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M1A2 ADJUNCT ANALYSIS

(POSNAV VOLUME)

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DEPARTMENT OF THE ARMY

US ARMY ARMOR CENTER
FORT KNOX, KENTUCKY 40121-5215

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December 1989

Department of the Army

United States Army Armor Center

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(POSNAV VOLUME)

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POSNAV

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The TRADOC Analysis Command (TRAC) completed the M1A2 COEA in March 1989. This report supplements the M1A2 COEA. The Defense Acquisition Board (DAB) authorized full scale development and testing of the preferred M1A2 tank configuration. The DAB stated that additional analytic justification is required to include the Position Navigation unit, the CO_2 Laser Rangefinder and the Survivability Enhancements Packages 1 and 2 in the Milestone III production decision. The analysis presented in this report is limited to the Position Navigation (POSNAV) system, proposed as one of the modifications to the M1A1 tank. The report is an analysis of the POSNAV capabilities, its impact on force effectiveness, operational suitability, and training effectiveness, and its cost effectiveness to the force.

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	M1A2 ADJUNCT ANALYSIS **(POSNAV VOLUME)**	**STUDY GIST**

THE REASON FOR PERFORMING THE STUDY was to provide the Conventional Systems Committee with analytic justification for including the position navigation system in the list of approved Block II components for the M1A2 tank. This study supplements the March 1989 M1A2 COEA.

THE PRINCIPAL RESULTS of this adjunct analysis are the impacts that navigation has on force effectiveness and training effectiveness. The analysis demonstrates the benefits of control of maneuver and the massing of combat power, both of which are benefits of accurate and reliable navigation. The analysis documents examples of detrimental, but far too common, training techniques designed to compensate for lack of navigation capability. The analysis determined that increased training alone would not correct for lack of navigation skills. The analysis presents life cycle cost estimates that are nominal in comparison to the total M1A2 system costs. The analysis concludes that the additional M1A2 system costs of the POSNAV component are strongly justified by the additional benefits.

THE MAIN ASSUMPTION is that the production quantities established in the March 1989 M1A2 COEA remain valid.

SCOPE: This volume of the adjunct analysis evaluated only the position navigation component of the M1A2. The cost analysis figures are in FY89 dollars for compatibility with the March 1989 M1A2 COEA. The analysis is based on the Airland Battle doctrine as presented in FM 100 - 5.

THE STUDY OBJECTIVES were to evaluate the cost and operational effectiveness of the position navigation component of the Block II improvements to the Abrams main battle tank and to provide the analytic results to the Conventional Systems Committee.

THE BASIC APPROACH included a four phase methodology. Phase I documents the operational requirements. Phase II analyzes armor capabilities with and without a navigation device and its impact on force effectiveness and training effectiveness. Phase III analyzes the proposed solution, including alternative systems and system life cycle costs. Phase IV weighs the burdens and the benefits and recommends the preferred solution.

THE STUDY SPONSOR was the Headquarters Department of the Army , Heavy Force Modernization Coordinating Office.

THE STUDY PROPONENT was the United States Army Armor Center and School.

THE STUDY AGENCY was the United States Army Armor Center and School.

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ABSTRACT

The TRADOC Analysis Command (TRAC) completed the M1A2 COEA in March 1989. This report supplements the M1A2 COEA. The Defense Acquisition Board (DAB) authorized full scale development and testing of the preferred M1A2 tank configuration. The DAB stated that additional analytic justification is required to include the Position Navigation unit, the CO_2 Laser Rangefinder and the Survivability Enhancements Packages 1 & 2 in the Milestone III production decision. The analysis presented in this report is limited to the Position Navigation (POSNAV) system, proposed as one of the modifications to the M1A1 tank. The report is an analysis of the POSNAV capabilities, its impact on force effectiveness, operational suitability, and training effectiveness, and its cost effectiveness to the force.

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SECTION I - EXECUTIVE SUMMARY

A. Introduction. This analysis supplements the March 1989 M1A2 Cost and Operational Effectiveness Analysis (COEA). The analysis is limited to the Position Navigation (POSNAV) system, proposed as one of the modifications to the M1A1 tank.

1. Purpose. Purpose is to support a Conventional Systems Committee Review of the M1A2 program.

2. Key Issues. Key issues to be addressed:

- What are the operational effectiveness contributions of the M1A2 POSNAV device?
- What are the operational suitability benefits of the M1A2 POSNAV?
- What are the technological alternatives to the M1A2 POSNAV?
- What are the Life Cycle Costs associated with the M1A2 POSNAV?
- What level of confidence is associated with analysis based on NTC or SIMNET data?
- Do the benefits (operational effectiveness and operational suitability) associated with a POSNAV device justify its cost?

3. Applicability of Results. The operational effectiveness and operational suitability results presented in this report apply equally to M1A1 or M1A2 tanks. Cost comparisons are only applicable to the M1A2 tank.

B. Summary of Results.

- The addition of a self-contained inertial POSNAV device to an M1A2 will increase operational effectiveness.
- The POSNAV will enhance the operational suitability of the M1A2 on the AirLand Battlefield.
- The POSNAV is the most cost effective alternative to meet the position navigation requirements for the M1A2 tank.
- The most significant portion of the POSNAV's Life Cycle Cost is recurring production costs. It will cost $21,000 apiece to place a POSNAV device on each M1A2 configured as approved by the Defense Acquisition Board. This represents less than a one percent increase in M1A2 system cost.
- For the issues examined in this analysis, data and observations from the NTC and SIMNET are considered very applicable.
- The battlefield capabilities provided by the POSNAV are an order of magnitude greater than its cost.

C. Background. This section provides a review of the rationale for this analysis and a description of the "navigation problem".

1. M1A2 Block II Program. The M1A2 tank program consists of a block of improvements to the M1A1 main battle tank. Originally, the Block II comprised the eight components depicted in figure 1-1. In August 1988, the Chief of Staff of the Army decided, due to affordability, to eliminate the Driver's Thermal Viewer (DTV) and the Inter-vehicular Information System (IVIS) from the M1A2 "production" tank. However, he recommended that the entire set of components enter into Full Scale Development (FSD). The M1A2 entered FSD on 12 December 1988.

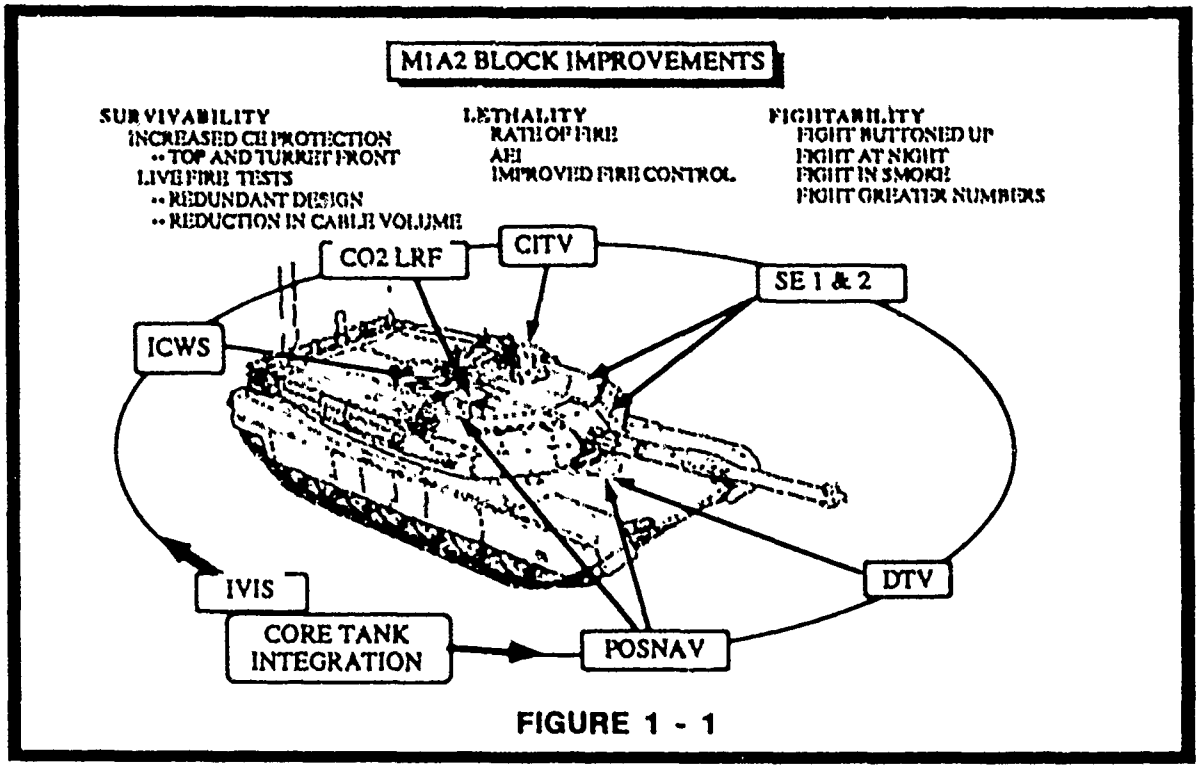


FIGURE 1 - 1

a. On 2 December 1988, the Defense Acquisition Board (DAB) authorized the M1A2 program to enter FSD, and tasked the Army to produce and deliver a new COEA to the Office of the Secretary of Defense (OSD) Conventional Systems Committee (CSC) on 31 March 1989.

b. At a 31 August 1989 meeting of the DAB, the following guidance was given to the Army:

- "The Army is authorized to complete Full Scale Development and testing of the preferred M1A2 tank configuration within an average unit weapon system cost threshold of $3.037 million (in FY89 dollars based on a FY91-97 quantity of 2926 tanks, one plant operation, and 516 tanks per year)."

Note: A $3.037 million tank corresponds to an M1A2 tank equipped with a Commander's Independent Thermal Viewer (CITV), an Improved Commander's Weapons Station (ICWS), and a CORE TANK systems integration package.

- "The CO_2 Laser Range Finder, the Position-Navigation unit, and the Survivability Enhancement Packages 1 and 2 should be examined further. If the Conventional Systems Committee (CSC) is persuaded of the value of these components by the additional analytic justification, these components will be included in the Milestone III production decision even if the average unit weapons system cost would exceed the threshold."

2. Navigation Problems - Past and Present. Problems associated with position navigation are not new. The battle, as described by Erwin Rommel, which occurred on the night of 27 June 1942, near Minqa Quaim, Egypt is a case in point. "One can scarcely conceive the confusion that reigned that night. It was pitch-dark and impossible to see one's hand before one's eyes. The R.A.F. bombed their own troops, and, with tracers flying in all directions, German units fired on each other".

a. The U.S. Army has never been so well equipped or so well trained, but the "fog of war" still reigns, during both day and night. The pace of battle, extremely accurate field artillery systems, artillery delivered mine fields, obscurants so dense they turn day into night, and a need to better utilize night fighting advantages all serve to accentuate the need to find more reliable means to navigate tank units.

b. The Abrams tank and Bradley fighting vehicle will provide leaders the ability to achieve the AirLand Battle tenets of agility, initiative, synchronization and depth. **Our ability to maneuver at greater speeds and fight at night have greatly exacerbated our inability to synchronize our efforts, maintain positive command and control, and maintain accurate terrain orientation.**

c. Despite seven years of experience and repeated emphasis at the NTC, U.S. forces have not been able to correct deficiencies such as piecemeal attacks. Perhaps the most significant evidence as to our inability to capitalize on the speed of our new systems and to execute synchronized operations is the extent to which we have accepted poor training habits. Tank soldiers fight from exposed (open hatch) positions while receiving heavy incoming fires. Routes and vehicles are marked with chemical lights at night. Scouts are used for road guides when they should be performing reconnaissance tasks. Most critically, poor maneuver formations, that lack mass and fire power, are adopted in an effort to insure that more forces get to the battle.

D. Methodology. This study addresses six key issues (Para. A.2. Pg 1). The organization of the POSNAV analysis supports the development of these issues. The POSNAV analysis is organized into the following sub-analyses:

Analysis of: (Requirement)

- Tactical Imperatives (Define the operational requirements)

Analysis of: (Problem and Impact)

- Capabilities (Determine the extent of the navigational problem)
- Force Effectiveness (Determine impact on effectiveness)
- Training Effectiveness (Determine impact of position navigation on training effectiveness)

Analysis of: (Alternative Solutions)

- System Requirements (Define the requirements from the ROC)
- Alternative Systems (Determine most acceptable alternative)
- Cost (Determine incremental Life Cycle Cost)

1. Approach. This analysis evaluates the performance of U. S. armored and mechanized forces in terms of the basic tenets of AirLand Battle and the Principles of War and their impact upon operational effectiveness and operational suitability. A wide range of data sources is analyzed to evaluate the cost, need and benefits of the M1A2 POSNAV. The relationships between the analysis of: Requirements, Problem and Impact, Alternative Solutions, and Preferred Alternative are presented in figure 1-2.

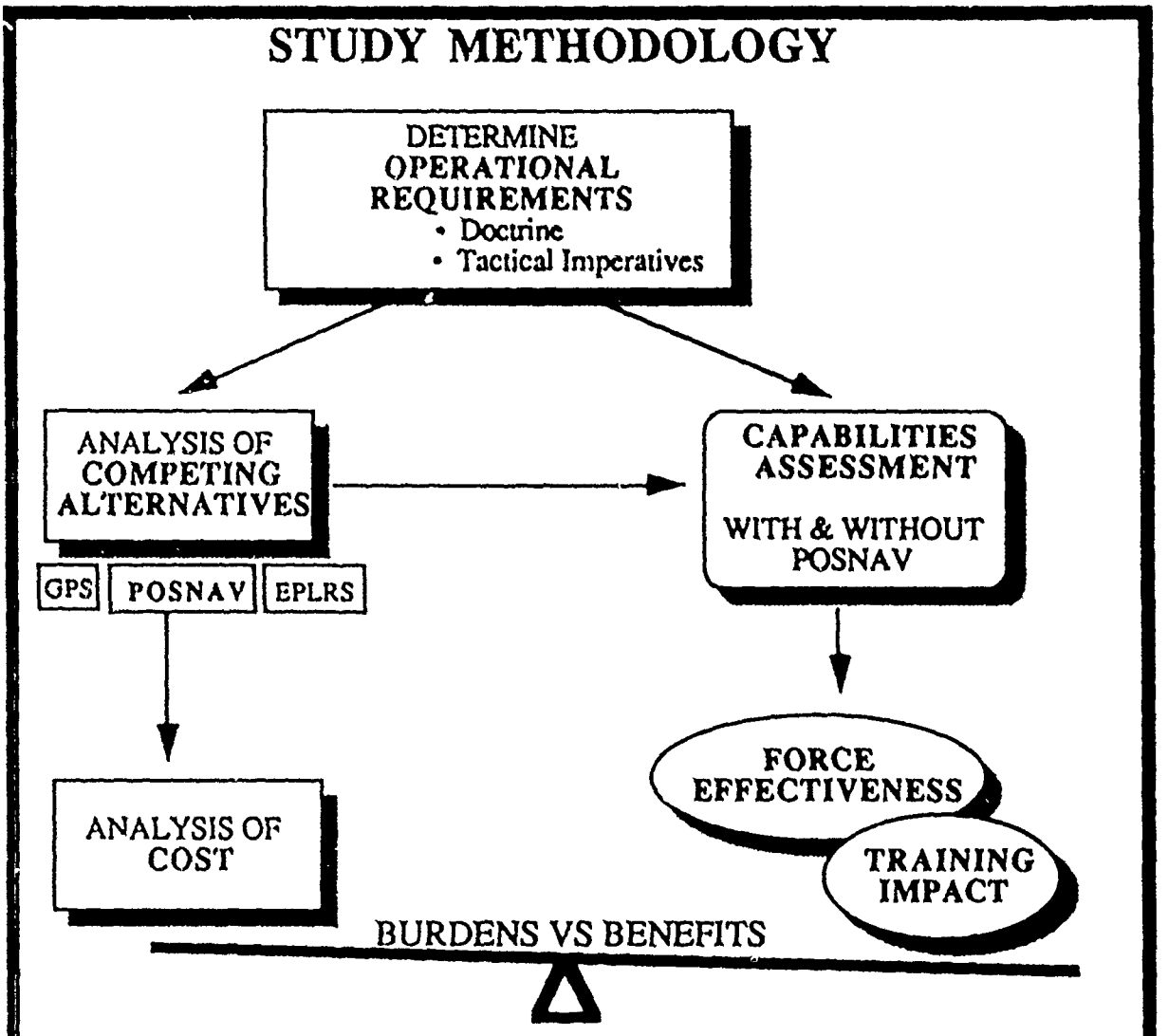


FIGURE 1-2

2. NTC and SIMNET. Much of this POSNAV analysis is based on data, observations, and experiments conducted at either the NTC or in SIMNET. It is imperative that anyone reviewing this analysis understand the nature of these two sources of data. Data from the NTC and SIMNET include many of the attributes commonly associated with computer simulations. At the same time, the NTC and SIMNET provide advantages of repeatability, or more accurately - large sample sizes, combined with many man-in-the-loop factors which the computer cannot adequately address. This is important because problems associated with position navigation are inextricably linked to human errors. For these reasons, the NTC and SIMNET were determined to be the most appropriate simulations available to evaluate the issues in this analysis. Descriptions of the NTC and SIMNET simulation environments are provided in appendices A and B.

