DOCUMENTED BRIEFING

RAND

Rapid Force Projection Technologies

A Quick-Look Analysis of Advanced Light Indirect Fire Systems

Randall Steeb, John Matsumura, Terrell Covington, Thomas Herbert, Scot Eisenhard, Laura Melody

Arroyo Center
National Defense Research Institute

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Prepared for the
United States Army
Office of the Secretary of Defense

Arroyo Center
National Defense Research Institute

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PREFACE

The Rapid Force Projection Technologies (RFPT) project is formally part of the Rapid Force Projection Initiative (RFPI) and the Rapid Force Projection Initiative/Enhanced Fiber Optic Guided-Missile Advanced Concept Technology Demonstration (RFPI/EFOG-M ACTD). RFPI is a joint effort between the Office of the Secretary of Defense (OSD) and the U. S. Army, and it is jointly sponsored by USD(A&T) and ASA(RDA). RFPI is managed by the RFPI Program Management Office established at the U.S. Army Missile Command (MICOM). At RAND, the RFPT project is jointly managed by the Acquisition and Technology Policy Center of RAND's National Defense Research Institute (NDRI) and the Force Development and Technology Program of RAND's Arroyo Center (AC), which are federally funded research and development centers (FFRDCs). The NDRI is sponsored by the Office of the Secretary of Defense, the Joint Staff, and the defense agencies. The AC is sponsored by the U. S. Army.

This annotated briefing presents results from a "quick look" analysis that was requested by the RFPT sponsoring office. The intention of the analysis is to provide decisionmakers with information on the military utility of advanced, light indirect-fire weapon alternatives for the RFPI force. This research will be of interest to OSD and Army technology policymakers, military analysts, simulation specialists, technologists, and operations research analysts.

(For an overview and broader analysis of RFPI systems, refer to RAND document DB-168-A/OSD, *Rapid Force Projection: Exploring New Technology Concepts for Light Airborne Forces,* Randall Steeb, John Matsumura, et al., 1996.)

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SUMMARY

OVERVIEW

The days of U.S. military forces defending a known area of terrain with a large, prepositioned force appear to be drawing to a close. In the future, as in the recent past, the U.S. Army will need to deploy to areas of potential or actual conflict. Furthermore, because time is often critical in overseas operations, the United States must have land forces that can deploy quickly both by air and by sea. The RFPT project at RAND concentrates on the airliftable portion of these forces in the early-entry role. RAND DB-168-A/OSD (Steeb et al., 1996) highlights this project and its recent accomplishments.

In this "quick look" study, we assess the effectiveness of different advanced indirect fire weapon alternatives to the light airborne forces. Some of the alternatives, briefly described below, represent either potential system replacements or simply munition additions to the force.

- EFOG-M: 15-kilometer range enhanced fiber-optic-guided missile; six missiles are mounted on a HMMWV launcher
- HIMARS/SADARM: Multipurpose launcher with a 6-MLRS (multiple-launch rocket system) rocket pod; each rocket contains six sense-and-destroy armor, a multimode sensor, and shoot-to-kill smart munitions
- HIMARS/Damocles: Multipurpose launcher with 6-MLRS rocket pod; each rocket contains three advanced concept, large footprint hit-to-kill smart munitions with target recognition capability
- PGMM-IR: 120-millimeter precision-guided mortar munition with infrared sensor in tandem with semiactive laser homing capability
- PGMM-MMW: 120-millimeter precision-guided mortar munition with millimeter wave radar sensor (from the British Merlin smart mortar) in tandem with semiactive laser homing capability
- STRIX: Swedish 120-millimeter precision-guided mortar munition with single-mode IR (infrared) sensor

- 155 SADARM: Lightweight towed 155-millimeter howitzer with SADARM submunition
- Smart 105: Terminally guided 105-millimeter howitzer projectile (based on the infrared terminally guided smart munition) with infrared sensor and hit-to-kill capability

We also examined the effectiveness of existing options such as the dual-purpose improved conventional munitions (DPICM) used with 155-millimeter howitzers and MLRS rockets in HIMARS. A number of different tactics-related options (e.g. moving EFOG-M and PGMM-IR forward versus retaining them in the main force) were also explored to determine the impact on weapon effectiveness.

ANALYTICAL METHODOLOGY

Our work focused on determining the specific contributions of advanced technology options within a future light force. We use an integrated set of high-resolution simulations to perform these detailed evaluations. Those simulations are:

- Janus: two-sided, system level, division scale force-on-force simulation
- CAGIS: Cartographic Analysis and Geographic Information System
- RJARS: high-fidelity air defense model
- MADAM: smart munitions and artillery model
- RTAM: RAND Target Acquisition Model (primarily used for signature modeling of low-observable vehicles)
- ASP: Acoustic sensor program (models acoustic sensing by unattended ground sensors and mines)

These models are linked together over the RAND local area network to operate as a single simulation in real time, using a software package called SEMINT (seamless model integration) (Marti et al., 1994). In addition to this combat effectiveness simulation, we employed a spreadsheet model to calculate air deployment sorties and times. We did not consider cost or technology risk in the evaluations.

SCENARIO USED FOR QUICK-LOOK ANALYSIS

Given the time constraints for this quick-look analysis (with sponsoring office approval), we used one scenario to evaluate the indirect fire alternatives. The scenario we used for the analysis is generally based on the Army TRAC LANTCOM high-resolution scenario (HRS 33.7). This scenario can be characterized as a forced-entry operation with hasty defense by a partially attrited airborne brigade. In our scenario, this brigade is defending a critical node against two heavy regiments until heavy reinforcements can arrive. This modified scenario is considered to be a highly stressing situation for the brigade. In addition to a large size-of-force imbalance, we also assume a modestly sophisticated threat.

It should be noted that verification of data, models, and scenarios is an important part of the analysis. A detailed verification, validation, and accreditation (VV&A) plan for RAND and other simulation activities is written in the RFPI study plan. Points of contact for the VV&A of data, models, and scenarios are as follows:

- System characteristics and data: MICOM RFPI Program Office
- Model and simulation software: AMSAA
- Scenarios, doctrine and tactics: TRADOC, Dismounted Battlespace Battle Lab (DBBL)

RESULTS FROM THE COMPARATIVE ANALYSIS

The main effort of our research evolved around answering four fundamental questions:

- Q.1—How does the planned division ready brigade (DRB), (first unit equipped, 1998) compare with an improved DRB with hunter/standoff-killer capability?
- Q.2—Can other advanced indirect fire systems or munitions substitute for EFOG-M?
- Q.3—What are the benefits of including a counterbattery capability with the RFPI force?
- Q.4—Is assumed RSTA capability sufficient for the indirect fire weapons?

Within the context of the models, methodology, and scenario described in the following subsections, we answer these questions in the order they are presented.

A.1—Providing a hunter/standoff-killer capability to the DRB substantially improved force lethality.

In the LANTCOM (Latin America–Atlantic Command) scenario, as in previous scenarios examined by the RFPT project, providing a hunter/standoff-killer capability to the relatively stationary airborne division ready brigade offered improvements to both survivability and lethality. When only direct fire system improvements (Javelin and AGS) were included with the DRB, system exchange ratios were relatively high; however, because of the substantially larger size of the attacking force, eventually this DRB was overrun (resulting in a loss-exchange ratio of 4.1 at the time of penetration). Taking out many of the HMMWV-TOWs and substituting a combination of hunter vehicles and EFOG-M launchers (HMMWV chassis) in their place favorably changed the outcome (the loss-exchange ratio improved to 10.0 or 7.3, depending on tactics assumed). The primary reason for the improvement is directly attributable to the hunter/standoff-killer concept, which affords the capability to extend the fight considerably to the non-line-of-sight region on the battlefield. Extending the fight not only provided the advantage of starting the fight sooner, but also created a "metering-in" of the closing threat forces at a rate by which the direct fire systems (Javelin and AGS) could better service them.

A.2—EFOG-M was the single most effective weapon—other attractive alternatives were Smart 105 munition and HIMARS with Damocles.

