artillery Basic Officer Leader Course–B (BOLC-B), "Course Overview & Requirements." U.S. Army. http://sill-www.army.mil/BOLC-B_1/ (accessed 15 October 2013).

U.S. Army Chief Warrant Officer Field Artillery School. "Precision Targeting Class." Field Artillery Targeting Technician School Curriculum, Ft. Sill, OK. DVD from Center for Army Lessons Learned, Ft. Leavenworth, KS, 25 May 2013.

Journals/Periodicals

Finely, Todd, LtCol USMC. After Action Review, "Target Location Errors in the MEB-Afghanistan Area of Operations." 3rd Battalion, 10th Marines, 28 December 2009.

Fraczek, Witold. "Mean Sea Level, GPS, and the Geoid." *Arcuser* (July-September 2003): 36-41.

Lipinski, Joseph. "Commonality of Towed Artillery Digital Fire Control Systems (DFCS)." *Army AL&T* (July-September 2010): 21-24. http://asc.army.mil/docs/pubs/alt/2010/3_JulAugSep/articles/21_Commonality_of_Towed_Artillery_Digital_Fire_Control_Systems_(DFCS)_201003.pdf (accessed 25 May 2013).

Milbert, Dennis, G., and Dru A. Smith. "Converting GPS Height into NAVD88 Elevation with the GEOID96 Geoid Height Model." National Geodetic Survey, National Oceanic and Atmospheric Administration. (http://www.ngs.noaa.gov/PUBS_LIB/gislis96.htm (accessed 12 July 2013).

Other Sources

Dana, Peter H. "Geodetic Datum Overview." University of Colorado Boulder, 2003. http://www.colorado.edu/geography/gcraft/notes/datum/datum.html (accessed 12 July 2013).

Driels, Morris, R. *Weaponeering: Conventional Weapon System Effectiveness.* Reston, VA: American Institute of Aeronautics and Astronautics, Inc., 2004.

Matts, James A., and Andrew G. Ellis. "Artillery Accuracy: Simple Models to Assess the Impact of New Equipment and Tactics." http://www.dtic.mil/dtic/tr/fulltext/u2/a221243.pdf (accessed 13 September 2013).

Simeone, Robert, J. “Mils and MOA.” SCRIBS. http://static.scribd.com/docs/d2ke2aetnlp77.pdf (accessed 28 September 2013).

Snyder, John P. Geological Survey, Professional Paper 1395, “Map Projections, A Working Manual.” Department of Oceanography, Navy Postgraduate School, 1987. http://www.oc.nps.edu/oc2902w/maps/synder.pdf (accessed 5 July 2013).