3. Measures of Effectiveness.

a. Loss Exchange Ratio (LER). One of the most accepted Measures of Effectiveness (MOE) in ground combat operational effectiveness analysis is the (LER). This measure is widely accepted because it measures the benefit of a particular system or organizational change to the entire force. The LER is defined as follows:

LER =Total # RED forces destroyed ÷ Total # BLUE forces destroyed.

b. Other MOE have been established for many of the analyses referenced. In each case the new MOE is defined and its relationship to LER explained.

E. Conclusions. The significant conclusions developed in this analysis are presented coincident with the six key study issues.

1. What are the operational effectiveness contributions of the M1A2 POSNAV device?

FINDINGS: The linkage between a POSNAV device and an increase in operational effectiveness can be established in two ways. An increase in the ratio of enemy losses to friendly losses (LER) is obtained if either (1) more RED systems are killed, or (2) more U.S. systems survive. As established in this analysis, the M1A2 POSNAV provides for increases in the LER by means of several mechanisms. Where the analysis supports a POSNAV-LER linkage with quantifiable data, a percentage band for the increase in LER is provided.

a. A POSNAV device will contribute to more RED systems killed.

• Provide commanders the capability of moving their forces on multiple axes of advance, during periods of limited visibility, and massing their combat power at the critical place and time.

• Provide every Tank Commander the capability to call for first-round fire-for-effect artillery fire by giving him the ability to send accurate target grid coordinates.

b. **A POSNAV device will contribute to more U.S. systems surviving.**

• More accurate artillery fires will suppress greater numbers of air defense and anti-tank systems.

• Fewer "adjust fire" missions will result in fewer opportunities for RED counter-battery artillery to fire on U.S. artillery systems.

• Offensive operations at night will greatly reduce the effectiveness of RED direct fire systems which rely on infra-red illumination to engage targets.

• Reduce the instances of fratricide.

• More accurate navigation will enable U.S. units to avoid known obstacles and contaminated areas.

• Eliminate poor training habits which will result in wartime casualties.

2. What are the operational suitability benefits of the M1A2 POSNAV?

FINDINGS: In terms of performance, the evidence indicating the existence of a significant position navigation problem is compelling. The ARI POSNAV test clearly establishes the superior capability of POSNAV equipped crews and platoons to accomplish navigation related tasks. The imperatives established by an offensive U.S. doctrine mandate, in terms of navigation skills, a more capable maneuver force. Inherent navigation capabilities preclude full maximization of U. S. investments in night acquisition devices and lethal artillery fires.

3. What are the technological alternatives to the M1A2 POSNAV?

FINDINGS: The POSNAV, GPS, and EPLRS were compared in terms of requirements and system cost. The results of this analysis are consistent with the Vehicle Navigation Aid System (VNAS) Abbreviated Analysis, which also concluded that **the POSNAV device is the most cost effective alternative to meet the needs of the M1A2 tank.** In fact, it is the only alternative which provides heading reference and is a self contained unit. These attributes are required to provide far target location capability and, as demonstrated in the Soviet Artillery Effects Test, to provide a survivable system which is not dependent upon an external antenna. Both these attribute contribute to increases in operational effectiveness and enhanced operational suitability.

4. What are the Life Cycle Costs associated with the M1A2 POSNAV?

FINDINGS: The incremental LCC for placing a POSNAV on M1A2s is $74.7 million (FY89 Constant Dollars, QTY=2926 tanks). Recurring production costs account for 82.2 percent of the increase. The incremental recurring Average Unit Cost (AUC) for an M1A2 with POSNAV is $21,000. This represents less than a one percent increase in the M1A2 system cost.

5. What level of confidence is associated with analysis based on NTC or SIMNET data?

FINDINGS: For the narrow spectrum of issues examined in this report, the data obtained from both SIMNET exercises and NTC after-action reports was found to be very acceptable. In both cases, the data were found to be objective, well organized, significant (large sample size), and most importantly, representative of soldier conduct under simulated combat conditions.

6. Do the benefits (operational effectiveness and operational suitability) associated with a POSNAV device justify its cost?

FINDINGS: The addition of a self-contained inertial POSNAV device to an M1A2 tank will increase the operational effectiveness of U.S. tank battalions. It is clearly an enhancement to the execution of tank battalion/task force and armored cavalry squadron missions, and provides battlefield capabilities that are greater than its cost. The ability of a maneuver force to mass its combat power at the critical place and time, the application of more accurate field artillery fires, and the reduction of instances of fratricide, all contribute to a more effective combat force. In terms of operational suitability, a POSNAV device will greatly enhance the ability of U.S. Forces to conduct offensive operations during periods of reduced visibility. The increased speed of movement and massed combat power, afforded by a POSNAV device, contribute to a unit's agility, synchronization, initiative, and depth - the cornerstones of our operational and tactical plans.

F. RECOMMENDATION. Adjust the M1A2 average unit weapon system cost threshold from $3.037 million to $3.058 million (in FY89 dollars based on a FY91-97 quantity of 2926 tanks, one plant operation, and 516 tanks per year). The purpose of this adjustment is to include the POSNAV device in the M1A2 Milestone III production decision.

SECTION II - POSNAV ANALYSIS

A. Introduction. The POSNAV analysis is organized into the following sub-analyses:

Analysis of: (Requirement)

- Tactical Imperatives (Define the operational requirements)

Analysis of: (Problem and Impact)

- Capabilities (Determine the extent of the problem)
- Force Effectiveness (Determine impact on effectiveness)
- Training Effectiveness (Determine impact of position navigation on training effectiveness)

Analysis of: (Alternative Solutions)

- System Requirements (Define the requirements from the ROC)
- Alternative Systems (Determine most acceptable alternative)
- Cost (Determine incremental Life Cycle Cost)

B. References. Appendix E. (References).

C. Distribution. Appendix F. (Distribution).

D. Tactical Imperatives.

1. Doctrinal Mandate. AirLand Battle mandated that our defensive based doctrine be replaced with an offensive, maneuver based doctrine.

a. AirLand Battle was codified in August, 1982 with the publication of FM 100-5 Operations. It established the tenets of **initiative, agility, depth, and synchronization** as the cornerstones of our operational and tactical plans.

b. In addition to recognizing the characteristics of modern warfare and refocusing our attention on the offensive, AirLand Battle doctrine reemphasized the importance of the historically established "Principles of War".

PRINCIPLES of War

• Objective	• Unity of Command	• Economy of Force
• Offensive	• Security	• Simplicity
• Mass	• Surprise	• Maneuver

Table 2 - 1

2. Critical Time and Place. As presented in FM 100-5 Operations, an important implication of initiative, agility, depth, and synchronization is the ability to focus ones combat power at the *critical time and place*. Figure 2-1 depicts the interaction of initiative, agility, and depth as they contribute to a synchronized and effective combat effort.

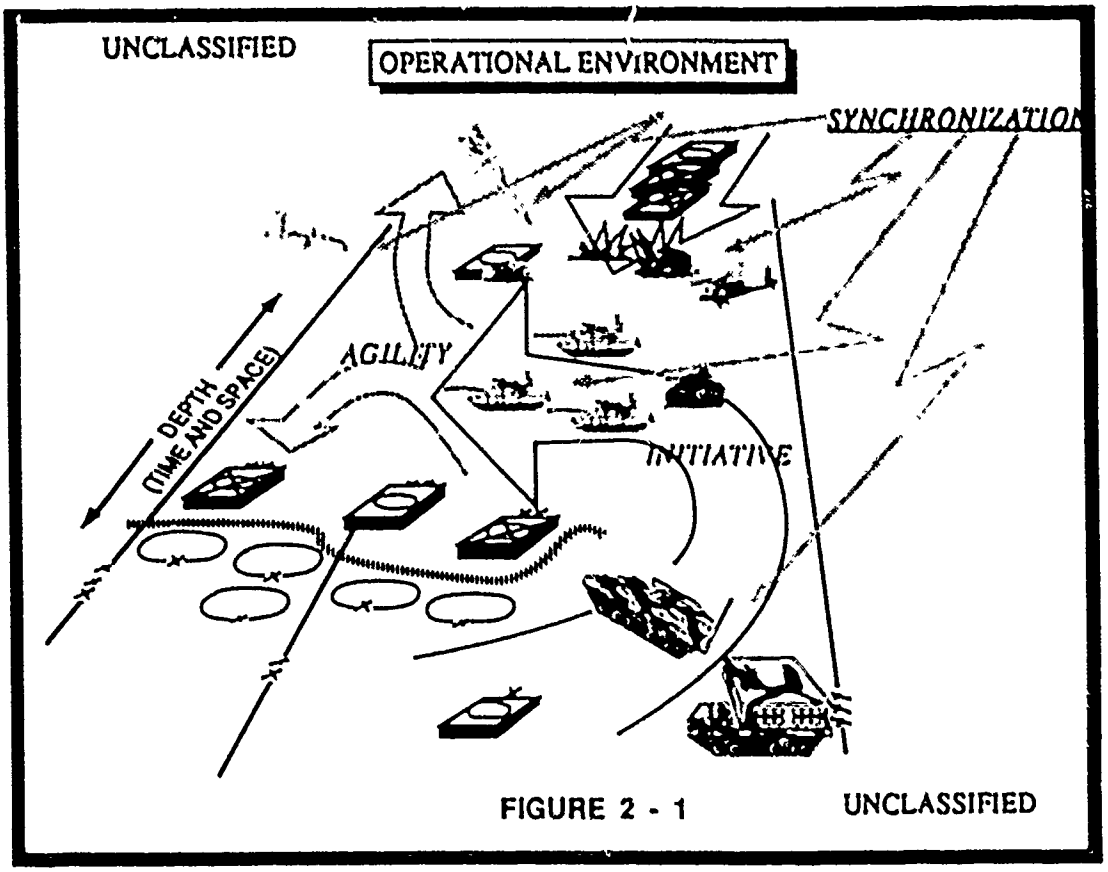


FIGURE 2 - 1

3. Speed and Cohesion. Requisite components of agility and synchronization are the attributes of speed and precision. As stated in FM 100-5, *"Speed is absolutely essential to success; it promotes surprise, keeps the enemy off balance, contributes to the security of the attacking force, and prevents the defender from taking effective countermeasures."* It also states, *"Speed can compensate for lack of mass and provide the momentum necessary for attacks to achieve their aims"*. As described in The Rommel Papers, Erwin Rommel states that *"Speed of movement and the organizational cohesion of one's own forces are decisive factors"*.

4. Operational Suitability. The concepts of critical time and place, speed and precision, and cohesive formations are essential to the efficient execution of a maneuver oriented doctrine. Any attempt to increase a system's ability to incorporate these concepts will contribute to the operational suitability of that system.

E. Capabilities Assessment - Determine the Extent of Problem. The purpose of this sub-analysis is to establish, in terms of performance, why a POSNAV device is needed. The March 1989 M1A2 COEA examined the issue of navigation shortfalls in the Armor Force. That report documented land navigation difficulties during a number of field training and evaluation exercises. The National Training Center (NTC) data base contains numerous examples of navigation shortfalls adversely affecting the success of combat training missions. Lessons learned from the Combined Arms in a Nuclear/Chemical Environment (CANE) series of evaluations reports a lack of controlled maneuver due to inadequate navigation capability.

1. NTC After-action Reports.

a. NTC after-action reports (AAR) cite repeated instances when units were out of position or completely failed to arrive in the proper locations to execute the plan. While there is clear evidence that the NTC experience has contributed immeasurably to the performance of U. S. maneuver forces, it is equally clear that, regardless of how often the point is highlighted, we find it difficult to concentrate our forces at the critical place in time. The following two observations span seven years of training at the NTC. NTC Training Observations, Volume II, released in September 1982, describes this trend:

"There is a general misunderstanding of what it means to concentrate overwhelming combat power.... The importance of isolating portions of the enemy and overwhelming him in detail while fixing the remainder of his force with the minimal force necessary is generally not practiced. Frontal attacks occur too often rather than flank attacks which concentrate the task force on platoons and roll up the enemy from the flank.... Attacking forces are subject to killing fires of the defender because shock, mass, and a heavy volume of fire cannot be generated."

b. Fourth Quarter FY89 trends from the NTC indicate that this same deficiency exists. The Chief of Observers/Controllers at the NTC, reports that:

- "Massing combat power, both in the offense and defense, is rarely done. In the offense, the TF [Task Force] will routinely throw one company at a time against an obstacle."

- Deliberate attack missions lost their momentum due to units being so scattered that the attack became piecemealed. Additionally, supporting elements such as scouts, mortars, air defense, and engineers became lost and were of no benefit to the maneuver elements. Otherwise solid battle plans failed due to confusion and loss of control by commanders because of poor navigation.

2. CANE. The CANE series of evaluations highlighted some serious deficiencies in combat units' ability to maintain unit cohesion under adverse conditions. Vehicle commanders in a closed-hatch, NBC environment experienced severe problems with control of fire and maneuver, and control of formations. Commanders reported serious degradations in their ability to control the scheme of maneuver because vehicles were not in the proper place, at the critical time, and in proper formations. A tank commander's preferred method of controlling his tank is with his head popped up through the commander's hatch allowing a full view of the area and events around him. With increases in battlefield lethality, volumes of artillery, and the threat of NBC attack, commanders are forced into a closed-hatch mode more often. With the additional burdens of battlefield obscurants and night time operations, navigation requirements are placing greater stress and time demands on an already overburdened tank commander.

3. Army Research Institute - Field Test. ARI conducted a Soldier Performance Research Project (SPRP) to assess the cognitive skill requirements of armor crewmen. The SPRP tested 120 19K (M1) tank commanders (TC) and 120 19K drivers from five continental U.S. (CONUS) divisions. Test surrogates were used for the gunners and loaders. TCs and drivers were paired as a function of four mental category groups as determined by the Armed Forces Qualification Test (AFQT).

a. The SPRP field test consisted of a high combat realism single tank tactical exercise which evaluated the speed and accuracy of each tank crew in combat related skills. The crew proceeded through a 15 km course at Ft. Knox, during which they encountered a number of engagements with opposing forces troops. At various points along the course, the crew was required to react to enemy encounters, send spot reports (including grid coordinates), negotiate a cleared lane in a friendly minefield while engaged with a partially concealed BMP, reconfigure as crew members became casualties, and identify their own location on a map. Performance measures included the speed and accuracy of command and control and combat reporting.

b. Four instances during each field test, the TC was required to identify the location of enemy targets (ranges up to 1600 meters) and in one instance, he was required to report his own location. Data for these location reporting requirements reveal an average grid deviation of nearly one kilometer (987 meters). The magnitude of these grid deviations reflect the difficulty tankers experience determining accurate grid coordinates.

4. Tank Crews/Platoons Equipped with POSNAV systems: The M1A2 COEA contained a description of an extensive series of SIMNET navigation exercises conducted by the U.S. Army Research Institute (ARI) designed to evaluate the effectiveness of a POSNAV system on the performance of individual tanks and on the performance of tank platoons. Results of these exercises demonstrated how a position navigation system is able to improve the Armor Force's capability to achieve the critical time and place, speed, and cohesiveness necessary for success on the battlefield. Findings of that study are summarized below.

Tank crews equipped with POSNAV systems:

- moved at greater speeds
- completed road march exercises quicker and more accurately
- traveled less distance
- expended 12 percent less fuel
- spent less time at a halt
- successfully bypassed more obstacles
- reported their own locations quicker and more accurately
- required fewer communications

Table 2 - 2

Tank platoons equipped with POSNAV systems:

- completed combat missions more frequently
- completed more mission segments
- successfully executed more fragmentary orders
- maintained appropriate platoon vehicle dispersion more consistently
- reported their own locations faster and more accurately
- reported target locations faster and more accurately
- reported shell impact locations more accurately

Table 2 - 3

5. Summary. In terms of performance, the evidence indicating the existence of a significant position navigation problem is compelling. The ARI POSNAV test clearly establishes the superior capability of POSNAV equipped crews and platoons to accomplish navigation related tasks. Tank crews and platoons with POSNAV exhibited greater speed and greater accuracy which in turn translates to better synchronization. It should not be inferred that the 12% fuel savings demonstrated in the tank crews exercise will translate to a training cost savings. It will, however, result in more efficient training.

F. Effect of Position Navigation On Force Effectiveness. The purpose of this sub-analysis is to establish the impacts of position navigation on operational effectiveness and operational suitability. A weapon system may be inherently lethal, but its effectiveness is dependent upon the ability to deliver that lethality at the critical time and place, as well as resupply, and training. Force effectiveness is, in turn, dependent upon the ability to synchronize the effects of several combat systems at the critical time and place. This portion of the analysis presents the results of high resolution simulation, graphical and regression analysis in the form of a masters thesis, observer/controller comments from the NTC, analysis conducted by the Army Research Institute and the Rand Corporation, and comments from a senior army commander extracted from a recent article in Military Review.