Because EFOG-M was able to find its own targets, operate at both close and longer ranges,[1] discriminate between live and dead targets, and use a lightweight launcher platform, it was the most effective single system. Next to EFOG-M, the Smart 105 munition was the only other single alternative that resulted in a win for the Blue DRB. HIMARS with Damocles proved to be highly effective per unit, but very few units were available (due to airlift constraints imposed). Nonetheless, when three HIMARS with Damocles were used in the counterbattery role in

[1]Longer ranges for EFOG-M were obtained by positioning launchers forward. While this tactic achieved an ability to reach farther on the battlefield, it resulted in a substantially reduced overall loss-exchange ratio (LER dropped from 10.0 to 7.3).

conjunction with EFOG-M as antiarmor, further improvement to the DRB was realized, and resulted in a win for Blue.

Before decisions about acquisition, force mix, and tactics can be made, much more analysis is needed about the costs, deployability, and robustness of the alternative systems.

A.3—With smart munitions, counterbattery fire can substantially increase Blue Force survivability.

Counterbattery fire was seen to be an extremely important mission in this scenario. Red artillery accounted for 30 percent of Blue losses in the notional DRB case and significantly disrupted the C2 system functions. The current counterbattery submunition, the dual-purpose improved conventional munition (DPICM), regardless of the means of delivery (cannon or rocket) did not provide the needed lethality to successfully attrit the Red artillery. The sense and destroy armor (SADARM) submunitions offered some improvement over DPICM. However, a high-end artillery upgrade, the HIMARS with Damocles system, was able to destroy virtually all Red artillery and reduced consequent Blue losses.

A.4—RSTA appeared to be sufficient for the indirect fire systems; in fact, it did not seem to be fully exploited.

The quick-look analysis concentrated on advanced indirect fire weapon systems for light forces, with the assumption of competent and relatively complete RSTA and C2 networks. A comparison between the detections provided by the RSTA and the kills (by range) indicated a significant surplus of target acquisitions—many more than were answered with indirect fire. Thus, when one of the more active (and more expensive) RSTA assets, the Remote Sentry, was removed from the force, the overall impact on loss-exchange-ratio was minor. Repositioning acoustic sensors to cover gaps created by Remote Sentry removal provided a means to regain many detections; however, the repositioning process resulted in less overall coverage (including dead space—where there was no activity, but which may be equally important as the number of actual detections).

Thus, we next need to examine the vulnerabilities of all systems in an advanced light force—from deployment of the forward unattended ground sensors to movement and supply of rear systems. This process should concentrate on such issues as new enemy tactics, simple technology upgrades, different mixes of sensors and weapons, and low-cost counters to high-tech, highly digitized systems.

The data we used to characterize the indirect fire systems sometimes originated from the developer. We questioned the validity of certain data for several conceptual or early development systems (specifically, the accuracy, time of flight, munition footprint size, and warhead lethality). Nonetheless, we used the data as provided by the weapon developers and coordinated the options for differing tactics, techniques, and procedures (TTPs) with the user/developer when possible, as no other credible source of data exists at this time.

ACKNOWLEDGMENTS

A number of RAND colleagues and U.S. Army and RFPI analysts contributed extensively to the formulation of this work. At RAND, Gail Halverson, Phyllis Kantar, John Pinder, and Angela Stich contributed simulation definition and programming support (separately documented). Elliot Axelband, John Gibson, and Eiichi Kamiya provided thoughtful reviews of this work.

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The research was conducted under the direction of Dr. Gene Gritton and Dr. Kenneth Horn at RAND. The authors, alone, are responsible for the information contained in this work.

ACRONYMS

AAWS-M	Advanced antitank weapon system–medium
AC	Arroyo Center (RAND FFRDC)
ACTD	Advanced Concept Technology Demonstration
ADRPM	Acoustic Detection Range Prediction Model
AFATDS	Army Field Artillery Tactical Distribution System
AGS	Armored Gun System
AMSAA	Army Materiel Systems Analysis Activity
APC	Armored personnel carrier
ARDEC	Armament Research, Development, and Engineering Center
ASP	Acoustic Sensor Program
ATCCS	Army Tactical Command and Control System
ATD	Advanced Technology Demonstration
ATGM	Antitank guided missile
BAI	Battlefield air interdiction
BAT	Brilliant Antiarmor munition
BDS-D	Battlefield Distributed Simulation—Developmental
BEWSS	Battlefield Environment Weapons Systems Simulation
BMP	Russian armored personnel carrier
CAC2	Combined arms command and control
CAGIS	Cartographic Analysis and Geographic Information System
Castforem	Constructive simulation model similar to Janus
CHAMP	CAGIS Helicopter Air Maneuver Program
COEA	Cost and operational effectiveness analysis
C2	Command and control
DBBL	Dismounted Battlespace Battle Lab
DIS	Distributed Interactive Simulation
DPICM	Dual-purpose improved conventional munitions
DRB	Division Ready Brigade
DSI	Distributed Simulation Internet
ECM	Electronic countermeasures
EFOG-M	Enhanced Fiber-Optic-Guided Missile
EFP	Explosively formed projectile
EXDRONE	Expendable drone
FDC	Fire direction center
FSE	Fire support element
FLIR	Forward-looking infrared
FLOT	Forward line of own troops
FO	Forward observer
FSD	Full-scale development

GPS	Global Positioning System
HE	High explosive
HIMARS	High Mobility Artillery Rocket System
HMMWV	High Mobility Multipurpose Wheeled Vehicle
ICM	Improved conventional munitions
IFV	Infantry fighting vehicle
IMF	Intelligent mine field
IIR	Imaging infrared
INS	Inertial Navigation System
IR	Infrared
IREMBASS	Improved Remotely Emplaced Battlefield Sensor System
IRTGSM	Infrared Terminally Guided Smart Munition
IVIS	Intervehicle Information System
Janus	High-fidelity, force-on-force simulation
JMEM	Joint Munitions Effectiveness Manual
JSTARS	Joint Surveillance Target Attack Radar System
KEM	Kinetic Energy Missile
LANTCOM	Latin America–Atlantic Command
LER	loss-exchange ratio (Red losses divided by Blue)
LO	Low observable
LOB	Line of bearing
LOS	Line of sight
LOSAT	Line-of-Sight Antitank
LW155	Lightweight 155 mm towed howitzer
MADAM	Model to Assess Damage to Armor with Munitions
MICOM	U.S. Army Missile Command, Redstone Arsenal
MLRS	Multiple-Launch Rocket System
MMW	Millimeter wave
MOE	Measure of effectiveness
MOUT	Military operations in urban terrain
MPL	Multipurpose Launcher
MRL	Multiple Rocket Launcher (Russian)
NDRI	National Defense Research Institute (RAND FFRDC)
NLOS	Non-line-of-sight
O&O	Operational and Organizational Plan
OOTW	Operations other than war
OSD	Office of the Secretary of Defense
PGMM	Precision-Guided Mortar Munition
RCS	Radar cross section
RFPI	Rapid Force Projection Initiative
RFPT	Rapid Force Projection Technologies
RJARS	RAND's Jamming Aircraft and Radar Simulation
RSTA	Reconnaissance, surveillance, and target acquisition

RTAM	RAND Target Acquisition Model
SADARM	Sense and Destroy Armor
SACLOS	Semiactive control, line-of-sight
SEMINT	Seamless model integration
SER	System exchange ratio (kills by a system in an engagement divided by losses of that system)
SINCGARS	Single Channel Ground and Air Radio System
SPH	Self-propelled howitzer
SWA	Southwest Asia
TACAIR	Tactical aircraft
TACOM	Army Tank and Automotive Command
TLD	Top-level demonstration
TLE	Target location error
TO&E	Table of Organization and Equipment
TOC	Tactical operations center
TOW	Tube-launched, Optically tracked, Wire-Guided Missile
TRAC	Army Training and Analysis Command
TRAC-WSMR	TRAC-White Sands Missile Range
TRADOC	Army Training and Doctrine Command
TTPs	Tactics, techniques, and procedures
21CLW	21st Century Land Warrior
UAV	Unmanned aerial vehicle
UGV	Unmanned ground vehicle
USD	Under Secretary of Defense
VIDS	Vehicle Integrated Defense System
VV&A	Verification, validation, and accreditation
WAM	Wide-Area Munition