1. Results of Position and Navigation Systems COEA. One of the most deliberate efforts to document the requirement and the combat effectiveness benefits associated with position navigation was the Position and Navigation Systems COEA conducted by TRASANA in 1978. Although somewhat dated, the portion of this study that deals with combat effectiveness is still considered valid and will be included in the ongoing follow-on Global Position System (GPS) COEA, scheduled for completion in 4Q FY 90.

a. The Position and Navigation Systems COEA determined that the timely arrival of a reinforcing tank company would contribute an 8.9 percent increase in the combat Effectiveness Ratio (ER). The ER is defined as follows:

ER = BLUE Force Effective Value / RED Force Effective Value

where: Effective Value = $\Sigma_{(\text{all system types})}$ # Surviving Systems * System Value

Percent increases/decreases in an EF are directly comparable to percent increases/decreases in the LER.

b. The COEA incorporated a scenario which evaluated the contribution of a reinforcing tank company to the outcome of a battalion level defense. The timely arrival of reinforcing units is dependent upon several factors. Some of these are: time required to plan the movement, time required to disseminate the maneuver plan, and time required to execute the movement. The factors contributing to time delays used in this COEA were substantiated during the 1988 ARI- POSNAV experiment.

2. Results of Naval Postgraduate School Approved Thesis. Although the concept of mass is well established as a Principle of War, no one had previously established a quantitative relationship between mass and operational effectiveness. **The results of this thesis provide a statistically significant correlation between mass of an attacking force and operational effectiveness.**

a. A typical Soviet attack, as represented at the NTC, is very short and intense. Soviet Motorized Rifle Regiments close rapidly in massed formations and are usually successful in maneuvering through to the rear of the U. S. task force defense. On the other hand, U.S. attacks are usually conducted at a much slower pace, and are rarely successful at getting past the opposing forces (OPFOR) forward defensive positions. A review of observer/controller comments from nearly 100 U.S. task force attacks, concludes that piecemeal attacks are the number one reason for failed attacks at the NTC. A piecemeal attack is the antithesis of applying one's combat power at the critical place and time.

b. Although the concepts of Mass and Synchronization, the ability to concentrate forces at the critical place in time and space, have been established as principles (tenets), Captain Dave Dryer (U.S. Army), at the Naval Postgraduate School in 1989, was the first to conduct a formal study to quantify the linkage between critical time and space, and force effectiveness. Figure 2-2 presents the hypothesis evaluated in this thesis.

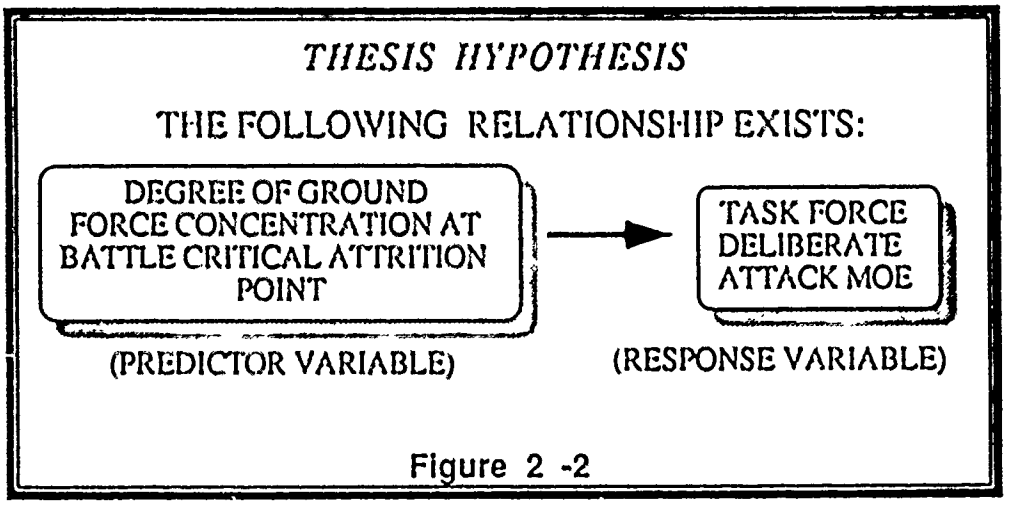


Figure 2 -2

c. The thesis developed "quartile radii" as a measure of mass at the critical point in space and time. This measure of ground force concentration calculates the radius of a circle (center located at the center of the defensive position) required to encompass a percentage of the number of live attacking vehicles. For example, a quartile radii, expressed as $R_{Q(25)}$ radius means that 25 percent of all attacking vehicle locations fall within the radius and 75 percent fall outside the radius.

d. The deliberate Attack mission MOE (AMOE) developed for this thesis is a modification of the more common LER. Although expressed differently, both MOE reward destruction of enemy forces and the preservation of own forces. As previously defined, the LER places equal weights on the destruction of enemy forces and the preservation of own forces. The AMOE differs from the LER in that the commander has the ability to "weight" the importance of the destruction of enemy forces and the preservation of his own forces. The weighting factors applied b PT Dryer were 0.5 and 0.5. This equal weighting is consonant with the equation for LER.

ATTACK MEASURE OF EFFECTIVENESS (AMOE)

$$\frac{\text{DESTROYED ENEMY TANKs/BMPs}}{\text{ENEMY START STRENGTH OF TANKs/BMPs}} * 100 = \%\ \text{ENEMY KILL}$$

• DESTROY ENEMY FORCE

$$\frac{\text{SURVIVING FRIENDLY TANKs/APCs}}{\text{FRIENDLY START STRENGTH OF TANKs/APCs}} * 100 = \%\ \text{FRIENDLY SURVIVAL}$$

• PRESERVE OWN FORCE

$$(0.5) * \%\ \text{ENEMY KILL} + (0.5) * \%\ \text{FRIENDLY SURVIVAL} = \text{AMOE}$$

FIGURE 2 - 3

e. Data examined in this thesis included the results of 23 randomly selected U. S. task force attacks at the NTC. The regression fit of AMOE against quartile radii $R_{Q(25)}$ is shown in figure 2-4. As shown, these results establish a statistically significant linkage between $R_{Q(25)}$ (mass) and AMOE (LER).

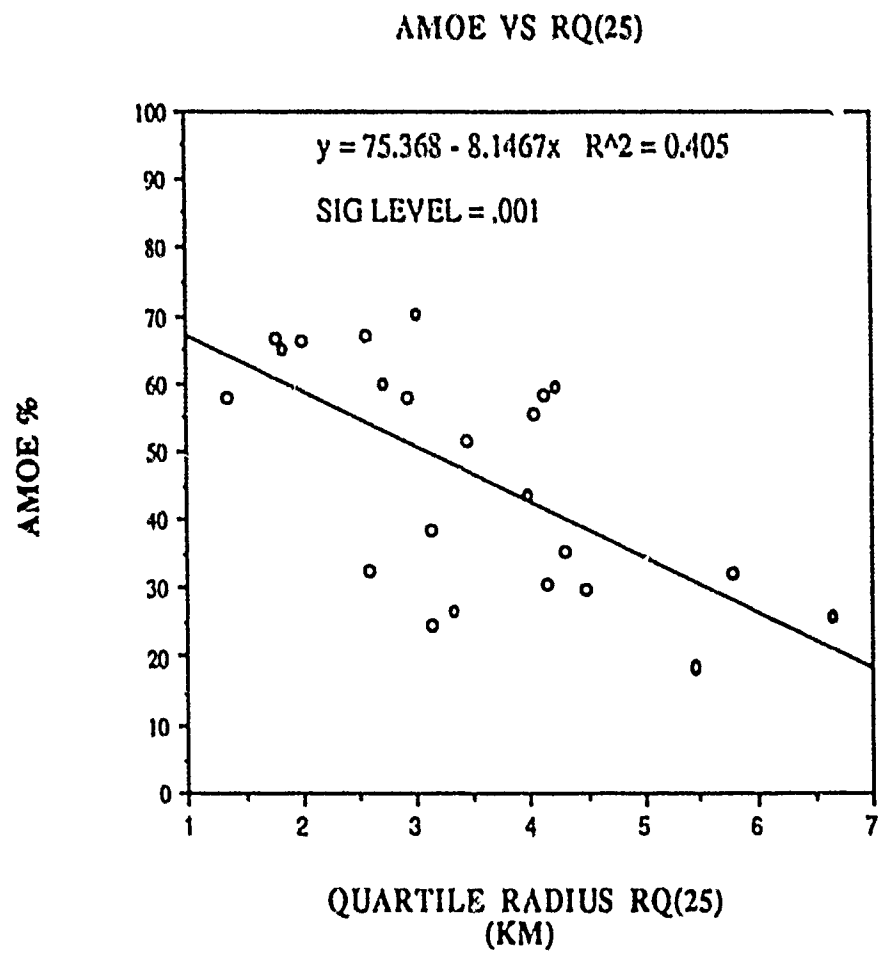


FIGURE 2 - 4

f. The thesis determined that the average U.S. task force AMOE was 46.6 percent. The average OPFOR AMOE was 67.7 percent. This represents a difference of 35 percent and is a direct result of the OPFOR's ability to affect the critical place and time of a battle.

g. The thesis concludes by stating, "it appears that the **massing of combat power at the critical attrition time is a prerequisite to success.** Task forces with deliberate attack MOEs above 50 percent have all massed 25 percent of their combat power within approximately 4 kilometers of the enemy center. These same successful units have all massed 50 percent of their combat power [direct fire systems] within approximately 5 kilometers of the enemy center."

h. In summary, the data examined in this thesis indicate the following:

• OPFOR units at the NTC (who have gained excellent position navigation through experience) are better able to synchronize and mass their maneuver formations. **OPFOR units win their battles.**

• Despite seven years of losing at the NTC, **U.S. task forces are unable to synchronize and mass their maneuver formations and continue to conduct piecemeal attacks.**

• The ability of a unit to mass its direct fire systems at the critical place and time correlates to higher levels of force effectiveness.

3. OPFOR Effectiveness. This section compares the capabilities of U.S. forces and the NTC OPFOR to conduct successful offensive operations. This sub-analysis will establish the following:

• In the offense, a primary difference between U.S. task force and OPFOR success rates is the ability of OPFOR units to mass their forces at the critical place and time.

• The ability of a unit to arrive at the critical place and time contributes not only to increases in force effectiveness (LER), but also to mission success or mission failure.

a. An analysis of NTC offensive missions examined 50 U.S. task force and 50 OPFOR attacks. The 100 battle sample includes results of 50 battles from FY89 rotations. These represent results of the most recent battles. Analysts selected the remaining 50 battles "at random" from the three previous years to provide an adequate sample.

b. The analysis examined results of the 100 offensive missions in terms of critical place and time. If an attacker is successful in avoiding the defender's engagement area and is able to attack at a point of weakness, his chances of success are greatly increased. First, through reconnaissance and maneuver, the attacking commander can choose the critical place and time of the battle. On the other hand, if the battle evolves in accordance with the defender's plan, and the attacker falls victim to the defender's engagement area(s), the defender has chosen the critical place and time of the battle.

c. The analysis examined the success of each attack, and the impact of the defender's plan in two ways. (1) Analysts superimposed system "kill location" plots over defensive plans, and (2) observed each battle in a "battle play-back". Analysts evaluated each battle to determine the effectiveness of the enemy's engagement area(s). If the defender was able to attrit the attacking force in one or more engagement areas, analysts rated the effect of the defender's plan as "significant". If the attacker was able to avoid the impact of a defender's engagement area, analysts rated the defender's plan as "overcome". Where a clear conclusion was not apparent, analysts rated the battle as "unclear". As depicted in figure 2-5, OPFOR units are clearly superior in their ability to combine tactical intelligence and maneuver skills and overcome (avoid) the defender's prepared defensive positions.

Impact of Defender's Engagement Area

	Significant	Overcome	Unclear
U.S ATTACKS (50)	31	10	9
OPFOR ATTACKS (50)	10	32	8

FIGURE 2 - 5

d. The following two examples illustrate the ability (inability) of an attacking unit to mass its forces at a point of weakness (critical time and place). The battles presented (one OPFOR and one U.S. attack) are two of the 100 battles analyzed in this section. These two battles are representative of the trends observed in the sample as a whole.

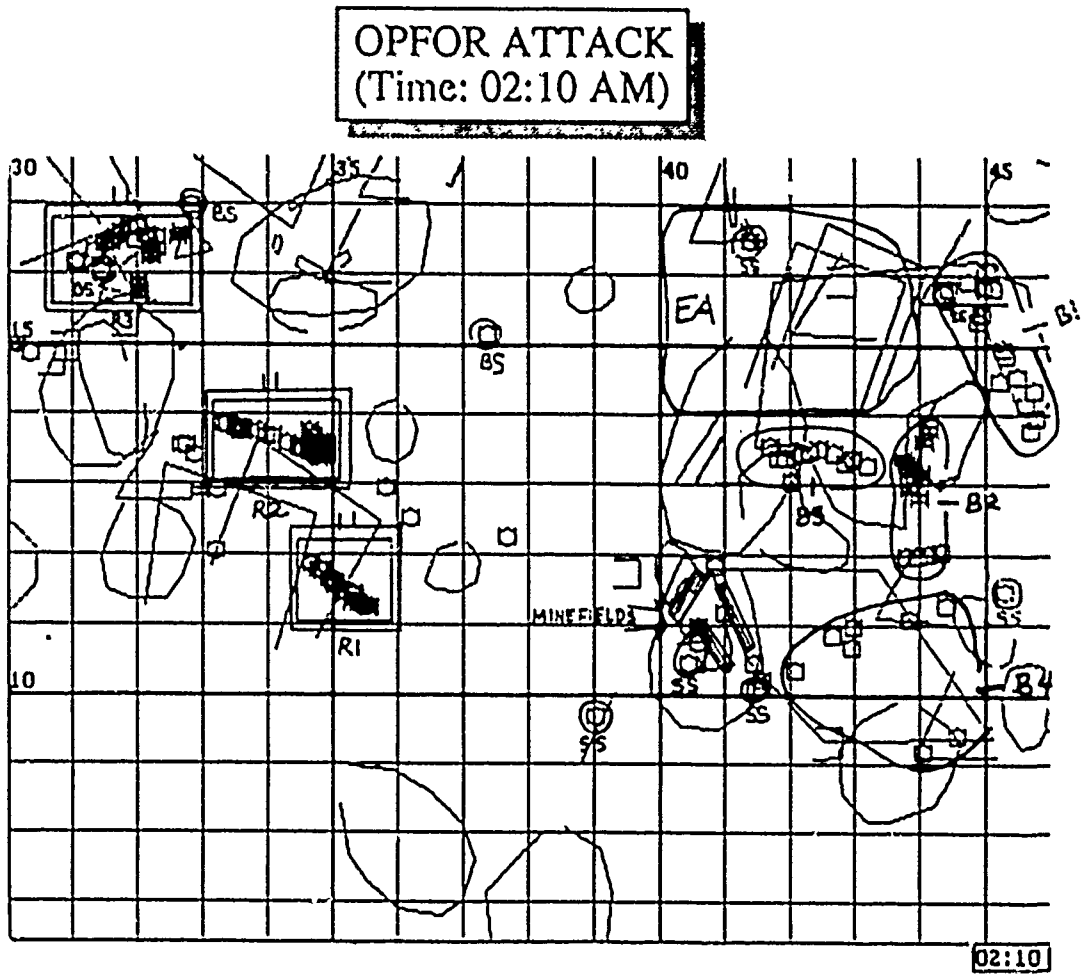
(1) Battle # 1 - OPFOR Attack. At 02:10 AM, the disposition of the attacking OPFOR motorized rifle regiment (3 battalions: R1, R2, R3) and the defending U.S. task force (4 companies: B1, B2, B3, B4) is depicted in figure 2-6. This figure was copied from a computer screen during a battle play-back.

• This battle takes place in the NTC "Central Corridor". The OPFOR motorized rifle regiment (MRR) is attacking from the West. When attacking through the Central Corridor, the attacker has three potential axes of attack (northern axis, southern axis or right up the middle). It is common knowledge that the OPFOR prefers to use the northern axis.

• As shown in figure 2-6, the U.S. defender has established a significant obstacle belt on the southern axis. The U.S. commander's intention was to convince the OPFOR that his main defensive effort was in the south, thus enticing him to take the northern (preferred) axis. The U.S. Commander then placed three of his four companies (all of his tanks) on the northern axis to form a significant engagement area (marked EA). His plan was to destroy the OPFOR regiment in this EA.

• Since the MRR entered the Central Corridor on the northern axis, we can assume that their initial plan may have been to attack along the northern axis. Regardless, by 02:10 AM, four OPFOR scouts (marked SS) have identified the weakness of the U.S. defense along the southern axis and the MRR has decided to attack at the point of weakness.

• By 02:10 AM the OPFOR scouts have also located a 200 meter gap in the obstacle belt. The MRR is 6 to 12 kilometers from the main defensive lines and must maneuver (navigate) to the 200 meter gap.

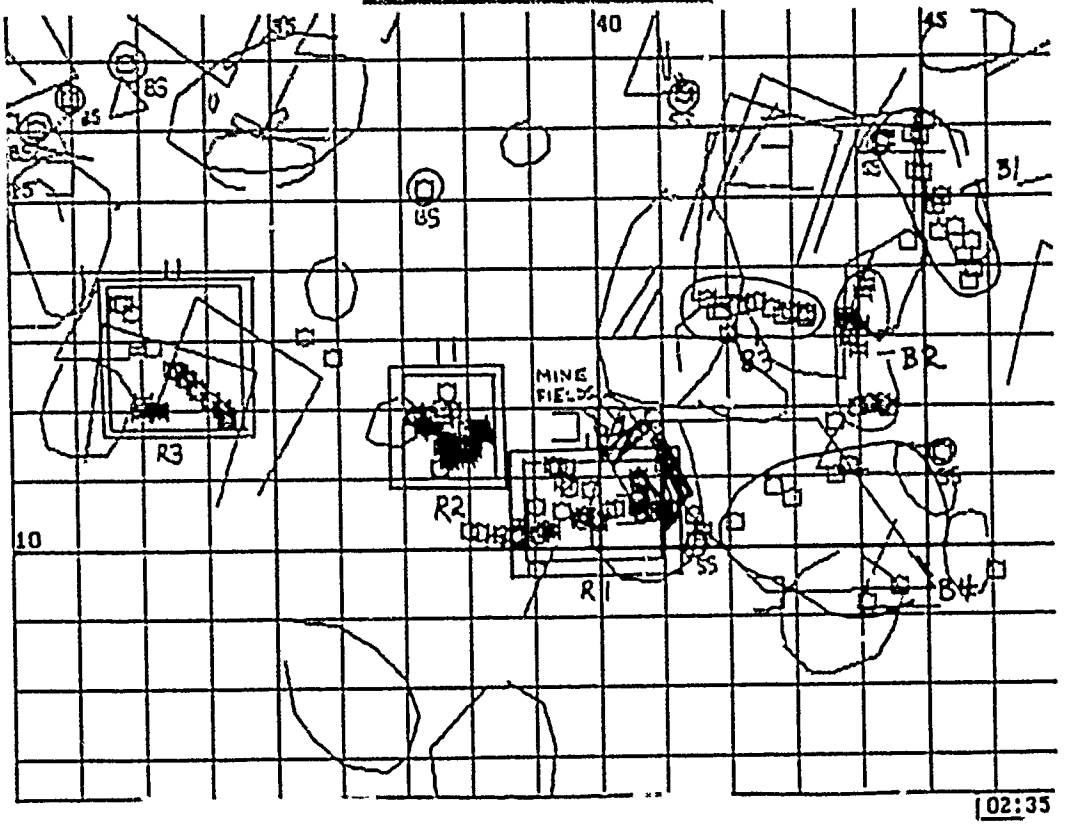


R1, R2, R3 - OPFOR Motorized Rifle Battalions
SS - OPFOR Scout

B1, - B4, U. S. Tank or Mechanized Infantry Teams

FIGURE 2 - 6

• The next battle play-back snap shot was taken at 02:35 AM (figure 2-7). The first motorized rifle battalion (MRB), R1, has successfully reached the 200 meter gap in the obstacle belt. MRBs R2 and R3 are approaching the gap on slightly different axes.



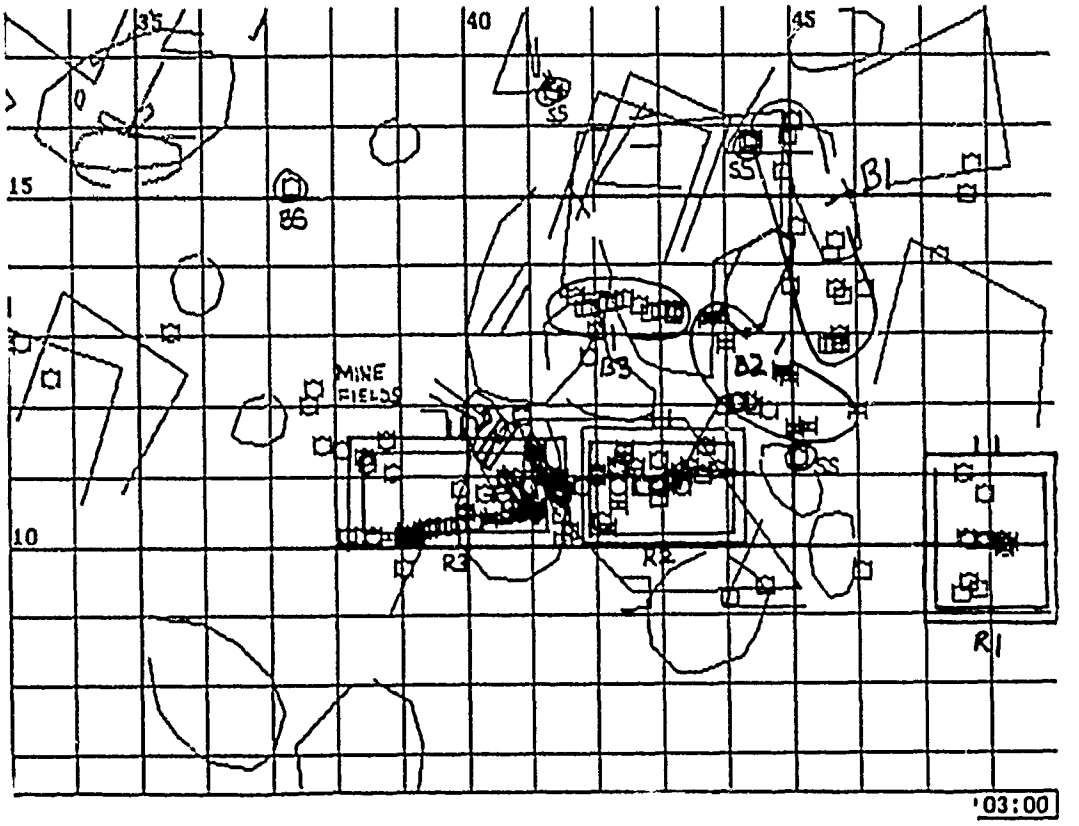
R1, R2, R3 - OPFOR Motorized Rifle Battalions
SS - OPFOR Scout
B1, - B4, U. S. Tank or Mechanized Infantry Teams

FIGURE 2 - 7

• The last snap shot of this battle was taken at 03:00 AM (figure 2-8). At this point in the battle, MRBs R1 and R2 are through the obstacle belt and MRB R3 is starting to cross the same gap. The U.S. task force commander has recognized that the OPFOR main attack is in the south and has started to move companies B1 and B2 to the south. MRB R1, however, is already behind them. The defender has failed his mission.

• Aside from the U.S. task force commander's poor use of obstacles, the success of this battle relied on two factors - accurate reconnaissance and accurate maneuver skills. As shown in the last snap shot of this OPFOR attack (figure 2-8), the OPFOR's ability to capitalize on the latest reconnaissance information and to quickly (and accurately) execute a precise maneuver enabled the maneuver force to avoid the enemy's true strength.

OPFOR ATTACK
(Time: 03:00 AM)



R1, R2, R3 - OPFOR Motorized Rifle Battalions
SS - OPFOR Scout

B1, - B4, U. S. Tank or Mechanized Infantry Teams

FIGURE 2 - 8

(2) Battle # 2 - U.S. Task Force Attack. At 9:03 PM, the disposition of the attacking U.S. task force (BB1) and the defending OPFOR motorized rifle company (R1) is depicted in figure 2-9. The U.S. task force has just made contact and is attacking directly into the heart of the OPFOR defense. The U.S. task force has very little firepower forward and is strung out for approximately 6-7 kilometers. As observed in figure 2-7, the OPFOR is able to mass two battalions into this same area. After observing the 50 U.S. task force attacks, the scene depicted in this graphic occurs far too often (31 out of 50 examined).

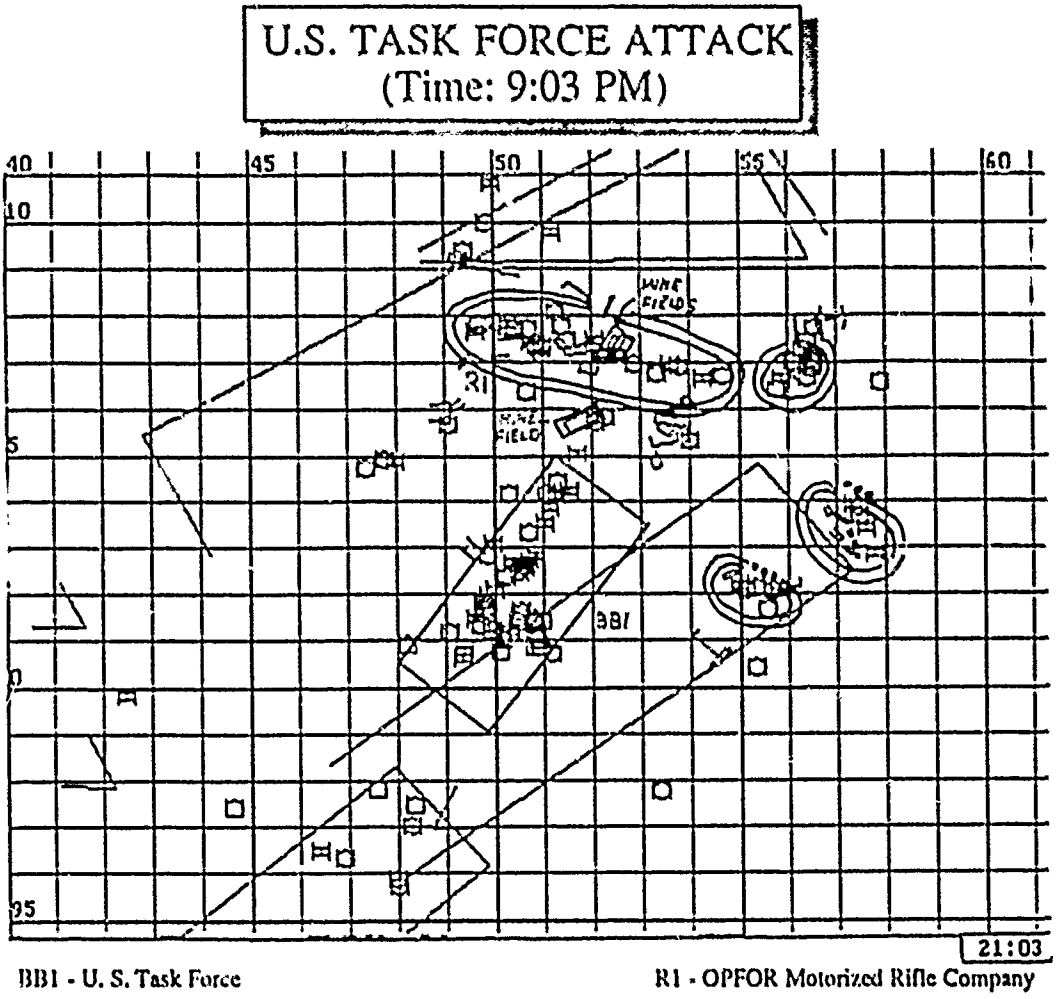
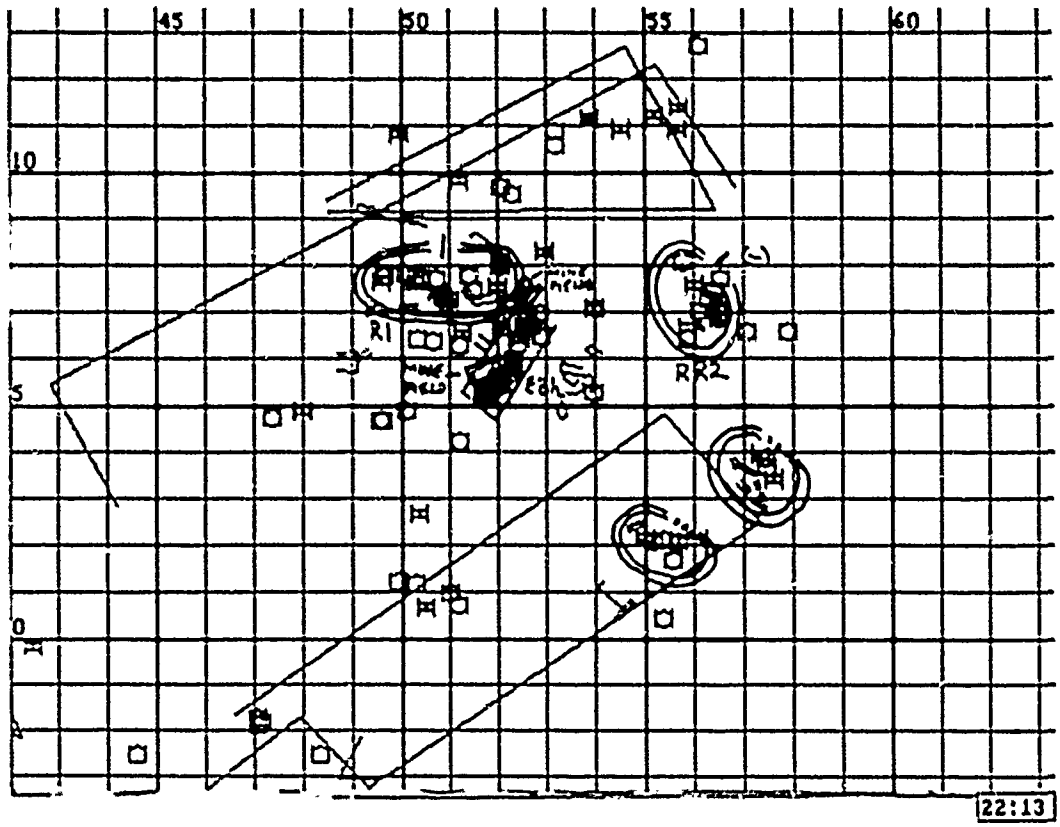


FIGURE 2 - 9

• The last snap shot of this battle was taken at 10:13 PM (figure 2-10). At this point in the battle, the effects of the OPFOR engagement area are obvious. The OPFOR has destroyed practically the entire U.S. task force within a 2 kilometer region.

• Because over an hour has elapsed, the OPFOR has also had time to commit his reserve forces (RR2) in time to influence the battle. In this case, although called in, the reserves were not actually needed.

U.S. TASK FORCE ATTACK
(Time: 10:13 PM)



BB1 - U. S. Task Force

R1 - OPFOR Motorized Rifle Company
RR2 - OPFOR Reserve Company

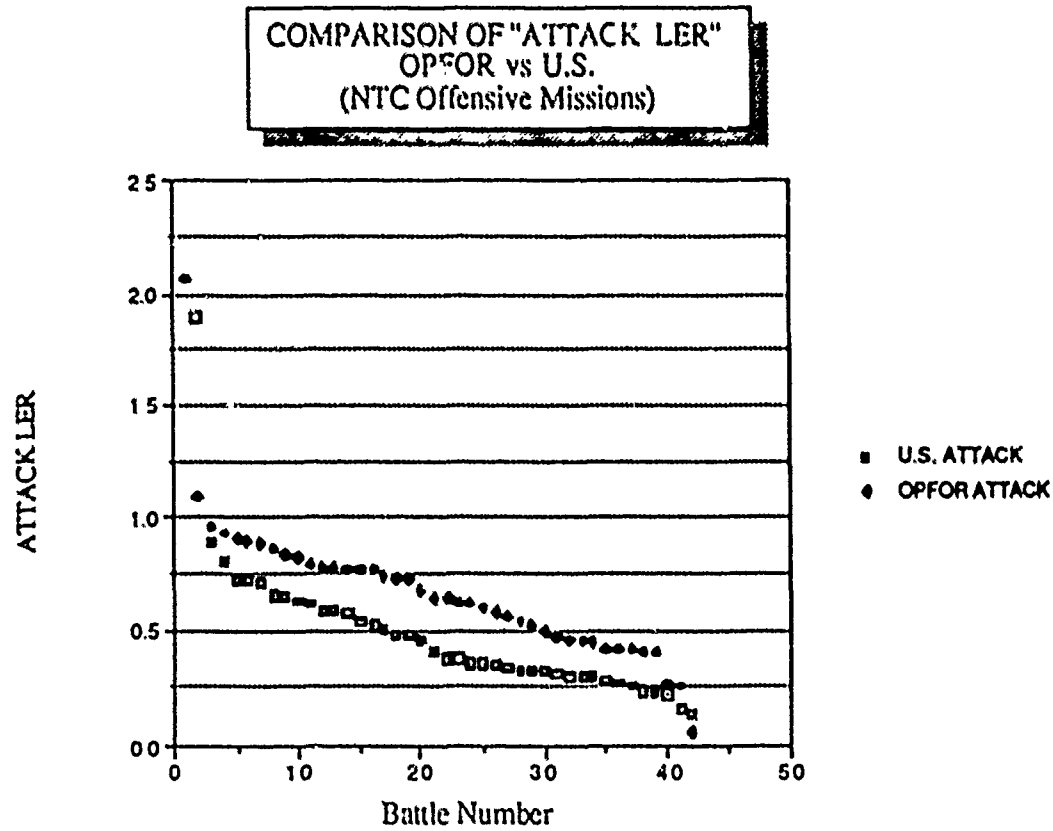
FIGURE 2 - 10

(3) The results depicted in these two examples are typical of the 100 battles examined. The OPFOR's ability to synchronize and mass forces at the critical place and time contributes directly to his ability to succeed on a more consistent basis. The success of the OPFOR is a direct result of training tempo and familiarity with the NTC training area. **The ability of the OPFOR to maneuver and accurately navigate is a direct consequence of their familarity with the training area.**

e. Analysts next examined the 100 battles in terms of LER. Complete data packages required to compute LERs were only available for 42 of the OPFOR attacks and 47 of the U.S. task force attacks. For sake of symmetry, and ease of comparison, analysts removed five additional U.S. task force attacks (randomly selected) from the data base, leaving a sample of 42 battles for each side. A modification to the LER equation is also required to make a direct comparison. The Attack LER (ALER) is defined as follows:

ALER = Defender Losses / Attacker Losses.