RAPID FORCE PROJECTION TECHNOLOGIES:

Quick-Look Analysis of Advanced Light Indirect Fire Systems

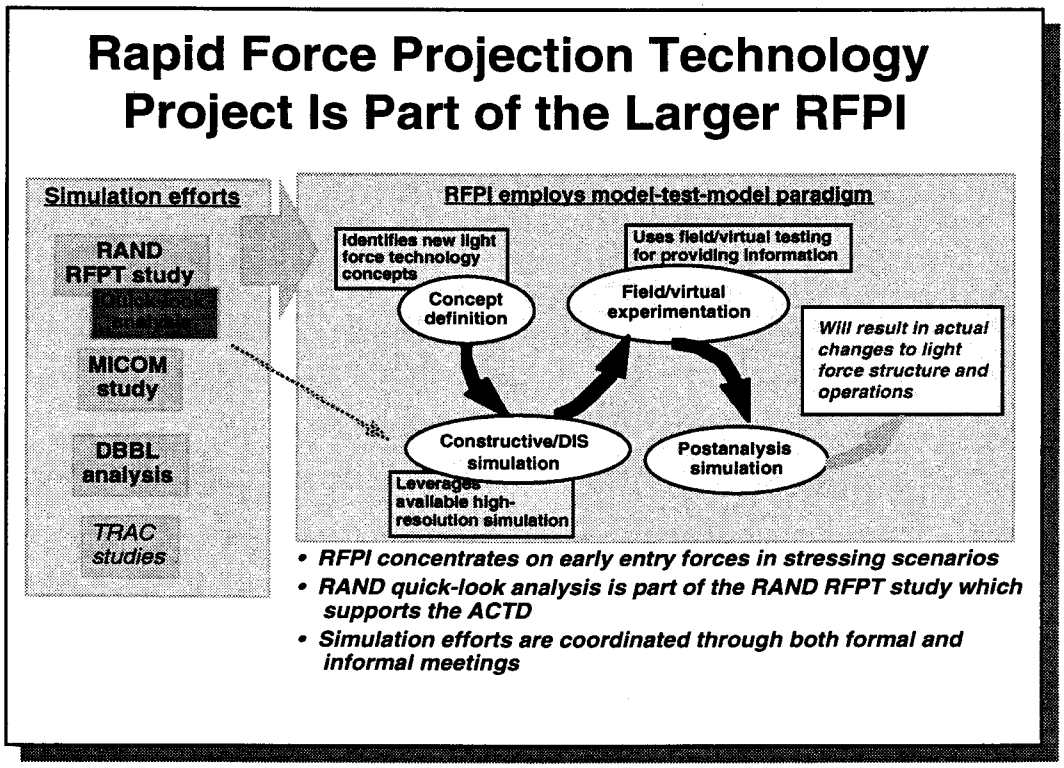
1. INTRODUCTION

In early 1995, RAND was asked to provide a quick-look analysis of candidate Rapid Force Projection Initiative (RFPI) systems. The purpose of this analysis was to provide insights to decisionmakers on the military utility of different weapon systems in the context of an RFPI force. The emphasis of this particular analysis was on the indirect fire weapon alternatives. This analysis is part of the larger Rapid Force Projection Technologies (RFPT) project being conducted jointly at RAND, within the Arroyo Center and the National Defense Research Institute. This work both builds on and benefits from previous RFPT project work. For an overview of the RFPT project, refer to RAND documented briefing DB-168-A/OSD (Steeb et al., 1996).

Objectives

- **Assess the military utility of advanced indirect fire weapon systems and munitions for early entry forces**
  - **Stressing scenario with high-tech threat**
  - **Robust RSTA environment**
- **Compare indirect fire candidates**
- **Examine sensitivity of indirect fire performance to different RSTA capabilities**

The objectives of this quick-look analysis are: (1) to assess the military utility of emerging rapid force projection technologies for light force operations, (2) to compare different indirect fire weapon candidates, and (3) to examine the sensitivity of the indirect fire system performance to a number of reconnaissance, surveillance, and target acquisition (RSTA) situations. To best differentiate the contributions of the force configurations, we simulate them in a stressing scenario with an overmatching Red force and assume relatively complete coverage by Blue RSTA assets. In this particular assessment, we focused on outcome measures such as kills, losses, loss-exchange ratios, and detection and kill ranges. Because of the developmental nature of many of the systems under study, we did not consider such factors as cost, technology risk, and countermeasure robustness in the analysis.



RAND is formally a member of the RFPI simulation team led by MICOM (Missile Command, Redstone Arsenal), and has responsibilities in each phase of development leading to actual implementation of systems in the force. RAND was instrumental in the first phase, concept development of many of the new systems, in particular the hunter/standoff killer combination, and continues to refine the many system components. RAND is responsible for Janus and associated modeling and analysis in the constructive/DIS (distributed interactive simulation) simulation effort. (RAND is developing Janus as part of the overall Army Janus effort and coordinates development with and provides software updates to TRAC (Army Training and Analysis Command)). RAND will also be observing and assisting in field experiments using the advanced technology demonstrators (ATDs) and in performing a significant portion of the last phase of the ACTD (Advanced Concept Technology Demonstration): postanalysis simulation. This quick-look analysis is part of the second phase—constructive simulation—in which system-level interactive models are used to evaluate options.

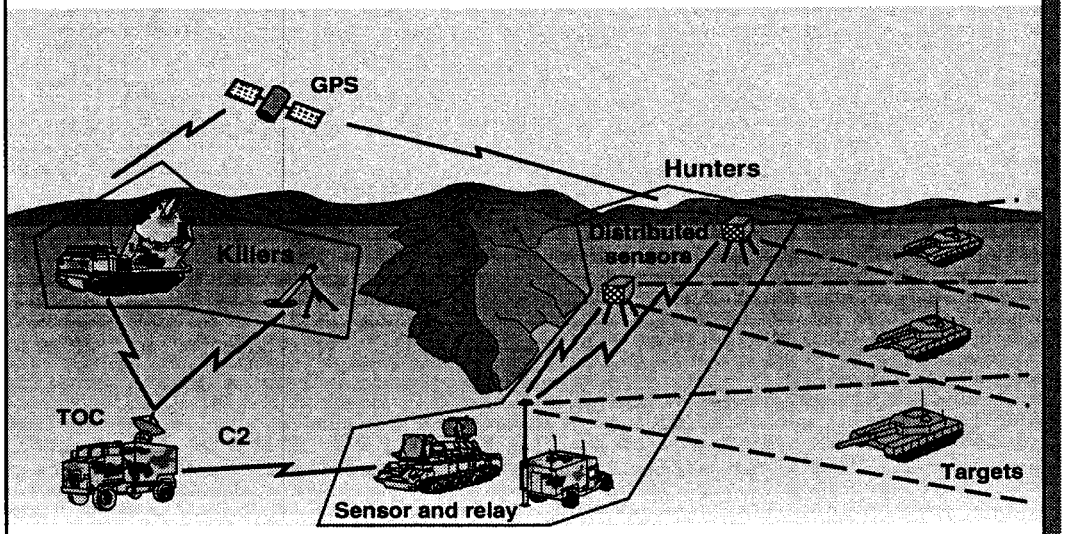
RFPT Emphasizes Exploring New Concepts Made Viable by Emerging Technologies

- **Significantly different ways to fight**
  - **Minimize direct fire (high attrition) engagements with the hunter/standoff killer concept**
  - **Use information technologies for flexible, accurate fires**
- **Emerging technology thrusts**
  - **Distributed sensor networks**
  - **Agile command and control architectures**
  - **Smart and brilliant indirect fire munitions**
  - **Enhanced weapons platforms**

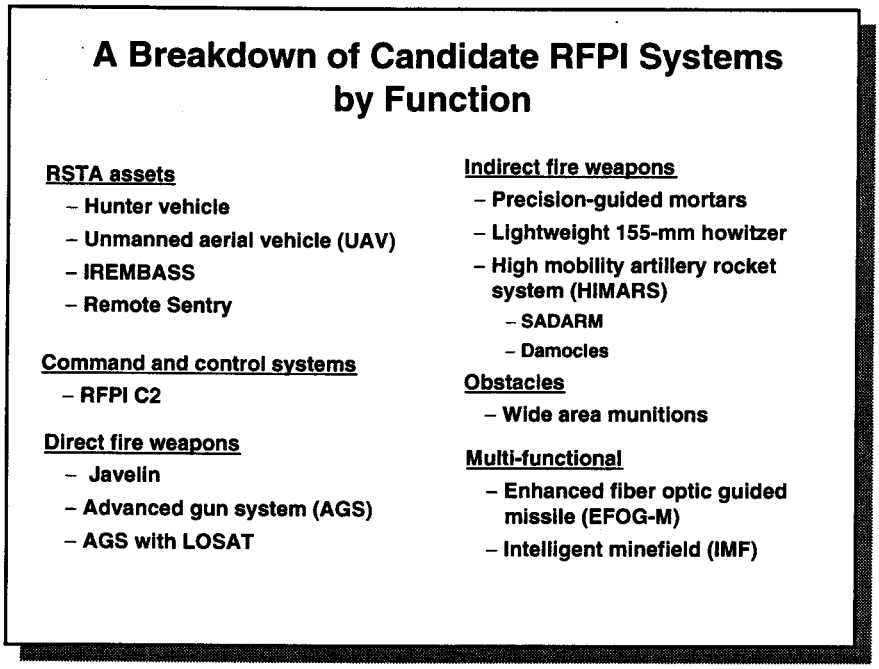
Much of the RFPI direction focuses on two major themes, both of them changing the ways forces traditionally fight. The first is an emphasis on indirect fire and non-line-of-sight systems, thus minimizing costly, high-attrition direct fire battles. Implementing this theme requires a network of sensors and hunters connected to standoff killers able to fire, move, and reload outside the range of enemy direct fire weapons. The second theme is a reliance on information technologies such as automated digital data transmission, GPS (Global Positioning System) navigation, and sophisticated operator displays to ensure accurate common views of the battlefield and fast command and control.

These capabilities have been made possible by emerging technological developments in sensors; command, control, and communication systems; autonomous and interactive weapon targeting systems; and enhanced platforms (with greater firing rates, mobility, and self-protection).

Hunters and Killers Can Contribute Across the Span and Depth of the Battlefield



This rendering shows exemplary components of the RFPI concept. Hunters (manned and unmanned, air or ground, and mobile or stationary) sense the position and status of enemy systems. They communicate the intelligence and targeting data back to C2 (command and control) nodes, which quickly match targets to weapons on the basis of range, availability, and effectiveness. Killers (ranging from mortars to cannon to missiles) fire at the targets. Battle damage assessment may sometimes be performed by the sensors and sometimes by the weapons themselves. GPS is used extensively throughout the force for positioning and navigation.



RFPI employs a wide range of manned and unmanned RSTA systems. The hunter vehicle is a HMMWV-based, target acquisition system; it uses an advanced sensor suite on an extensible sensor mast and can be equipped with a reduced signature package. Unmanned aerial vehicles such as EXDRONE (expendable drone) can be enhanced to carry FLIRs and video communication links. Both IREMBASS (improved remotely emplaced battlefield sensor system) and Remote Sentry are stationary ground sensors.

The RFPI C2 system is a networked set of C2 nodes with automated routing and decisionmaking overseen by human operators; the system primarily relies on SINGCARS (single channel ground and air radio system) links.

RFPI also employs a wide range of weapons. Direct fire systems include Javelin, a short range shoulder-fired antitank guided missile (soon to replace the Dragon), the AGS, a light (18+ tons) tank with a 105-millimeter main gun, and LOSAT (Line-of-Sight Antitank), a variant of AGS in which the main gun turret is replaced by a missile pod with 12 kinetic energy missiles. Indirect fire weapons include precision guided mortars with semiactive laser in conjunction with either IR (infrared) or MMW (millimeter wave) for target acquisition, 155-millimeter howitzers with SADARM (sense and destroy armor) submunitions, and HIMARS, a 14-ton platform carrying a pod of six MLRS (Multiple-Launch Rocket System) rockets with either SADARM or Damocles munitions. The

wide-area munition (WAM) is used as an autonomous obstacle, killing armored vehicles out to a 100-meter range.

The last category of RFPI components, the multifunctional systems, can act as both sensors and weapons. These components include EFOG-M (Enhanced Fiber-Optic-Guided Missile), a 15-kilometer-range missile with GPS antenna onboard and an imaging sensor in the nose that sends back video along the fiber-optic link. This system flies slower and has a longer time of flight than the other indirect fire systems, but it has a very high level of delivery accuracy and a large munition footprint due to its man-in-the-loop imaging and control. The IMF (intelligent minefield) is envisioned to leverage acoustic information from WAMs and other acoustic sensors, such as the overwatch sensor. This information is fused and used to better engage targets both by the minefield and through coordinated attacks with other systems.

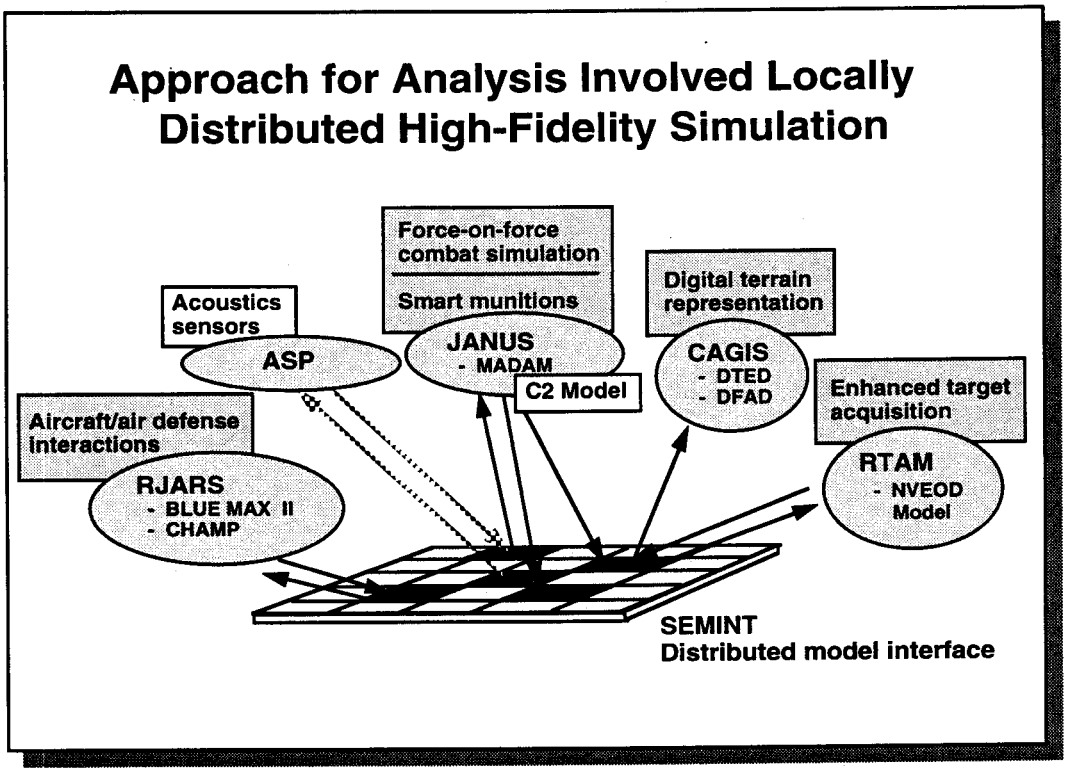
In this study, we concentrate on the indirect fire systems—EFOG-M, HIMARS (high mobility artillery and rocket system), Smart-105, PGMM (precision-guided mortar munition), and 155-SADARM. Direct fire systems will include only those systems currently planned for the 82nd DRB—HMMWV-TOW, Javelin, Apache, and AGS. WAM, IMF, and AGS with LOSAT will not be in the force. Other advanced systems being considered for light forces, such as Commanche-Longbow and STAFF, are also not within the scope of this study.