A larger ALER means that the attacker was able to kill a higher percentage of defending systems. For the 84 battles examined (42 OPFOR and 42 U. S. attacks) the mean OPFOR ALER was .673. The mean U.S. ALER was .593. The average difference between OPFOR performance in the attack and U.S. performance is 13.5 percent.



* Attack LER = Defender Losses/Attacker Losses

FIGURE 2 - 11

f. In the offense, a primary difference between U.S. task forces and the OPFOR is the ability of OPFOR units to mass their forces at the critical place and time. The OPFOR's ability to mass its forces at the critical place and time results in a better success rate and a better loss exchange ratio (LER). The evidence of this fact is portrayed in the results shown in figure 2-11.

4. Accuracy of Field Artillery Fires. Results of high resolution simulation, significant advances in artillery technology (such as MLRS and TACFIRE), and the rapid growth in Soviet field artillery capability have supported significant investments in U. S. indirect fire systems. The ability of our indirect fire systems to conduct "deep fires", provide accurate counter-battery fires, and support the close battle, adds a new dimension to the concept of critical time and space. At a given moment, the key to wresting the initiative from the enemy, or retaining the initiative, may depend on placing accurate indirect fires in any or all of these areas.

a. In an ongoing study, the Arroyo Center (the Army's federally funded Research and Development Center for studies and analysis operated by The Rand Corporation) has examined the accuracy of field artillery fires at the NTC over a four year (1985 -1988) period. The Arroyo Center first examined the effectiveness of field artillery at the NTC in 1985. During this study, two significant findings evolved. (1) Volume of field artillery fires was lower than expected or desired. (2) Approximately one-third of artillery fires fell close enough to OPFOR units to be rated as effective (in causing casualties) or suppressive. Findings from this study include:

• Increased training, and "improvements in tactics, techniques and procedures reflected in improved volume had not affected the issue of accuracy",

• "Platoon FOs [Forward Observers] were generally under utilized,

• "The underlying capability for position/location must be one of the factors limiting artillery accuracy at NTC."

b. The finding that FOs are under utilized is significant. The Arroyo Center study states that "an explanation may be that the FIST [Fire Support Team] leaders have simply recognized the limited capability of an observer who is confined to a platoon leader's vehicle and who is unable to orient himself to the battlefield or to maintain observation of potential targets." **In practical terms, this finding concludes that our inadequate position location capabilities seriously inhibit the execution of U.S. Army doctrine.**

c. The impact of this deficiency is particularly critical for U.S. tank units. Doctrinally, infantry units receive one FO for every infantry platoon. This is not the case for armor (tank) units. Armor units are not allocated FOs. Every Tank Commander (TC) is trained to be an FO for his unit.

d. The Arroyo Center determined from a variety of studies conducted by the field artillery community during the late 1970s and early 1980s that "trained" FOs, equipped with map, compass, and binoculars "can expect a mean target location error of about 500 meters. This is insufficient to obtain reliable first-round fire-for-effect". "Based on these findings, we [Arroyo Center] recommend that an eye-safe laser rangefinder-based target location system be provided for training. A position/location (navigation) system is also necessary for pre-battle target location, as well as for targets of opportunity during the battle."

e. The implications of these inaccuracies are obvious. Despite the fact that we have installed a very expensive Stabilization Reference Package/Position Determining System (SRP/PDS) on the MLRS and plan to install the SRP/PDS on the AHIP, we cannot expect to execute effective first-round fire-for-effect missions.

f. The HELBAT (Human Engineering Laboratories Battalion Artillery Test) was an extensive series of tests directed at many aspects of indirect fire support. The Ballistics Research Laboratory (BRL) conducted these tests in 1984. In addition to substantiating the findings of the other tests already discussed, it translates the effects of accuracy into time required to obtain

effective FO initiated fires. Data depicted in figure 2-12 were extracted from figure 14 of the original BRL report These data indicate that, on the average, a tank which has a Laser Range Finder (LRF) can put the first round 400 meters from a moving target in 7.5 minutes. In a tactical situation, if an advancing enemy target is identified at 3500 meters, the enemy will have closed to within 1000 meters before the first round impacts. The evidence suggests effective field artillery fires(first round) initiated from FOs will occur less than 50 percent of the time. Due to rapid closure rates, effective fires may never be brought to bear on many intended targets.

UNCLASSIFIED

PERFORMANCE SUMMARY
FO FIRE MISSIONS

METHOD	SYSTEM DELIVERY ERROR (CEP)	GRID ERROR (METERS)		# ADJ RDS (STAT TARGET)		AVE RESP TIME (MINUTES)		
		STAT TARGET	MOVING TARGET	# RDS	LAST RD ERROR-M	1ST RD	FFE	1ST RD M-TGT
CONVENTIONAL	+ 1 % OF RANGE OR + 150 METERS AT 15 KM	390	700	4 TO 8	100	3	14	13
HANDHELD LASER RANGEFINDER (LRF)		180	400	4	85	2.5	5.0	7.5
LRF ON TRACKING MOUNT W/ AUTO DATA LINK		<25	80	2	40	1.0	2.4	1.8

• FO-TARGET RANGE: 1.5KM FOR CONV AND HANDHELD; 2.5KM FOR LRF ON TRACKING MOUNT

FIGURE 2 - 12

UNCLASSIFIED

g. Following an evaluation of the BRL data presented above and the NTC data base, the Arroyo Center study makes the following conclusions:

- "Overall, we conclude that the values we have found for percentages of effective/suppressive fires are consonant with the basic capability. Improvement will not come from more intensive training, but from improved equipment."

- "We found that doctrine does not clearly indicate the limitations on accuracy under differing observation conditions and with various levels of supporting equipment. While first-round fire-for-effect is encouraged, the problems with accuracy to be anticipated are not delineated."

h. An important capability of the M1A2 (with POSNAV) is the innate capability to range on a target and instantaneously obtain an eight digit grid (10 meters) coordinate for the target. As evidenced in the recent Soviet Artillery Effects Test (conducted at Ft. Sill, Oklahoma), the inherent survivability of the tank, coupled with its ability to accurately place artillery fires, will make it the most capable and durable Forward Observer on the battlefield.

i. In summary, the data examined in this sub-analysis indicate the following:

• Tank Commanders comprise a large portion of the potential FOs on the battlefield, but they are limited from fully utilizing the capability of available indirect fire support.

• Increasing the capability of an FO to accurately call for fires will reduce the amount of time required to obtain effective fires from 14 minutes to 2.4 minutes.

• Reducing the time required to obtain effective fires will also contribute significantly to the number of effective missions achieved. An increase in the number of effective missions must result in an increase in the number of enemy systems destroyed and suppressed. As already presented in the LER equation, an increase in enemy systems destroyed results in an increase in force effectiveness.

• An increase in our ability to place more effective fires will also result in an increased number of enemy Air Defense and Anti-Tank missile systems suppressed. This will contribute to the survivability of Army aviation, Close Air Support (CAS) and armored ground systems. Increased survivability for our air combat system also results in an increase in our force effectiveness.

5. Lack of Speed and Mass in the Offense. "Dust, confusion, smoke and various levels of driver skills all contribute to a gradual, yet constant, elongation of [the attack] formation ... By 4,000 meters from the objective, the task force is spread 3 kilometers long and 1,500 to 2,000 meters wide... The unit has lost responsiveness, orientation, control and its battle impact." This depiction of a U.S. task force attack was made by BG William W. Crouch in a June 1989, Military Review article. Given a POSNAV device, each unit will have the capability of entering way points which correspond to their respective axes of advance. This capability would enable units to maintain orientation and mass forces from several different directions

a. BG Crouch was the Assistant Division Commander (ADC), Operations and Training, 4th Infantry Division (Mechanized), Ft. Carson Colorado. During his tenure as the ADC, BG Crouch was able to observe, first hand, approximately 45 task force battles at the NTC. As a senior army commander in Europe and CONUS, his breadth of experience with mechanized forces, provide him with exceptional qualifications to provide insights, and recommendations concerning what Tactics, Techniques, and Procedures (TTP) result in better force effectiveness. In essence, BG Crouch has seen first hand what does, and does not work at the NTC. Additionally, his extensive experience in Europe has tempered his conclusions and they can be considered applicable in many different tactical environments.

b. With respect to mass, these personal observations confirm the conclusions developed by Captain Dryer in his thesis. But, in addition to mass, BG Crouch adds the imperative of speed. According to BG Crouch, speed of execution is directly linked to enhanced combat effectiveness. Speed permits U.S. Task Forces to successfully accomplish the following:

• Place security and over watching elements into position. These elements provide early warning, and killing and suppressive fires which in turn contribute directly to the survivability of the attacking force.

• More rapidly negotiate enemy direct and indirect fire killing zones. The defender loses many of the advantages inherent in a tactical defense once the attacker closes to within 1000 meters.

• Prevents the defender the time required to reposition his forces.

6. Fratricide. Fratricide is often the result when units become disoriented or too widely dispersed as a result of improper navigation. Inaccurate calls for fire often bring indirect fires on friendly locations. NTC data indicate at least 3.6 percent of artillery fire missions resulted in fratricide. A study by the Combined Arms Training Activity (CATA) concluded that between 2.3 and 3.7 tanks/Bradleys are killed by friendly direct fire for each mission executed.

a. The CATA study determined that at least 50 percent of the NTC fratricide incidents can be traced to navigation breakdowns. A RAND study of NTC fratricide incidents concludes that one-half of the incidents could have been prevented had the shooter been aware of the location of a sister unit. A POSNAV device will provide more accurate position reporting and the increased ability to adhere to graphical control measures. Each of these enhanced abilities will provide a greater awareness as to the location of sister units. Another one-third of the incidents could have been prevented if the shooter had knowledge of the location of individual isolated friendly vehicles.

b. Ironically, our increased capability to fight at night with thermal image devices, has accentuated our requirements for better command and control. Thermal image devices do exactly what their name implies; they produce an image based on temperature changes. While this capability is good for acquiring and engaging targets, it is not a very good device for target recognition. Units depend on positive command and control for target recognition, and fire upon any system which appears outside the framework of the friendly maneuver plan.

c. Tragically, the difficulty of target recognition, and the consequences of a navigation error, was recently demonstrated during a gunnery exercise in Germany. As an M1 tank sat in its defensive position waiting for the enemy to appear, the tank fired on, and destroyed, two U.S. M2 Bradley Fighting Vehicles (BFV) that had wandered out of sector and into the field of view of the M1 tanks. One U.S. soldier was killed and two others were seriously injured by friendly fire, due to a navigation error. The accident which occurred is not unlike most instances of fratricide which occur at the NTC or have occurred in war. Regardless of how well we improve our target recognition training, the inherent resolution capabilities of our thermal sights will not prevent this type of accident from occurring again. As the RAND report concluded, position navigation may reduce fratricides by up to 50 percent, and possibly 66 percent if position locations are shared through a mutual POSNAV device such as the Inter-Vehicular Information System (IVIS) (not part of the POSNAV package).

7. Summary In terms of effectiveness, the benefits derived from the ability to mass forces at the critical point in time have been demonstrated repeatedly. This fact has been proven to be statistically significant for both U. S. forces and OPFOR at the NTC. Likewise, the inability of U. S. forces to consistently apply their superior combat systems, as planned, has been demonstrated all too often. Results of a combat simulation indicate that a 8.9 percent increase in the Effectiveness Ratio (ER) can be realized during a reinforcing mission. This increase in effectiveness did not include a potential 2 to 4 additional U. S. survivors because of reduced fratricide or the increased effectiveness of field artillery. To a large degree, the success of NTC OPFOR units must be associated with their superior navigation skills. The skills, accrued through experience, are in fact very analogous to an on board navigation device.

G. Effect of Position Navigation On Training. "Realistic training", "Train as we expect to fight - fight as we train", and "Train at night" are common throughout our training lexicon. While common sense and military judgment dictate that we strive for realistic training, even the casual observer of a field training exercise will notice many poor Tactics, Techniques, and Procedures (TTP) being practiced. It is difficult to understand how we can accept: Tank Commanders maneuvering, under fire, from (open hatch) unprotected positions, extensive use of visual light markings at night, column (piecemeal) formations, and inflexible Task Force organizations. This portion of the analysis establishes a direct linkage between many of these poor training techniques and our inherently poor navigation skills.

1. Effective Training. As described in Section I, the NTC provides us with the most realistic training environment short of war. Expense and availability dictate that each unit maximize his opportunity to train and perform while at the NTC. Why some units do well, or poorly, at the NTC is the subject of many debates. One common theory is that there should be a linkage between the availability of pre-rotation training opportunities and NTC performance.

a. The Army Research Institute has evaluated the linkage between pre-rotation training and performance at the NTC. The MOE used in the study included the Casualty Exchange Ratio(CXR) and "tank miles" driven in the year preceding the rotation to the NTC. The CXR is equivalent to the LER divided by the initial force ratio. In many analyses, this MOE is defined as the Fractional Exchange Ratio. Any correlation between OPTEMPO miles and CXR is mathematically identical to the correlation between OPTEMPO miles and LER. The principle findings from this research effort are as follows:

• A highly significant positive correlation between ground OPTEMPO and unit performance on defensive missions.

• The correlation between ground OPTEMPO and unit performance in the offense is not significant.

b. The data collected during this research included 58 defensive and 42 offensive missions which were performed during 16 unit rotations. Variation in OPTEMPO tank miles ranged from 550 to 780 miles.

c. The results of this analysis indicate that within reasonable bounds (550-780 annual tank miles), we may have maximized our capability to train offensive maneuver skills. These data are consistent with the RAND (Arroyo Center) study on position and target location errors - "Improvement will not come from more intensive training, but from improved equipment".

2. Open Hatches. The results from several studies previously cited have quantified the extent of the navigation errors between 800 to 1000 meters. With the exception of the CANE test, which did not provide quantifiable data, it must be stressed that each of these tests were conducted under optimal conditions. Since these tests were conducted in daylight, no battlefield obscurants were present, and tank commanders were operating from open hatch positions, 800 to 1000 meters must be considered the lower bound on the magnitude of navigation errors we must expect.

a. Regardless of training site (FRG, Ft. Hood, NTC, Ft. Lewis, or Ft. Benning), TCs will fight buttoned up only after artillery simulators have exploded in the immediate area, and then, only if an observer/controller is observing him. A TC can fight his tank, buttoned up during the day time for short periods of time. If he is forced to button up at night, it is extremely difficult to maintain terrain orientation, difficult to read the map, and the only means of maintaining an orientation with other vehicles in the formation is to point his gunner's sight (and main gun tube) at the other vehicles. The CITV on the M1A2 will contribute significantly to better control of formations.

b. U.S. tacticians have monitored the growth of Soviet artillery capability for many years. In addition to the quantities now available to Soviet ground commanders, recent live fire tests have graphically proven the lethality of a Soviet styled artillery barrage. If the U. S. Army tank force fights the next war in the same manner that it trains, the consequences will be tragic.

c. **The fact that, with clear understanding of the effectiveness of Soviet artillery, we permit our tank commanders to operate from exposed positions, is perhaps the single most convincing piece of evidence substantiating the difficulty of ground maneuver tasks.**

3. Piecemeal Attack "By Design". Another fact which documents the extent to which we have learned to cope with navigation errors is the selection of our combat formations. Regardless of training site location, if a commander is required to move a company or task force formation under periods of reduced visibility, he will usually select a combat formation comprised of a single column. A task force column, tactically deployed at night, is 7 to10 kilometers long. Deployed in this manner, it takes a Task Force Commander, 21 to 30 minutes to get all his forces into a fight once it starts. Even if a commander accepts some risks, and deploys his task force in two columns, his formation is anything but agile. Again, we have observed an example of U.S. task force commanders planning and executing less than optimal plans (combat formations) because of our inherent navigation deficiencies.