Research Questions

- **How does the baseline DRB (FUE 98) compare with an improved DRB with hunter/standoff killer capability?**
- **Can other advanced indirect fire systems or munitions substitute for EFOG-M?**
- **What are the benefits of including a counterfire capability with the improved DRB force?**
- **Is assumed RSTA capability sufficient for the indirect fire weapons?**

For this quick look analysis, several key questions were identified. First, how does the baseline DRB (division ready brigade) FUE98 (first unit equipped, 1998) compare with an improved DRB that employs a hunter/standoff killer capability? Can other advanced indirect fire system concepts or munition concepts substitute for the EFOG-M system (envisioned as a critical part of the improved DRB)? What are the benefits of a dedicated counterfire capability—especially given the already constrained airlift? The last question focuses on how some potential changes to the RSTA systems might affect force capability. Do significant mismatches exist between the capabilities provided by the RFPI RSTA systems and the capability required of the indirect fire systems?

To help answer these questions, we used high-fidelity simulation.



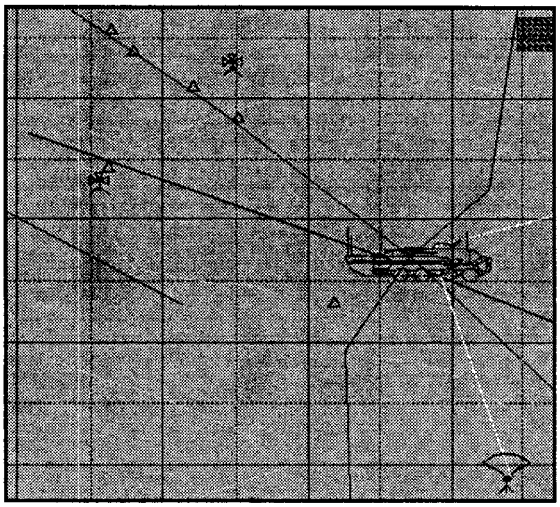
Generally, our RFPT research involves development of high-resolution models capable of representing the performance of the advanced RFPI systems. We assembled a distributed simulation environment in which to model the many different aspects of ground combat. Janus provides the overall context, individually modeling as many as 1,200 systems on a side. Events such as movement, slewing sensors, detections, and firing are modeled every few seconds in a battle. RTAM (RAND target Acqusition Model) and CAGIS (Cartographic Analysis and Geographic Information System) allow us to represent target acquisition of reduced signature vehicles on the battlefield. RJARS (RAND's version of the Jamming Aircraft and Radar Simulation) models the detection, tracking, flyout and fusing of air defense missiles fired against helicopters and UAVs (unmanned ground vehicles) (Sollfrey, 1992). MADAM (model to assess damage to armor with munitions) and CAGIS simulate the dispensing, search process, and attack sequence of smart munitions, including multiple hits, shots at hulks, and unreliable submunitions. SEMINT (seamless model integration), finally, allows all of these simulations to communicate during an exercise (Marti et al., 1994).

For modeling acoustics phenomena of several RFPI systems, TACOM's (Tank and Automotive Command's) acoustic detection and range prediction model were examined. The TACOM model was useful for defining wave attenuation phenomenology; the ARDEC (Armament Research, Development, and Engineering Center) models and data provided a means for calculating acoustics track and sensor fusion phenomenology.

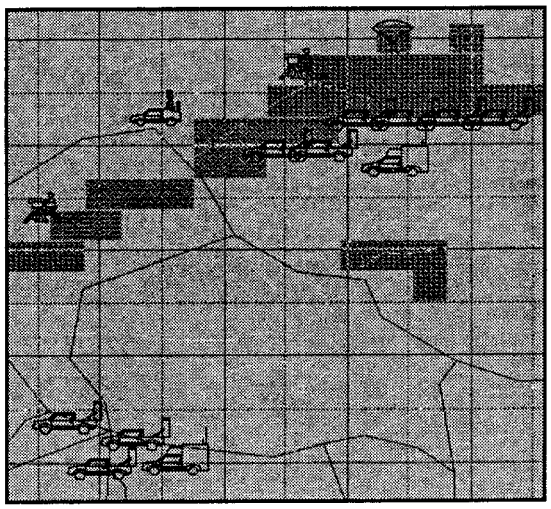
The command and control model architecture is generally based on components of the highly notional RFPI C2 concept and components of the advanced field artillery tactical distributing system (AFATDS). It models delays associated with message transmission, options planning, and assignment of weapons to targets. It also represents delays and degradations caused by loss of command and control nodes and the subsequent reconfiguration. The acoustics model and command and control model we used for this analysis are described in more detail in Appendices A and B of this document, respectively.

It should be noted that while Janus is an accredited model, the modifications and augmentations we made to represent advanced systems have not been accredited or validated. They have, however, undergone extensive examination and refinement by users, developers, and other interested parties over several years.

Janus Was Modified to Include Both Acoustic Sensor & C2 Representations



Acoustic detections



C2 nodes (FDC and FSE)

Representation of acoustic detections and simulation of command and control functions are key components of the suite of simulations used in this study. Representative screen images from these models are shown above. The left image shows two unattended acoustic sensors in the northwest detecting many vehicles on the roads (triangles represent tracked vehicle locations). A subsequent imaging sensor detection is shown by the pairing lines and vehicle icons (a tank and personnel carrier). The right image shows several fire direction centers (FDCs) amid a group of fiber-optic-guided missile launchers. These FDCs communicate contacts and commands to these indirect fire systems. It is our understanding that none of the other candidate system-level simulation tools (Castforem, BEWSS, DIS) are able to model these aspects. This flexibility and efficiency of the Janus suite of models is the reason we chose to rely on them for our studies.

LANTCOM Puts Light Infantry in Hasty Defense Against Heavy Division(-) in Mixed Terrain



Janus (with modified TRAC HRS 33.7)

The scenario we used for the analysis is a high-stress variation of the TRAC High Resolution Scenario 33.7 in LANTCOM (Latin America–Atlantic command).[1] Because of the rolling, partially covered terrain, variations of this scenario were chosen by the Army to examine the military usefulness of RFPI systems. In this scenario, a partially attrited Blue DRB (following forced entry) faces a substantially larger Red force, a division (-) consisting of two brigades and a battalion attacking along three primary avenues of approach.

The partially attrited DRB is assumed to have enough time to set up a defensive position complete with extensive ground-based RSTA—prior to the Red attack near the center of the Janus screen image. The main body of the Blue force (2 battalions) is positioned around a town. Forward of this (to the west) are RSTA systems spread over the likely Red areas of advance. The Red forces in the northeast are moving to block reinforcing Blue heavy forces marching from a seaport off the screen. The area shown is approximately 60 by 60 kilometers.

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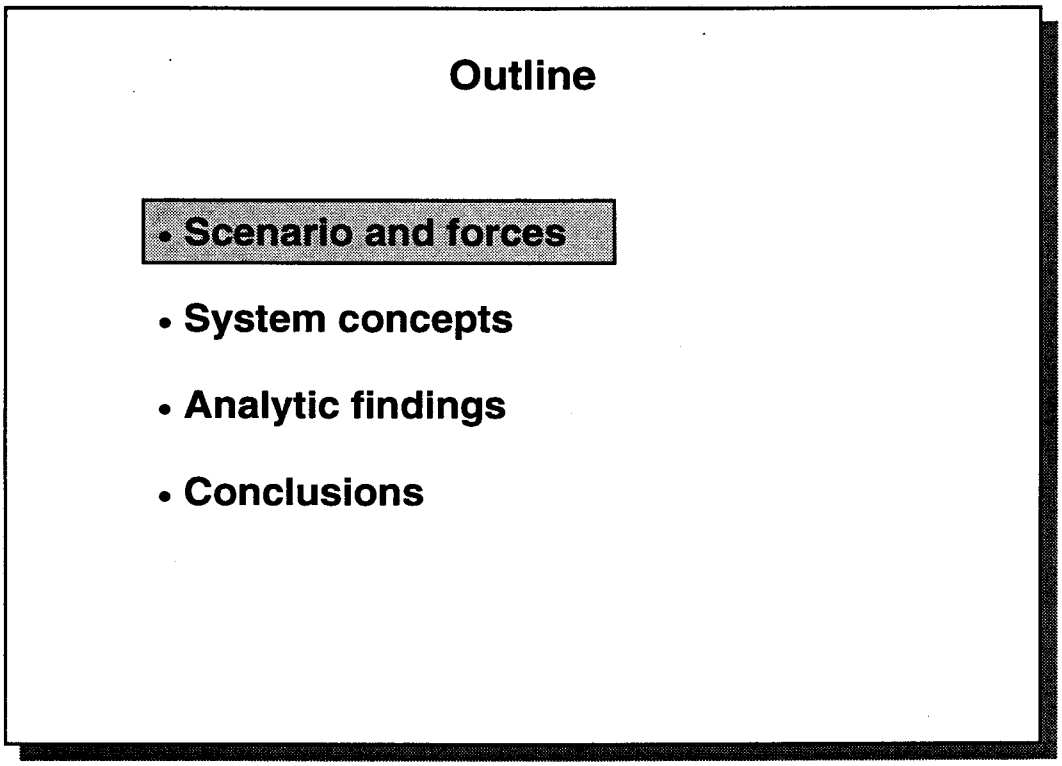
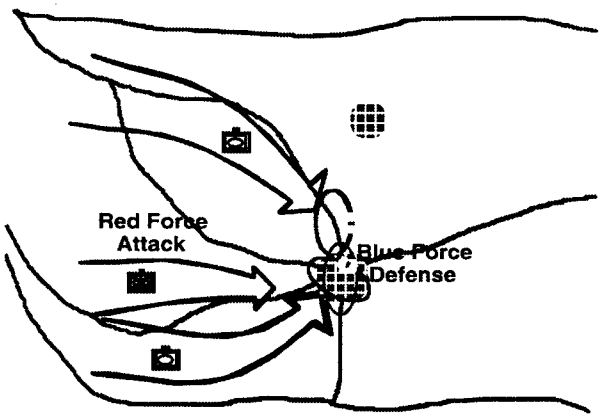
[1]This scenario variation was coordinated with MICOM and the Dismounted Battlespace Battle Lab at Ft. Benning.



2. SCENARIO AND FORCES

This document is organized into four basic sections. First, we describe in some detail the scenario and the "RFPI" light force examined in this quick-look analysis. Second, since many of the systems examined in this work have system concepts that appear to be, to some extent, in flux, we highlight some of the critical assumptions that we made regarding their capabilities and employment. Third, we present detailed findings that emerged from our analytic combat simulation. Lastly, we wrap up with a conclusions section.

Blue Force is Heavily Outnumbered



1998 Force	Red		Baseline DRB
Tank	131	T-72S	4 AGS
ATGM	0		24 Javelin
APC/IFV	131	BMP	34 HMMWV-TOW
Rocket artillery	6	MRL	0
Cannon artillery	12	SPH[a]	26 105/155 (towed)
Helicopters	6	Havoc	6 Apache

[a] 2S3 with lower vulnerability to DPICM than towed

The Blue force objective is to hold the key strategic point (airstrip) until heavy reinforcements can arrive (already en route). The Red objective is to destroy the Blue force as fast as possible before reinforcements can arrive. Preparatory fires from Red self-propelled artillery—improved conventional munitions (ICM) and high explosive (HE) rounds—support the deliberate Red armor attack.

The Red force contains some sophisticated weapons including T-72S tanks with AT-11 (fire on move) missiles, BMP-2 armored personnel carriers with AT/P-6 missiles, self-propelled 120-millimeter MRLs (multiple rocket launchers) and 152-millimeter (2S3) howitzers, which are considered to be medium to hard targets, and mobile air defense units (2S6) with radar track 30-millimeter guns and SA-19 missiles. Red does not have sophisticated RSTA and must rely on command vehicle FLIRs and visual recognitions for the direct fire engagements.

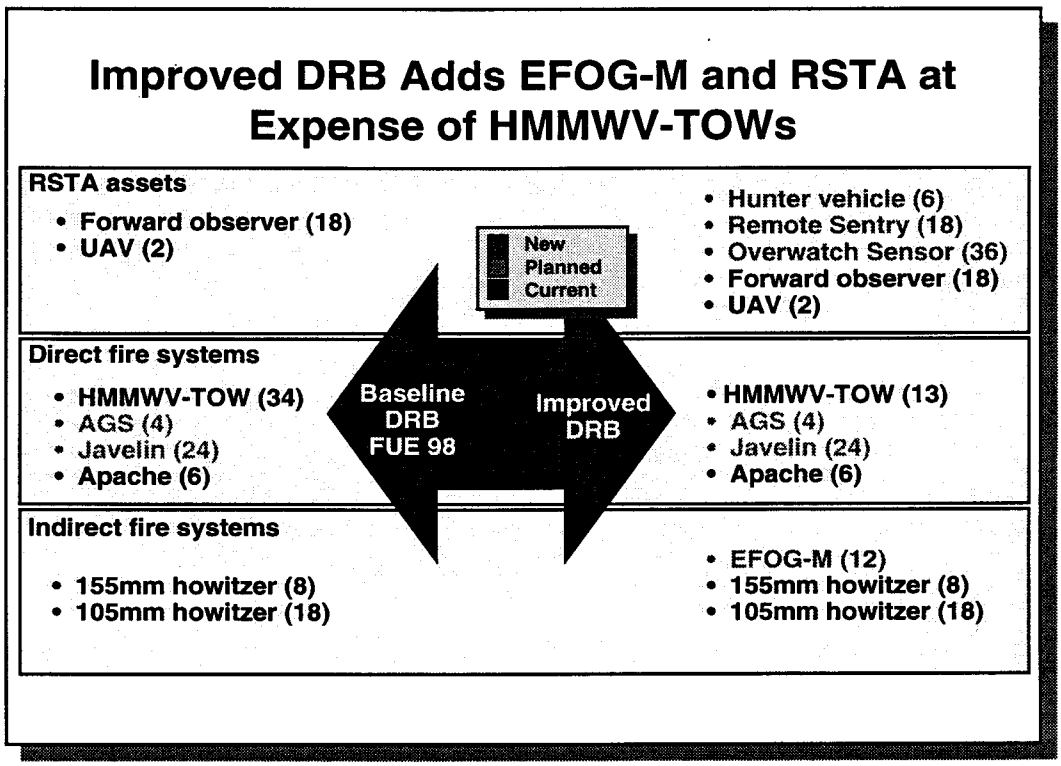
Scenario Represents Second Phase of Forced Entry Operation Against a "Future" Threat

Deployment, employment, and air support assumed

- **Airborne DRB is partially attrited on air-drop entry to forward-position**
- **DRB has time to set up defense prior to main attack**
- **TACAIR establishes air superiority and attrits 10-15% of attacking threat force in BAI operation**
- **JSTARS provides initial situation awareness**

The LANTCOM scenario we used for this analysis represents the second phase of a forced-entry operation. The first phase of the scenario involved an engagement with local militia forces, which resulted in a partially attrited Blue force. Because the Red main effort does not occur until after this initial engagement, the partially attrited DRB is presumed to have some time to regroup and to set up a hasty defense. In our version of the scenario, we assumed tactical air (Air Force fixed-wing attack) was able to conduct battlefield air interdiction (BAI) as the Red main effort approached the DRB. No close support during the engagement was assumed. Joint Surveillance and Target Attack Radar System (JSTARS) provides initial situation awareness to the Blue commander but does not contribute to the targeting of the indirect fire weapons. Logistics support elements are not included in the Janus simulation (although they are included in the airlift analysis).