4. Chemical Lights. If we attempt to fight the first two nights of the next battle like we train, we will pay a very high toll in friendly losses. The prolific use of chemical lights to aid navigation and position location will compromise command post locations, primary and secondary defensive positions, and locations of key routes.

a. During a recent visit to the NTC (August 1989), an observer who was standing on a small sand dune, made the following comment: "This reminds me of a travelling circus." There were different color lights everywhere. In addition to being colorful, the scene presented did give off an aura of orderliness. Apparently every company team had their own color of "chem light". The observer knew that blue belonged to the Headquarters Company because he had just left the task force Tactical Operations Center (TOC). There had been blue chem lights on top of at least four of the FM antennas. Apparently this was required so that you could find the TOC.

b. In addition to being colorful, this practice is also expensive. **In FY89, the Army purchased 6,800,000, 6 inch chem lights, at a cost of $6.5 million.** This cost data was obtained from the Defense General Supply Center.

5. Best Navigator. Another common practice of Task Force Commanders' is to place their "best navigator" at the front of his maneuver column. Again, during a recent visit to the NTC, an armored task force was observed as it conducted nine different missions. The fact that this Battalion Commander selected his B Company Commander to lead every battalion formation seemed curious. It didn't seem probable that an analysis of Mission, Enemy, Terrain, Troops available, and Time (METT-T) and a robust training philosophy would lead to the same solution every time. As it turned out, the B Company Commander had been an OPFOR Scout Platoon Leader for two years. His knowledge of the NTC and his ability to navigate were considered more important factors than whether the attack should be led with a Mechanized Team or a Tank Team.

6. Night Operations. Although the U.S. Army's investment in night fighting capabilities has produced the most capable night fighting force in the world, our current investment has, in essence, been limited to the procurement of thermal imaging devices. Other than first generation image intensification (I^2) devices for armored vehicle drivers, we have done very little to enhance our ability to navigate during periods of limited visibility. The tank (and other armored vehicles) driver's present night driving viewer is virtually useless on very dark nights.

7. Summary. Land navigation has not changed in 15-30 years; current navigation capabilities depend on soldier being able to correlate his position on the ground with surrounding terrain and to maintain his position on the map during all types of operations. Increasingly, we have required our soldiers to do this at night and at increased tempos. The difficulty of the task is obvious. As evidenced in this sub-analysis the difficulty of the tasks has manifest itself into many poor and, in some cases, deadly training practices.

H. Alternative Systems. The 1983 Vehicular Navigation Aids System (VNAS) Abbreviated Analysis established that the preferred position navigation system for the tank was the VNAS. The POSNAV device discussed throughout this analysis is the tank version of a VNAS. Because two of the VNAS study alternatives (Enhanced Position Location and Reporting System (EPLRS) and Global Positioning System (GPS)) are currently being developed to fulfill the needs of standard Army and DOD position location systems, the cost effectiveness of these alternatives continues to be a pertinent issue. This analysis presents the M1A2 requirements document and compares the three alternatives in terms of performance and cost.

1. System Requirements. The Abrams Block II Statement of Materiel Need describes a requirement for "...self-contained position/navigation equipment that operates independently of any external reporting or navigational systems." The system shall "...provide display of heading information accurate to within +/- 3 degrees RMS (root mean square) of actual vehicle heading, with reference to MGRS (military grid reference system) a grid north line...Provide readings, over time, that do not exceed cumulative error greater than 1 degree per hour with hourly updates permitted. Be self initializing..., shall provide position/information in 6 digit (required)(8 digit desired) MGRS plus alpha-numeric grid designators, accurate to 2% of distance travelled...Provide the capability to display azimuth and distance from a preset or current position to at least one (and preferably more, sequentially) preselected objectives (checkpoints)..."

2. Position and Navigation System (POSNAV). The M1A2 POSNAV is a non-magnetic, gyro based system that requires no external references or signals. The system utilizes inertial sensors and electronics to determine the tank's position. Because the unit is self-contained and does not rely on Geosynchronous Position Satellites (GPS) it has no antenna, is not subject to atmospherics and cannot be jammed. POSNAV provides both heading (degrees) and position (MGRS coordinates) while operating within the required mobility parameters. It will provide the range and bearing from the present or pre-set vehicle coordinates to a minimum of five waypoint coordinates. A position update feature allows the elimination of position errors when the vehicle crosses a known location.

a. Field Demonstrations. The M1A2 POSNAV system incorporates a mature technology which was first developed in 1978 for use in Air Force drones. The system has had over 50 field demonstrations on more than 25 different vehicle types, worldwide, during the last 10 years. The typical accuracy achieved by various vehicles in these field tests ranged from 0.25% of total distance travelled for an M113, to 0.85% of distance travelled for an M2. Typical accuracy for an Abrams tank was 0.84% of distance travelled. The test courses varied in length from 30 - 135 km.

b. Physical Characteristics. The unit is relatively light (21 lbs) and compact (12" x 5.8" x 7.1"). The unit is hardened against nuclear and Electromagnetic Pulse (EMP) bombardment. It uses the 1553B Data Bus but can be hardwired with no design changes (to allow fleet retrofit). The unit uses the M1A2's Commander's Integrated Display (CID) and Driver's Integrated Display (DID) for its display requirements.

c. Cost. The incremental LCC for placing a POSNAV on an M1A2 is $74.7 million (FY89 Constant Dollars, QTY=2926 tanks). Recurring production costs account for 82.2 percent of the increase. The incremental recurring Average Unit Cost (AUC) for an M1A2 with POSNAV is $21,000. This represents less than a one percent increase in the M1A2 system cost.

d. Performance Characteristics.

(1) Gyrocompass function. The gyrocompass will initialize the heading of the POSNAV sensor within one degree, root mean square (rms), of true north within five minutes at 70 +/- 10 degrees Fahrenheit (F), not to exceed ten minutes over the full temperature range. The gyrocompass function performs properly only when the vehicle pitch and roll angles do not exceed five degrees and the vehicle is located at latitudes less than 65 degrees (the Arctic Circle is located at 66 degrees 33 minutes north).

(2) Position initialization. POSNAV is initialized by the entry of an eight digit initial vehicle position and waypoint coordinates with a five character alphanumeric grid designator.

(3) Navigation function. After initial position is entered and initial heading is determined, POSNAV provides a continuous output of vehicle position in eight digit MGRS coordinates (ten meter resolution), accurate within two percent (one standard deviation) distance travelled. Heading is provided continuously with a resolution of 0.1 degrees and an accuracy of one degree rms of actual vehicle heading over a one hour period of time. Hourly updates are required to correct position/heading error.

(4) Course correction. The driver is provided a heading indicator (in degrees) and a "steer-to" indicator to assist in movement to preselected way points.

(5) Waypoint calculation. The distance between the vehicle and the entered waypoint is calculated with an accuracy of ten meters and the bearing to the entered waypoint with an accuracy of 0.1 degrees.

(6) "Far target" location. Vehicle navigation data are combined with hull/turret position and rangefinder data to determine the eight digit MGRS coordinates (ten meter resolution) of a distant enemy target. The data collecting and processing necessary for this function require system integration with the M1A2 data bus. A POSNAV device mounted on a system without the data bus will not perform the "far target" location function.

(7) Update function. The tank commander can manually update vehicle position and heading and/or way points.

(8) Quick-start function. The quick-start function allows the tank commander to initialize heading within 30 seconds based on previously saved or entered heading data. This function is used if available time does not allow use of the full gyrocompass function. Performance is degraded as a function of the operating conditions.

(9) Shutdown function. The shutdown function allows the gyroscope to realign, nulling heading error. This function also allows storage of the present vehicle position and heading in nonvolatile memory for use in the next initialization. Nonvolatile memory will retain these data for a period of not less than 72 hours.

(10) Built-in test. Built-in test (BIT) is performed periodically while the POSNAV sensor is operating.

3. Global Positioning System (GPS).

a. The Global Positioning System (GPS) is a spaced-based radio navigation system which provides continuous, global, three-dimensional position location, velocity, and time of day. GPS is a joint program with the U.S. Army, Air Force, Navy, Marine Corps, Coast Guard, the U.S. Defense Mapping Agency, Australia, and NATO.

b. GPS consists of three major segments: space, control, user.

(1) The space segment consists of a set of satellites which know where they are in relation to the earth at all times and also know exactly the time-of-day. The satellites transmit this information continuously to any GPS receiver on or near the ground any where and at any time of the day. A secure anti-spoof channel is available to qualified military users and a second, unsecured channel is available to nonmilitary users.

(2) The control segment consists of a set of ground control stations which constantly monitor satellite location, satellite clock accuracy, and general satellite health. The master control station then updates any satellite that is shown to contain errors.

(3) The user segment consists of the ground receivers used by soldiers, ground vehicles, ships, and aircraft. These receivers select four satellites and process their signals to calculate the receiver's location. The system's output is limited to the position location of the user.

c. Cost. The estimated unit cost of the GPS system is $27,900. This cost reflects a non-developmental item (NDI) with minimum risk. Other, less expensive, GPS configurations were not considered due to the reduced accuracy, reliability, and durability. The cost of integrating GPS with the tank is not included.

4. Enhanced Position Location and Reporting System (EPLRS).

a. EPLRS is a ground-based radio position and reporting system which uses range triangulation to locate the position of the user. The system will locate beyond radio line-of-sight by the use of relays. The system consists of a master unit and user units. The master unit accomplishes all range triangulation calculations and produces a map display. The user units allow a digital readout of location and also act as relays when required. The system requires one master unit per 370 active users. Each master unit controls approximately a brigade-sized deployment of users.

b. EPLRS correlates unit locations with other unit locations or with points on the ground, computes the range and bearing between their locations, and delivers this information to the users. EPLRS can assist in navigation to a predesignated grid coordinate or to another system user. A user can send a message with the grid coordinate of the intended destination and receive the bearing and range to the intended point. Up to 104 predesignated items can be input at the master station.

c. Cost. The unit production cost of the EPLRS is $65,000 with an additional cost of $8,300 to integrate the system with the tank.

5. Comparison of Alternative Systems. The Abrams Block II mission needs statement (discussed in para. G,1 of this section) states a need for self-contained position navigation equipment that operates independently of any external position reporting or navigational systems. The position navigation equipment must provide position location and heading reference information. The equipment must have the capability to provide the azimuth and distance from a preset or current position to at least one and preferably multiple preselected objectives. Figure 2-13 is a checklist of system costs and requirements.

a. The POSNAV system meets all the mission needs statement requirements. It is a totally self-contained system. It provides position location and heading reference information. It will provide azimuth and distance to the grid coordinates of the next checkpoint.

b. GPS is not a self-contained, stand alone system. The GPS user is radio linked to satellites and ground control stations. GPS only provides position location, with no heading reference information. GPS provides no capability for continuous navigation to selected

checkpoints or for "far target" designation. GPS requires radio antennas on combat vehicle users. Abrams live fire testing has demonstrated that radio antennas are vulnerable to nearly every weapon system encountered on the battlefield. It is not prudent to tie the Army's position navigation system to one of its most easily exploited vulnerabilities.

c. EPLRS is not a self-contained, stand alone system. EPLRS is also dependent on a radio link to a set of ground control stations. EPLRS provides position location, as well as bearing and range to preselected points, but does not provide a capability for "far target" designation. EPLRS also requires radio antennas on combat vehicle users. As discussed in regards to the GPS, this requirement means tying the Army's position navigation system to a known deficiency.

ALTERNATIVES COMPARISON

	POSNAV	GPS	EPLRS
COST	$21 K	$27.9 K*	$73.3 K
SELF - CONTAINED	YES	NO	NO
POSITION LOCATION	YES	YES	YES
HEADING REFERENCE	YES	NO	NO
SELF INITIALIZING	YES	YES	YES
AZIMUTH TO CHECKPOINTS	YES	NO	YES**
RANGE TO CHECKPOINTS	YES	NO	YES**
FAR TARGET LOCATION	YES	NO	NO

* Does not include cost to integrate into tank
** Preselected points only

FIGURE 2 - 13

I. Cost. This section presents the key findings of the Position Navigation (POSNAV) device Cost Analysis. This analysis is an extension of the M1A2 Tank Cost and Operational Effectiveness Analysis (COEA). The complete update is contained in Appendix D Cost Analysis of this report. The scope of this analysis is limited to determining the incremental Life Cycle Cost changes associated with the Position Navigation (POSNAV) device.

1. Cost Update. In March 1989, TRAC-WSMR and USAARMS published the M1A2 COEA while the Tank-Automotive Command (TACOM) and Cost and Economic Analysis Center (CEAC) formulated the Army Cost Position (ACP). The ACP and M1A2 COEA difference focused mainly on additional production costs associated with systems technical support and supporting training devices. This analysis reviewed and incorporated these differences.

2. Incremental LCC for POSNAV. The incremental LCC for placing a POSNAV on an M1A2 is $74.7 million (FY89 Constant Dollars, QTY=2926 tanks). Recurring production costs account for 82.2 percent of the increase. The following table details the Incremental Production Costs for the M1A2 with POSNAV.

INCREMENTAL PRODUCTION COST (QTY = 2926)
FY 89 CONSTANT DOLLARS - MILLIONS

COST ELEMENT	POSNAV
NON-RECURRING	$0.00
RECURRING	$61.40
ENG CHANGES	$1.20
DATA	$0.40
TEST	$0.30
TRAINING EQUIP	$0.00
SPARES	$3.00
OTHER	$0.70
TOTAL	$67.00

MOST SIGNIFICANT COST DRIVER

TOTAL TANK PRODUCTION RECURRING AUC	$3.058

COMPONENT COST IN THOUSANDS OF
FY 89 CONSTANT DOLLARS

INCREMENTAL PRODUCTION RECURRING AUC	$21.00

FIGURE 2 - 14

3. Component and System Cost Increase. As shown in figure 2-14, the incremental recurring Average Unit Cost (AUC) for an M1A2 with POSNAV is $21,000. This represents less than a one percent increase in the M1A2 system cost.

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SECTION III - RESULTS

A. CONCLUSIONS. The significant conclusions developed in this analysis are presented coincident with the six key study issues.

1. What are the operational effectiveness contributions of the M1A2 POSNAV device?

FINDINGS: The linkage between a POSNAV device and an increase in operational effectiveness can be established in two ways. An increase in the ratio of enemy losses to friendly losses (LER) is obtained if either (1) more RED systems are killed, or (2) more U.S. systems survive. As established in this analysis, the M1A2 POSNAV provides for increases in the LER by means of several mechanisms. Where the analysis supports a POSNAV-LER linkage with quantifiable data, a percentage band for the increase in LER is provided (page 24).

a. A POSNAV device will contribute to more RED systems killed.

• Provide commanders the capability of moving their forces on multiple axes of advance, during periods of limited visibility, and massing their combat power at the critical place and time.

• Provide every Tank Commander the capability to call for first-round fire-for-effect artillery fire.

b. A POSNAV device will contribute to more U.S. systems surviving.

• More accurate artillery fires will suppress greater numbers of air defense and anti-tank systems.

• Fewer "adjust fire" missions will result in fewer opportunities for RED counter-battery artillery to fire on U.S. artillery systems.

• Offensive operations at night will greatly reduce the effectiveness of RED direct fire systems which rely on infra-red illumination to engage targets.

• Reduce the instances of fratricide.

• More accurate navigation will help U.S. units avoid known obstacles and contaminated areas.

• Help eliminate poor training habits which will result in wartime casualties.

2. What are the operational suitability benefits of the M1A2 POSNAV?

FINDINGS: In terms of performance, the evidence indicating the existence of a significant position navigation problem is compelling. The ARI POSNAV test clearly establishes the superior capability of POSNAV equipped crews and platoons to accomplish navigation related tasks. The imperatives established by an offensive U.S. doctrine mandate, in terms of navigation skills, a more capable maneuver force. Inherent navigation capabilities preclude full maximization of U. S. investments in night acquisition devices and lethal artillery fires.

3. What are the technological alternatives to the M1A2 POSNAV?

FINDINGS: The POSNAV, GPS, and EPLRS were compared in terms of requirements and system cost. The results of this analysis are consistent with the Vehicle Navigation Aid System (VNAS) Abbreviated Analysis, which also concluded that **the POSNAV device is the most cost effective alternative to meet the needs of the M1A2 tank.** In fact, it is the only alternative which provides heading reference and is a self contained unit. These attributes are required to provide far target location capability and, as demonstrated in the Soviet Artillery Effects Test, to provide a survivable system which is not dependent upon an external antenna. Both these attribute contribute to increases in operational effectiveness and enhanced operational suitability.