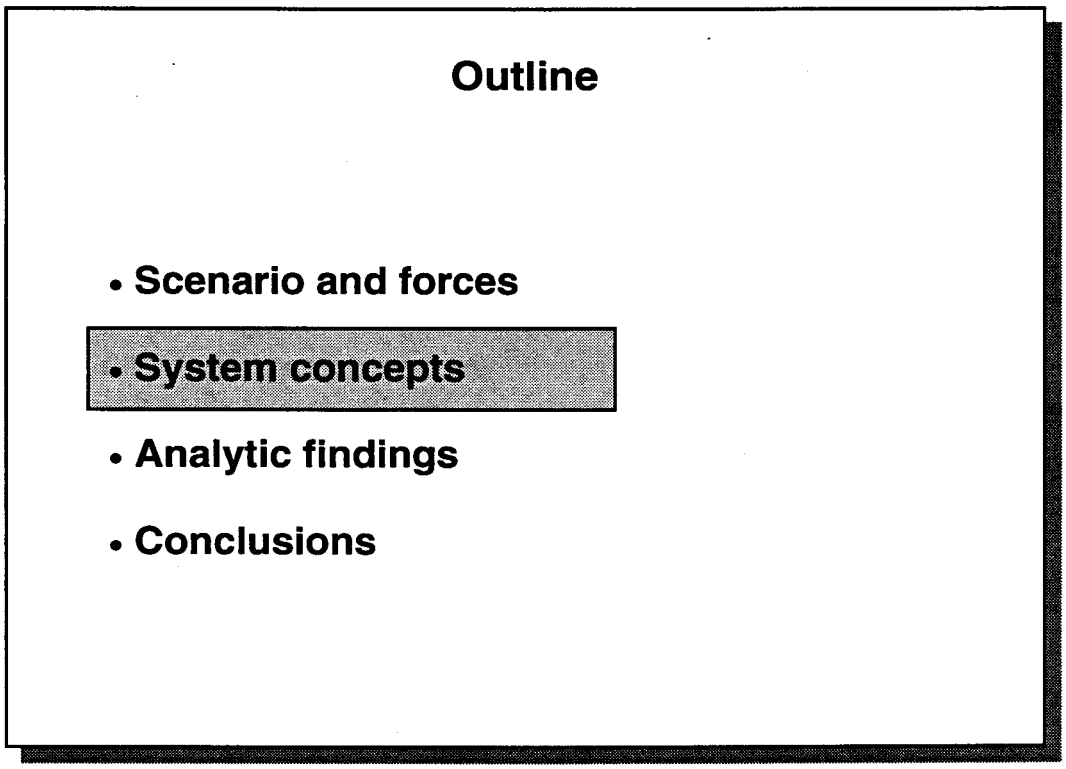
Many of the RFPI systems require emplacement along roads, bridges, and other avenues of approach. Advanced acoustic sensors, Remote Sentry, and intelligent minefields all must be placed with some care prior to the engagement to ensure coverage, line-of-sight, and communication links. While delivery means for these devices have not yet been established, we assume that some combination of helicopter, rocket, and hand emplacement will allow successful positioning.



Interactions that we have had with the Ft. Benning Dismounted Battlespace Battle Lab (DBBL) personnel have supplied information about the composition of the 82nd Division Ready Brigade. As we understand it, the planned or "baseline" DRB is defined as the first unit equipped in 1998. The inclusion of the four armored-gun-system platforms appears to be in question.

For our analysis, we were asked by the RFPI executive director to assess an "upgraded" or "improved" DRB force. The above chart shows how this force differs from the "baseline" DRB (note that the numbers of systems are for the attrited DRB following an earlier engagement; for example, the baseline DRB has some 58 HMMWV-TOWs). Generally, new RSTA systems are added (hunter vehicles, remote sentries, and the overwatch sensors from the intelligent minefield) along with the NLOS/EFOG-M system. HMMWV-TOWs are "traded-out" to make room—assuming constant airlift—for these new systems (Steeb et al., 1996).

The tactics, techniques, and procedures (TTPs) for these and other systems we examined will be described next in the System Concepts section.



3. SYSTEM CONCEPTS

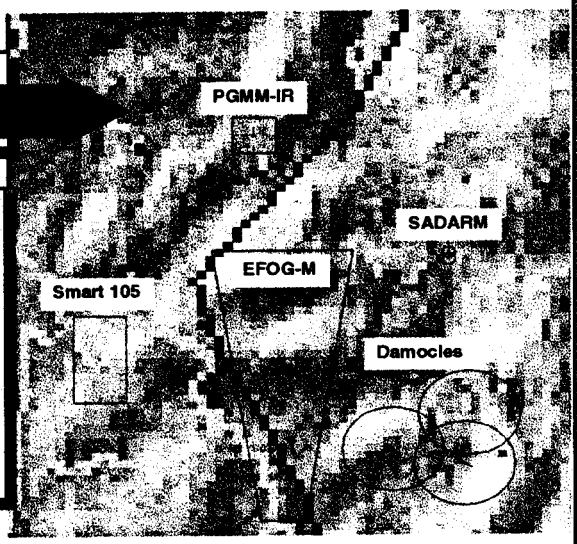
In this section, we present an important system concept of operation, the hunter/standoff killer; and we provide a description of the individual RFPI systems by function and their employment/locations on the battlefield.

Key Characteristics of Indirect Fire Alternatives

Image from smart munition model showing search footprint sizes for different indirect fire options

Weapon	Max. range	Footprint
155 SADARM	18 km	75 m radius
PGMM-IR	15 km	500 x 500 m
Smart 105[a]	19 km	600 x 1200 m
HIMARS/ Damocles	40 km	560 m radius
EFOG-M	15 km	1.6 km swath

[a] Projected system capabilities

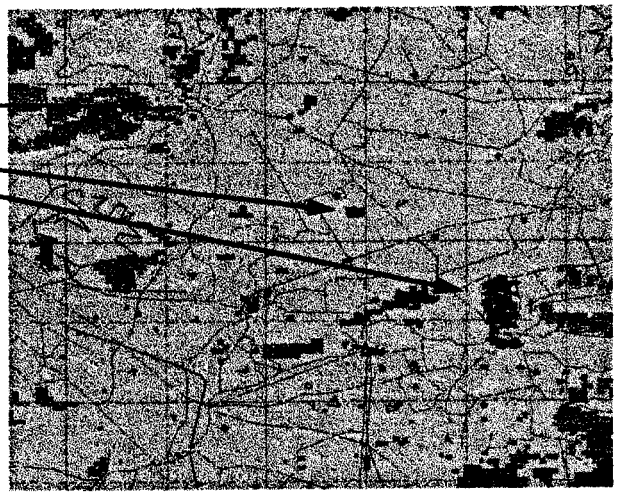


Some first-order characteristics of the different indirect fire systems are shown above. The range of the weapons varies considerably from the shorter-range PGMM-IR and EFOG-M (15 kilometers) to the longer-range HIMARS (40 kilometers). The ranges shown are the maxima for howitzers and mortars without rocket assistance and for MLRS rockets with a smart munition payload. Because value appeared to be operationally associated with attacking deep, both of the short-range systems were assessed in two ways—positioned back with the main force and positioned forward, effectively increasing their "reach" on the battlefield. (This tactic was applied to both EFOG-M and PGMM, even though the EFOG-M, because of its self-contained launch operation, was envisioned to be much more capable performing forward of the force).

In addition to range, the indirect fire systems also vary in the size of their munition search footprints. This characteristic generally defines the ability of the munition to encounter a target and is a function of sensor field-of-view and the munition's maneuvering capability. The graphic above shows the relative sizes of the search footprints of the different munitions.

Force Laydown and Implementation Was Coordinated with Developers and Users

- **Functionality of new systems coordinated with developers (data through AMSAA)**
  - **Overwatch Sensors**
  - **PGMM concepts**
  - **Smart 105**
  - **Damocles**
- **Tactics, techniques, and procedures discussed with various users**
  - **Engineer**
  - **Infantry**
  - **Artillery**
  - **Aviation**
- **TRAC-WSMR also provided input/feedback**



Janus screen (30 x 30 km) showing initial force laydown

The DRB capabilities assessed in this analysis involved many new systems with evolving characteristics. Accordingly, we coordinated our simulation effort with both developers and users before conducting the analysis. We interacted with developers regarding issues that were predominantly technical and with users on such areas as tactics, techniques, and procedures.

For example, a significant amount of controversy exists regarding the ability to emplace ground sensors such as remote sentry and overwatch sensors in enemy controlled areas. We received information from users and developers that suggested that acoustic sensors such as the overwatch sensor may be emplaced at the outermost edges of the Blue defensive area. Other imaging sensors and manned scouts (hunter vehicles) would also be positioned well forward of the main defensive position but not as far as the acoustic sensors.