4. What are the Life Cycle Costs associated with the M1A2 POSNAV?

FINDINGS: The incremental LCC for placing a POSNAV on M1A2s is $74.7 million (FY89 Constant Dollars, QTY=2926 tanks). Recurring production costs account for 82.2 percent of the increase. The incremental recurring Average Unit Cost (AUC) for an M1A2 with POSNAV is $21,000. This represents less than a one percent increase in the M1A2 system cost.

5. What level of confidence is associated with analysis based on NTC or SIMNET data?

FINDINGS: For the narrow spectrum of issues examined in this report, the data obtained from both SIMNET and the NTC was found to be very acceptable. In both cases, the data were found to be objective, well organized, significant (large sample size), and most importantly, representative of soldier conduct under simulated combat conditions.

6. Do the benefits (operational effectiveness and operational suitability) associated with a POSNAV device justify its cost?

FINDINGS: The addition of a self-contained inertial POSNAV device to an M1A2 tank will increase the operational effectiveness of U.S. tank battalions. It is clearly an enhancement to the execution of tank battalion/task force and armored cavalry squadron missions, and provides battlefield capabilities that are greater than its cost. The ability of a maneuver force to mass its combat power at the critical place and time, the application of more accurate field artillery fires, and the reduction of instances of fratricide, all contribute to a more effective combat force. In terms of operational suitability, a POSNAV device will greatly enhance the ability of U.S. Forces to conduct offensive operations during periods of reduced visibility. The increased speed of movement and massed combat power, afforded by a POSNAV device, contribute to a unit's agility, synchronization, initiative, and depth - the cornerstones of our operational and tactical plans.

B. RECOMMENDATION. Adjust the M1A2 average unit weapon system cost threshold from $3.037 million to $3.058 million (in FY89 dollars based on a FY91-97 quantity of 2926 tanks, one plant operation, and 516 tanks per year). The purpose of this adjustment is to include the POSNAV device in the M1A2 Milestone III production decision.

APPENDICES

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APPENDIX A. USE OF NATIONAL TRAINING CENTER (NTC) DATA

A. Introduction. The National Training Center is a 640,000 acre U.S. Army training ground located in the high desert region of southern California. The NTC has a two-fold mission; to provide a tough realistic combined arms joint services training in accordance with Airland Battle doctrine focusing at task force level, and to provide a data source for training, doctrine, leadership, organization, and equipment improvements. Training is "free play" to the maximum extent possible to force the unit to operate in an environment close to actual combat.

B. Data Collection.

1. The NTC instrumentation system consists of three major subsystems; the Core Instrumentation Subsystem (CIS), the Range Data Measurement Subsystem (RDMS), and the Range Monitoring and Control Subsystem (RMCS). The CIS and the RDMS are the primary subsystems used to monitor armored ground tank killing systems engagements. The RDMS collects and provides data of real-time position locations, engagement events, and vehicle status to the CIS mainframe computer. The Multiple Integrated Laser Engagement System (MILES) is an eye-safe laser transmitter which simulates the vehicles' direct fire systems. Targeted vehicle crews are instantly aware of a kill, near miss, or hit to its system by audio and visual means. MILES is a subcomponent of the RDMS. In addition to MILES, NTC observer/controllers (OC) working with personnel at the CIS assess casualties caused by indirect fires and minefields and use a hand-held MILES laser to kill systems.

2. Observer/controllers are in the field alongside the visiting units during training at the NTC. They correlate subjective observations with the data collected from the instrumentation and other sources to conduct after-action reviews (AAR) with the units. Objective and computer-gathered information and subjective field observations gathered by video cameras and the OCs are fed to the operations center for analysis.

3. NTC data are routinely collected and forwarded to the Army Research Institute - Presidio of Monterey (ARI-POM). ARI interacts with the Center for Army Lessons Learned (CALL) to tailor databases to address Army issues. ARI conducts research to develop measures of NTC unit performance and effectiveness to support CALL in developing Lessons Learned and estimating training readiness. The Combined Arms Training Activity (CATA) is the TRADOC coordinator for the development and implementation of NTC programs and dissemination of NTC Lessons Learned.

C. Data Source for Army Analyses.

1. Precedents for the use of NTC data to support analysis are becoming increasingly more common. In a recent research effort (September 1989), the Army Research Institute provided the following rationale for utilizing NTC data.

"The performance of units training on simulated combat missions at the NTC was selected as the focus of measurement, because its training realistically simulates battlefield conditions, and the difficulty of its training is relatively constant for all units (the terrain is constant and the OPFOR are reliably effective). The Multiple Integrated Laser Engagement System (MILES) data for vehicle kills stored at the ARI Research Center provided the basis for objective performance measurement."

2. Although not part of a formal "experimental design" many of the basic attributes of a properly designed test are being incorporated at the NTC. These attributes include: variance reduction, objectivity, large sample size, random samples, and repeatability.

a. Variance reduction is accomplished indirectly through the following:

(1) OPFOR is a fixed organization. All regimental attacks are conducted by a Motorized Rifle Regiment. All attack and defend missions are structured to provide an approximate three to one attacker to defender initial force ratio.

(2) Rotations schedules are relatively set. Since all rotations are 14 days long, fatigue is consistently applied to all units.

(3) Most rotations include one armor and one mechanized battalion. These battalions habitually cross-attach two teams each to form two balanced task forces.

(4) Unit rotations are scheduled approximately every 18 months. Therefore the "NTC" experience level for each training unit is approximately the same.

(5) The weapon systems available to the OPFOR have remained very constant, while U.S. battalions have trained with various combinations of modernized equipment (M60s, M1s, M113s, M2s, etc.). If a particular issue is being examined, such as "success at night", then the analyst has the capability of sorting through the available data to insure that his results are not confounded by differing weapon system capabilities.

b. Objectivity is established in several ways:

(1) The soldiers and units participating in a rotation have one objective to achieve. They are there to beat the OPFOR Regiment. No training, no mission, and no motivation takes place during an NTC battle for the express purpose of supporting the requirement for a particular weapons system.

(2) The instrumentation system which records firing events, vehicle locations, and weapon system status, provides an objective set of data which depicts what actually takes place during a battle. These data are not manipulated, or edited in any way prior to being reduced for analysis.

(3) The identities of all player units are removed from the data base prior to their use in any analysis.

c. The ARI archives have accumulated a significant data base over the last few years. With 14 rotations per year, 14 battles per rotation (seven for each task force), data are now available on over 100 defensive or 100 offensive missions.

d. The analyst can establish randomness in one of two ways. He can select the results of any one particular rotation as a representative random sample, or he can select at random the results of 10, 20, or even 50 or more of the more than 100 battles available in the data base.

e. Within the bounds of a free play exercise, an analyst's requirement for repeatability are, in part, satisfied via the large sample size, and variance reduction techniques already discussed.

APPENDIX B. USE OF SIMNET DATA

A. Introduction.

1. The POSNAV analysis contained in the March 1989 M1A2 COEA contains data from a series of navigation exercises conducted on the Simulation Networking (SIMNET) system. This POSNAV Analysis Update references that series of SIMNET exercises, as well as an ARI Soldier Performance Research Project (SPRP) and an ARI Combat Vehicle C2 (IVIS) Test, both of which used SIMNET as a primary tool for evaluation.

2. In 1988, the U.S. Army Armor and Engineer Board performed a critique of SIMNET as a tool for training and evaluation assessments. The investigation concluded that SIMNET was an excellent tool for training tank combat tasks, including navigation skills. The following analysis evaluates the validity of SIMNET as a proper tool for assessing the benefits of position navigation equipment.

B. SIMNET Description. SIMNET is a product of an advance technology project sponsored by the Defense Advanced Research Projects Agency (DARPA) in close cooperation with the U.S. Army. The SIMNET system interconnects manned microcomputer-based simulators on a common network. A real-time computer image generation system in each simulator provides a multi-window view of the battlefield, with all other combat vehicles shown at the positions and orientations determined by the control inputs of their crews. SIMNET allows low-cost simulation of platoon, company, and task force-level exercises incorporating most of the tactical, logistics, and communications elements critical to field operations. The project's objective was to develop a technology base for extended local and long-haul networking of low-cost, full-crew combat system simulators.

C. Discussion.

1. Traditional computer models attempt to approximate reality through a series of mathematical algorithms and decision rules. These models generally perform well at imitating absolute functions which can be defined by statistical probability distributions. However, these purely mathematical models usually suffer from a lack of human interactive thought processes and spontaneity. Full-scale field testing comes closest to reproducing the combat environment for new system evaluations. The ideal evaluation of the merits of a tank navigation system is a field test with a large sample size of well-trained tank crews negotiating unfamiliar terrain. An evaluation exercise of such magnitude is a costly, time-consuming endeavor. SIMNET provides a simulated field test using individual tank crews in a system of networked tank simulators. In a simulator model, the decisions are made by soldiers. SIMNET allows an evaluation using a large sample size of well-trained tank crews negotiating unfamiliar terrain. In traditional computer models, events tend to occur without a hitch and with perfect timing. With simulators, as in actual combat, human decisions and errors, combined with the confusion of battle, tends to alter the events that occur. SIMNET, like any simulation tool, does not duplicate reality but it does provide as realistic a simulated environment as possible without going to the field.

2. In order for the simulators to be effective in training tank crew tasks, they must successfully reproduce the environment of the M1A1 tank at a level of fidelity that permits the crew to perform their specified tasks under the same workload and time constraints that they would experience in an actual tank. Additionally, the simulators must be constrained to the performance limitations of the actual tank to avoid any negative training. Achieving a high level of fidelity was given maximum priority in the design of modeling functions of tactical significance, such as hull and turret dynamics, controls, and display sequencing and timing, and the ballistics characteristics. Validation of the performance characteristics was a critical element in the simulation development.

a. The primary source of data for development of the hull dynamics simulation was the TOTPERF simulation. TOTPERF was developed by the General Dynamics Land Systems Division for the development of the actual M1 Abrams tank. TOTPERF is a very detailed mathematical model which simulates steady-state and transient performance characteristics of the Abrams hull. Validation tests have yielded nearly 100% correlation between TOTPERF predicted performance and actual M1 field tests. Figure B-1 displays selected test performance parameters for actual M1/M1A1 automotive tests and TOTPERF predicted ranges.

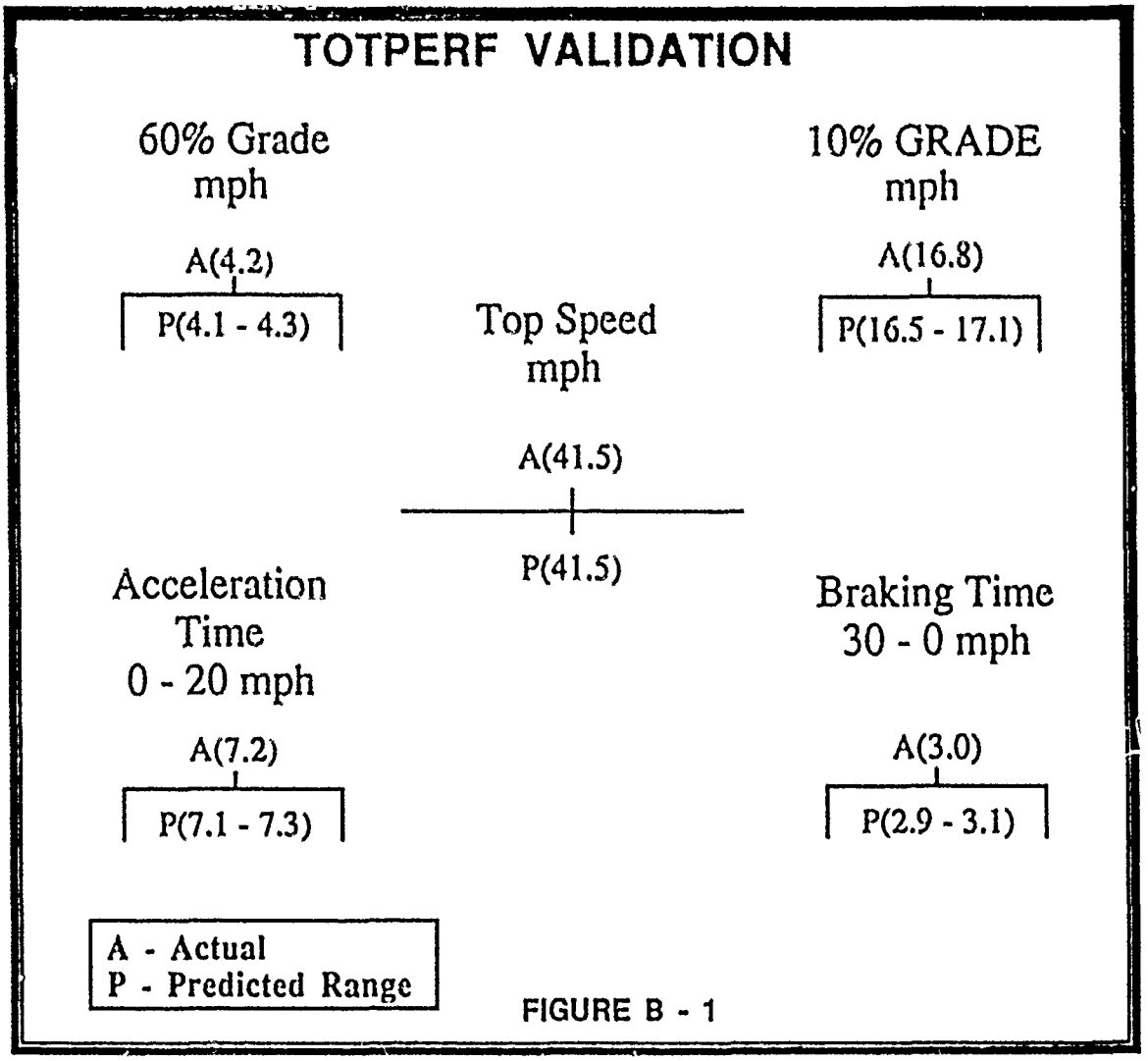

FIGURE B - 1

b. The SIMNET hull dynamics simulation was designed to match the TOTPERF database. The hull dynamics simulation includes modeling of the engine, transmission, torque converter, and final drive which yields such performance characteristics as maximum speed, acceleration, slope climbing, braking, steering and fuel consumption. SIMNET tank automotive performance is a nearly identical duplication of TOTPERF predicted automotive performance. Figure B-2 is an example of how closely SIMNET and TOTPERF automotive performance data match for one selected parameter (acceleration). TOTPERF is a validated simulator of tank automotive performance with very high correlation to actual M1/M1A1 performance. SIMNET was designed to match the automotive performance predictions of TOTPERF. This chain (SIMNET = TOTPERF = M1/M1A1) leads to a high correlation between actual M1/M1A1 automotive performance and SIMNET automotive performance.

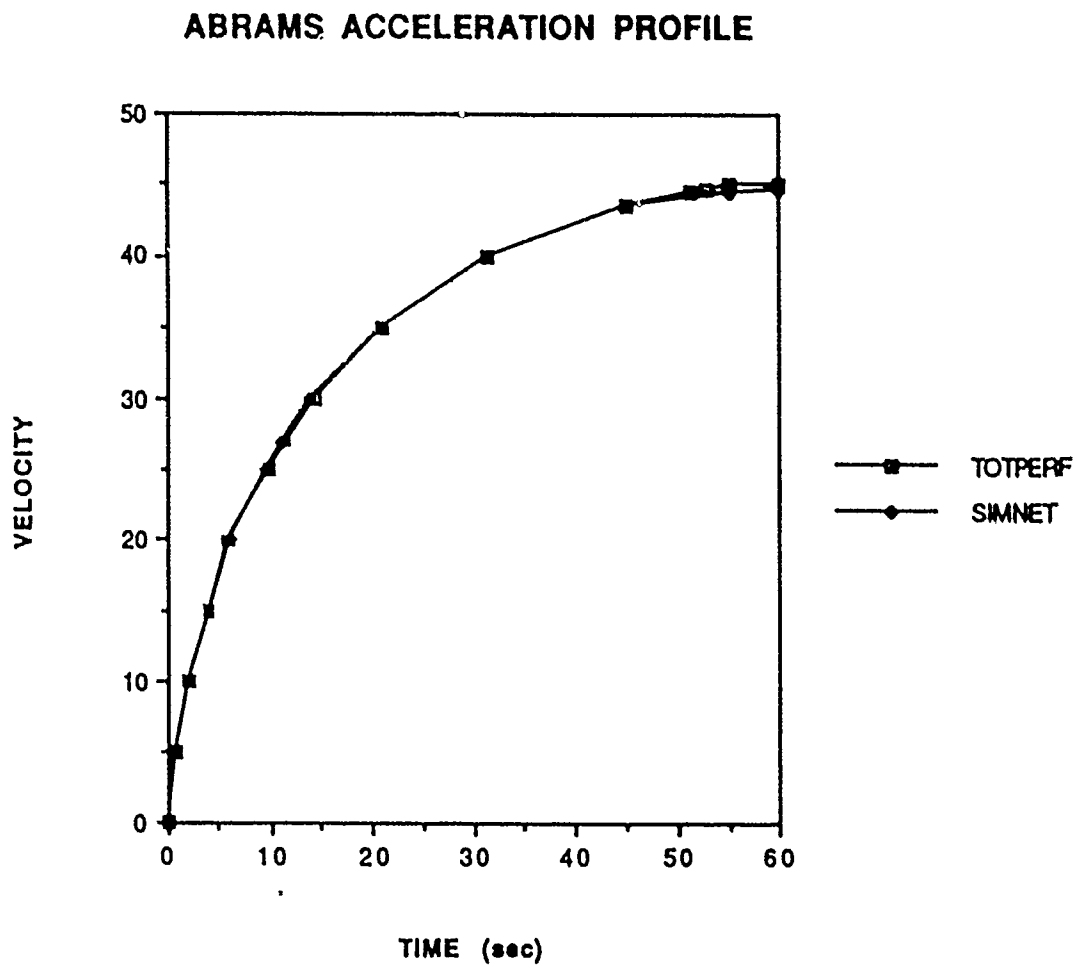

FIGURE B - 2

3. The U.S. Army Armor and Engineer Board's critique of SIMNET concluded that SIMNET was an excellent tool for training navigation task skills since crewmen were forced to concentrate on individual tasks to navigate the tank. However, the report states that standard military map sheets are difficult to align with the terrain features as seen through the vision blocks of the simulators. This lack of correlation between the graphics representation and standard map sheets makes navigation in SIMNET more difficult than field navigation. As a result of this critique, SIMNET personnel have developed special SIMNET terrain maps which better correspond to the graphics representation which tankers see through their simulator vision blocks. These maps accurately portray all buildings, roads, hills, and rivers as they appear in the terrain data base. These maps have eased the discrepancy between actual and simulated navigation. Additionally, a Turret-to-Hull Reference Indicator was installed which compensates for the lack of an open-hatch view of the hull and turret position. The level of fidelity in SIMNET does not match that of a full-scale field exercise but SIMNET does provide a good tool for combat system evaluations.

4. ARI has conducted at least two separate, extensive tests to assess the magnitude of position navigation errors; (1) the Soldier Performance Research Project (SPRP), and (2) the Effect of POSNAV Information Displays on the Performance of Armor Crews and Platoons (both tests are described in Section II-D, Capabilities Assessment). Each of these tests was scientifically designed and controlled and contained the requisite sample sizes to establish a level of statistical significance.

a. The SPRP was a two-phased test which required 120 tank crews, from five different CONUS divisions, to perform a realistic single tank tactical exercise in a field test environment and then perform similar combat tasks as part of a platoon exercise in the SIMNET environment. Each phase of the test required the tank commanders to report both own location grid coordinates and the locations of enemy targets. The average grid deviation in the field test phase was 987 meters. The average grid deviation in the SIMNET phase was 976 meters. The scenarios in the two phases were different but the requirements of the tested crews were similar.

b. The second test, the POSNAV evaluation , required 60 individual tank crews to complete a navigation exercise, first using only conventional navigation tools, and then with the aid of a POSNAV system. For the no POSNAV phase, the grid deviation in reporting own location was 1056 meters.

c. The significance of these results is that the magnitude of navigation errors reported in SIMNET tests correlates very closely with those experienced in actual field tests.

5. Both the March 1989 M1A2 COEA and this POSNAV Analysis Update have documented the difficulties combat vehicle crewmen have with field navigation. Large discrepancies often exist between actual and reported locations. SIMNET navigation is also very difficult for combat vehicle crewmen. Combined exercises using both SIMNET and field navigation tests have resulted in the similar trend of large navigation errors. Field validation tests of position navigation systems (e.g. VNAS CEP test, U.S. Army Infantry Board, Nov 1983) have demonstrated improved field navigation capabilities. Extensive SIMNET testing of the POSNAV system (ARI SIMNET Exercise, 1988) has demonstrated tremendous improvement in simulated navigation capability. Large errors with unaided navigation in SIMNET exercises were largely eliminated when the POSNAV system was used.

6. In simulating combat vehicle navigation exercises, the failure of achieving total fidelity in the graphics representation of battlefield terrain places the experimental error on the conservative side. In other words, if navigating in SIMNET is more difficult than in field exercises, then any levels of navigation speed and accuracy achieved with a navigation aid in SIMNET should also be expected with that same navigation aid in an actual field exercise. The percentage of improvement may be greater in SIMNET, but the level of speed and accuracy achieved can conservatively be expected in field exercises.

D. Conclusions.

1. SIMNET is a valuable, credible tool for land navigation evaluations. A high fidelity network of tank simulators has a distinct advantage over traditional computer models which are based on mathematical algorithms and automated decision rules. The human element present in the simulators adds a great deal of realism to the objective of imitating field exercises.

2. The automotive performance characteristics of the tank simulators has nearly 100% correlation with the actual Abrams series tanks. The graphics representation of the landscape, as seen through the vision blocks of the simulators, has received criticism of its degree of fidelity. SIMNET personnel have taken action (special SIMNET maps, hull-to-turret reference indicator) to compensate for the graphics fidelity.

3. Field exercises and SIMNET exercises have demonstrated similar trends in navigation problems. Position navigation systems have shown great improvements in accuracy and speed of navigation in both field and SIMNET exercises.

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APPENDIX C. PAST ANALYSIS

Problems associated with navigation are not new. In an effort to quantify the extent of the problem, many different studies have addressed the issue. Table C-1 lists the studies that are used, or simply referenced, in this investigation to evaluate the cost and operational effectiveness impact of position navigation. A brief summary of the findings of these studies follows.

POSITION AND NAVIGATION STUDIES

- 1978 Position and Location Systems COEA
- Vehicle Navigation Aid System (VNAS) Abbreviated Analysis
- ARI-Field Test
- Rand Fratricide Study
- ARI-POSNAV Test
- National Training Center-Trendline Analysis
- Combined Arms in a Nuclear Chemical Environment Test (CANE)
- ARI-Combat Vehicle Command and Control (Platoon level test)
- Rand Artillery Targeting Accuracy Study

Table C - 1

A. Position and Navigation Systems COEA (1978). Computer modeling found that position navigation aids enabled a reinforcing unit to achieve a timely arrival at a desired defensive position which resulted in a force effectiveness increase over a unit with no navigation assistance. The force effectiveness increase demonstrated in this scenario (U.S. battalion, RED Regiment) was 8.9 percent.

B. VNAS Abbreviated Analysis (November 1983). This study compared the effectiveness of a Vehiclular Navigation Aids System (VNAS), a Global Positioning System (GPS), an Enhanced Position Location System (EPLRS), and a Modular Azimuth Positioning System (MAPS). The preferred system is the VNAS which is a self-contained system which performs all required functions at a relatively low cost. The POSNAV system is the tank - specific version of VNAS. POSNAV uses the commander's and driver's displays and the data bus of the M1A2 for some of its functions.

C. ARI-Field Test (June 1989). This study examined the effects of soldier mental categories on mission success in a series of both field and SIMNET exercises. Navigation errors of similar magnitude (800-1000 meters) occurred in both the field and in the SIMNET portions of the test.

D. RAND Fratricide Study (February 1986). Investigated NTC shots data for both direct and indirect fires and found alarmingly high incidence of fratricidal fires. An examination of the causes of fratricide concluded that one-half of NTC fratricidal incidents could be avoided if the shooter knew the location of sister units. Another one-third of the incidents could be avoided if the shooter knew the location of individual isolated friendly vehicles.

E. ARI-POSNAV Test (October 1988). Extensive simulated exercises which found that navigation errors resulting from missions conducted without benefit of navigation aids were largely eliminated when POSNAV systems were used. Tank crews were quicker and more accurate in locating themselves as well as potential targets and completed missions sooner, while placing less of the navigation burden on tank commanders.

F. NTC-Trendline Analysis (1989). Examination of data from NTC database revealed numerous examples of disoriented units, erroneous calls for fire, high incidence of fratricide, and improper training practices all resulting from poor land navigation skills.

G. CANE Test ((November 1988). Commanders attempting to control maneuver forces in extensive field tests under closed-hatch NBC conditions reported great difficulty controlling the scheme of maneuver and maintaining proper command and control.

H. ARI-Combat Vehicle C2 Test (1989). Extensive simulated (SIMNET) exercises that found that IVIS equipped tank crews and tank platoons performed combat related tasks significantly better than crews using map sheets and a turret heading indicator (simulates a compass in SIMNET). Tank commanders participating in the exercises indicated particularly strong support for the position navigation component of IVIS. Many commanders asserted that the POSNAV map display was especially helpful for navigating and coordinating unit movement and formations. POSNAV allowed drivers to navigate without continuous tank commander direction, thus freeing commanders for other tasks.

I. RAND Artillery Targeting Accuracy Study (May 1989). The RAND Arroyo Center determined from an assessment of a BRL field test and NTC data that improvements to field artillery effectiveness will not come from more intensive training, but from improved equipment.

APPENDIX D. COST ANALYSIS

A. Introduction.

1. Purpose. The scope of this analysis is limited to an analysis of incremental cost for the Position Navigation (POSNAV) system within a M1A2 tank configuration.

2. Background.

a. In August 1989, the Defense Acquisition Board (DAB) authorized Full Scale Development and testing of the Army M1A2 preferred tank configuration within a production recurring average unit cost (AUC) goal of $3.037 million (FY 89 constant dollars). This AUC corresponds to a M1A2 production configuration that includes the following additional components to the Baseline M1A1: CITV, ICWS, and Core Tank Systems Integration Package. Conventional System Committee (CSC) approval of the additional components (POSNAV, Survivability Enhancement Package 1 and 2, and CO2 Laser Range Finder) to the M1A2 production configuration require additional analytical justification.

b. In March 1989, TRAC-WSMR and USAARMS published the M1A2 COEA while the ACP was being formulated. The ACP and M1A2 COEA difference totalled $93.3 million and consisted primarily of additional production costs associated with systems technical support and supporting training devices for the total M1A2 tank configuration. These differences were briefed by CEAC to DA and OSD during the M1A2 DAB review. The POSNAV specific ACP is incorporated into this POSNAV cost analysis. Cost data below summarizes those differences.

FY - 89 Constant $ - Million

Production Cost Element	M1A2 COEA	TOTAL ACP	POSNAV ALLOCATION
2.03 Eng. Changes	0	31.0	1.2
2.04 Data	0	9.5	0.4
2.05 Test	0	15.0	0.3
2.06 Train Devices	51.1	65.2	0.0
2.07 Spares	72.2	77.6	3.0
2.09 other	0	18.3	0.7
Total	123.3	216.6	5.6

3. Alternatives.

a. Alternative 1 is the approved production M1A2 tank. This tank configuration is a 1992 programmed (13th year) baseline production M1A1 tank (Base Case in March 1989 M1A2 COEA) with additional M1A2 mission components. The M1A2 additional mission components include the ICWS, CITV and Core Tank (systems Integration Package).

b. Alternative 2 adds the POSNAV mission component to the approved M1A2 production configuration tank. The POSNAV capability is achieved by adding a sensor to the M1A2 Core Tank Systems Integration package.

4. Ground Rules. All costs will be presented in FY 89 constant dollars, in order that the cost in this analysis is consistent with the March 1989 M1A2 COEA, BCE, ACP, and cost data presented to the Defense Acquisition Board (DAB). Remaining ground rules specified in the original M1A2 COEA apply.

5. Methodology. This analysis uses the same validated cost data used for the March 1989 M1A2 COEA, provided by the TACOM and HFM PEO-Abrams cost analysis organizations. HFM PEO-Abrams cost analysis personnel reported no changes in the original cost data associated with POSNAV. The only change to these cost data reflects the POSNAV ACP allocation as outlined in paragraph A.2.b. of this appendix. USAARMS provided the lead with support from TRAC-WSMR in the development of this analysis. Copy of this cost analysis has been forwarded to TRAC-RPD for final certification. TRAC RPD has reviewed and approved the cost analysis (awaiting final certification letter). This analysis concentrated on a Life Cycle Cost Analysis (LCCA) to reflect the incremental cost impact of adding POSNAV to the Approved M1A2 production configuration.

B. Life Cycle Cost Analysis. The Life Cycle Cost Analysis (LCCA) provided in table D-1 is a summary level presentation of the LCCEs for the approved M1A2 configuration (alternative 1) and incremental LCC associated with POSNAV (alternative 2). The greatest POSNAV incremental LCC cost difference is associated with production costs.

SUMMARY OF LIFE CYCLE COSTS (LCC)
FY 89 CONSTANT DOLLARS - MILLIONS

COST ELEMENT	TOTAL APPROVED M1A2	PLUS POSNAV
1. DEVELOPMENT	$168.90	$0.00
2. PRODUCTION (QTY - 2926)	$9,841.70	$67.00
3. MILITARY	$0.00	$0.00
4. FIELDING	$424.50	$0.20
5. SUSTAINMENT (QTY - FLEET)	$37,487.70	$7.50
TOTAL LCC	$47,922.80	$74.70

TOTAL TANK PRODUCTION RECURRING AUC	$3.037	$3.06

TABLE D - 1

1. Development Costs. All costs are sunk (no change in cost data published in original M1A2 COEA).

2. Production Costs. Production cost is the single largest contributor to the incremental changes in the LCC. Table D-2 shows that significant incremental costs are associated with recurring production cost.

INCREMENTAL PRODUCTION COST (QTY = 2926)
FY 89 CONSTANT DOLLARS - MILLIONS

COST ELEMENT	POSNAV
NON-RECURRING	$0.00
RECURRING	$61.40
ENG CHANGES	$1.20
DATA	$0.40
TEST	$0.30
TRAINING EQUIP	$0.00
SPARES	$3.00
OTHER	$0.70
TOTAL	$67.00

MOST SIGNIFICANT COST DRIVER

TOTAL TANK PRODUCTION RECURRING AUC	$3.058

COMPONENT COST IN THOUSANDS OF
FY 89 CONSTANT DOLLARS

INCREMENTAL PRODUCTION RECURRING AUC	$21.00

TABLE D - 2

a. Recurring. Recurring cost is the main cost driver within the LCCA. A total of $ 61.4 M or AUC of $ 21 K in table D-2 reflects the total recurring manufacturing cost for adding the POSNAV capability to the approved M1A2 production configuration. AUC of $ 21 K reflects the cost for a sensor that is the only additional component required in providing the POSNAV capability to the M1A2 production tank configuration.

b. Non-recurring. Non-recurring costs represent the total manufacturing preparation requirements for design, and development of tools and test equipment for M1A2 components (no change in cost data published in original M1A2 COEA). No nonrecurring costs are solely attributable to POSNAV.

c. Engineering changes, data, test, spares, and others are all based on a historical fraction of the recurring production cost of the component and/or components. These cost elements reflect ACP adjustments to the original cost data published in the M1A2 COEA.

d. Training devices cost is required for the modifications and/or new unit conduct of fire trainer (UCOFT) as indicated in the March 1989 M1A2 COEA. The main cost driver for these modifications is associated with the CITV (included within the total M1A2 configuration). Thus, no UCOFT modifications costs are solely attributable to POSNAV.

3. Military Construction. No military construction was required to facilitate any M1A2 Block II improvements (no change in cost data published in March 1989 M1A2 COEA).

4. Fielding. The increase of fielding costs is attributable to the fielding of initial spares to fill the pipeline (no change in cost data published in March 1989 M1A2 COEA). The cost of these initial spares is a percentage of the recurring production costs.

5. Sustainment. Adding the POSNAV mission capability increases sustainment cost for the approved M1A2 production configuration by only $ 207 per tank per year ($ 7.5 M / 20 years / 1813 fielded and active tanks) (see Appendix G, Annex B of the M1A2 COEA). The increase is attributable to additional replenishment repair parts and depot maintenance support for the POSNAV sensor. A breakdown of the sustainment costs by mission component (POSNAV) was obtained from utilization of RAM data (Mean Miles between Failures) as outlined in Appendix H in the published M1A2 COEA.

a. Annual Maintenance Manhours (AMMH). POSNAV should add AMMH to each tank. POSNAV RAM estimates (Mean Time Between Failures and Mean Time to Repair) from the U.S. Army Material Systems Analysis Activity (AMSAA) were used to estimate that .08 AMMH per tank (4.7 AMMH per tank bn) will be required for POSNAV. This is insignificant for cost purposes.

b. Institutional Training Impact. The March 1989 M1A2 COEA TIA indicated 253 additional training Program of Instruction (POI) hours, at an estimated $ 6.1 M per 20 years, will be required to facilitate all M1A2 mission components. POSNAV alone requires an additional 29.5 POI hours (11.7% of total) or an estimated $.7 M per 20 years. However, TRADOC has not approved these incremental POI increases and they are displayed as potential increases only.

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