In a similar vein, we received technical performance information about many of the munition concepts that are still in a relatively early phase of development, such as precision guided mortar munitions and Smart 105. We followed the guidance provided by ARDEC and AMSAA on such systems. Future excursions may be needed to bracket the likely range of performance for such conceptual systems.

System Description and Configuration *(RSTA Assets)*

- **Overwatch sensor: eight-element acoustic array using sensor fusion for target location; emplaced farthest out from main force (≈20 km)**
- **Remote Sentry: mast-mounted IR/TV sensor with co-located acoustic cuer; only visual information passed; emplaced between overwatch sensors and main force**
- **Hunter vehicle: manned HMMWV with extensible mast (5-meter total height) carrying FLIR, TV, acoustic sensor; mobile units positioned in front of main force**
- **UAV: EXDRONE with ASSI gimbaled FLIR; fully survivable or not; two in air at 1000-meter altitude overflying major avenues of threat approach**

The overwatch sensors are acoustic sensors that are placed farthest out from the Blue defensive position, providing a band of early warning and targeting information. The overwatch sensors consist of an eight-component array of microphones and a processing center (part of the long-range acoustic sensor of the intelligent minefield system). Sensing performance depends on target sound pressure level, terrain characteristics, and number of sensors in range. Fusion between sensors allows triangulation and rough location of the targets. Target types (wheeled, light-tracked, heavy-tracked) can be ascertained by matching acoustic templates. Communication between sensors is by SINCGARS.

Remote Sentry is a nonmobile unattended ground sensor with both imaging and acoustic sensing capabilities. Like many other RFPI systems, it has a SINCGARS link (conservatively assumed to have a 4-kilometer maximum range) and is able to transmit video frames using data compression techniques. Two remote sentries are associated with each hunter, and additional independent ones cover open areas in front of the main Blue defensive position.

We model the overflight of UAVs very simply in the current representation, because we have not yet received sufficient data specifying EXDRONE (expendable drone) signature and survivability. In most excursions, we assume the UAVs to be fully survivable and able to overfly the Red force at a constant 1,000-meter altitude.

The hunter is configured as a manned HMMWV with an extensive sensor suite and communications package. Through the SINCGARS link, it is able to collect information from associated remote sensors and communicate to other vehicles and C2 elements. Several parametric levels of reduced IR and visible signatures, corresponding to moderate levels of camouflage, were also examined.

System Description and Configuration *(Direct Fire Weapons)*

- **Apache: armed with 16 Hellfire; flies 6-8 km forward of FLOT; performs pop-up maneuver to fire missiles**
- **HMMWV-TOW: TOW-2B missiles with improved TOW sight; stays back with main force; 3.75-km missile range**
- **Javelin: Two-man team in hasty fighting position at FLOT; 2-km missile range**
- **AGS: Light tank with 105mm main gun; stays back with main force**

The direct fire systems included in this study are listed above. Although the Apaches are still being debated, we presumed their presence as an integral part of this DRB. Each of these weapon systems is configured for the anti-armor mission with 16 Hellfire missiles (four pods). Because of the threat of local air defense, these systems were employed in the simulation assuming relatively conservative tactics. Commanche-Longbow is not currently planned for the light force and so was not examined, but it would be expected to have greater survivability and standoff capability if used.

The HMMWV-TOW is presumed to have the increased-lethality TOW-2B (tube-launched, optically tracked, wire-guided missile). Mounted on a HMMWV chassis, the TOW-2B missile is considered a direct fire weapon system, in which the gunner must maintain line-of-sight (align crosshairs) on the intended target.

The Javelin or advanced antitank weapon system-medium is a shoulder-fired antiarmor, five-inch-diameter missile (2-kilometer range) employing a staring focal plane IR array sensor. Unlike the system that it replaces (the Dragon, which requires the gunner to guide the missile all the way to the target), the Javelin missile is a fire-and-forget system that is expected to greatly improve the survivability of the gunner.

The armored gun system (AGS) or XM-8, is the planned replacement for the aging Sheridan light tank. It has a low-recoil 105-millimeter gun in a

conventional manned turret and includes an autoloader for a total crew of three. An alternative that we did not examine is the AGS-chassis with the line-of-sight antitank (LOSAT) missile that replaces the 105-millimeter gun.

All ground-based direct fire systems were played back in the main force in accordance with conventional tactics.

System Description and Configuration *(Indirect Fire Weapons)*

- **EFOG-M: examined with main force and forward-positioned; 15-km max range, fired two-in-trail**
- **HIMARS: kept back in safe locations; 40 km max range with unguided MLRS rocket with DPICM, SADARM, or Damocles, fired full launcher loads at a time**
- **PGMM: examined with main force and forward-positioned; MMW and IR versions with 12 km max range; fired in two mortar sections**
- **Smart 105: colocated with main force; seeker similar to IRTGSM, fired in three-gun sections**
- **155 SADARM: colocated with main force; two SADARM submunition per projectile, fired in two-gun sections**

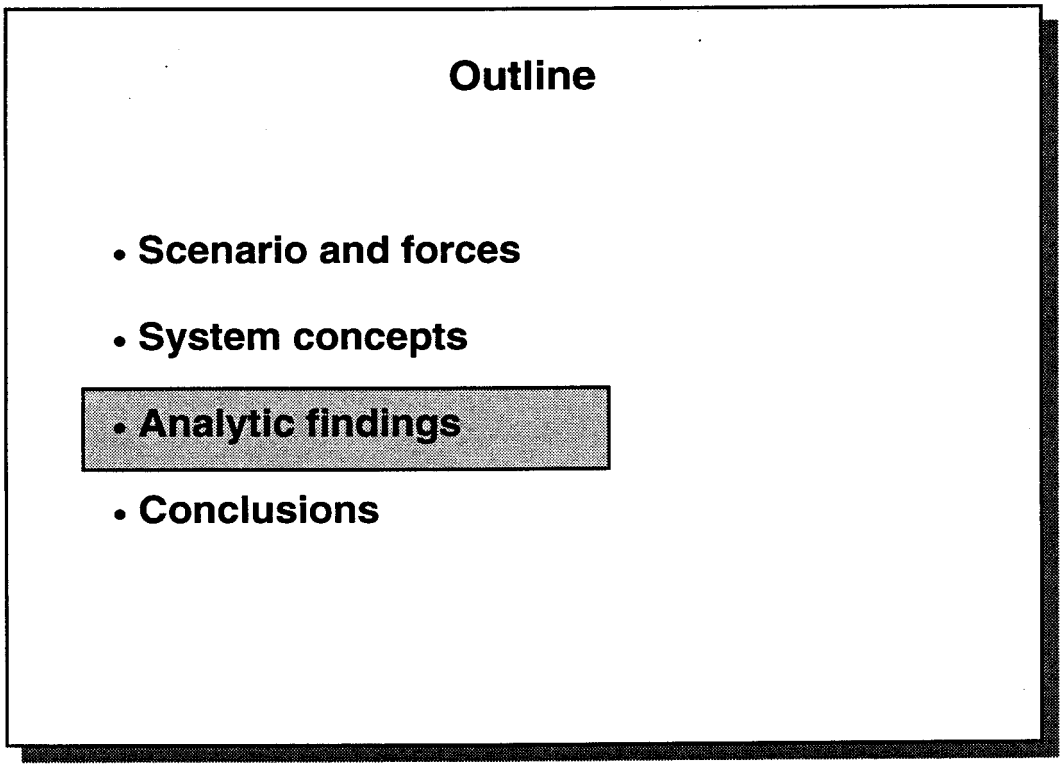
EFOG-M is a unique concept, because it is able to act as both a RSTA asset and a weapon system. It has a 15-kilometer range. Two missiles are typically fired in trail, and each is able to locate targets and call for additional missiles to be fired from its launcher at these targets.

HIMARS is the lightweight MLRS launcher, based on a 5-ton truck with a single 6-rocket pod and launcher. The standard MLRS rocket is assumed, without extended range or special navigation upgrades. Full launcher loads of six rockets are fired at company-sized targets or larger units. This and all other indirect fire systems are given lead based on sensed target velocity.

Precision-guided mortar munitions are fired from a 120-millimeter standard mortar mounted on a HMMWV. The types range from the existing Swedish Strix with a small footprint IR seeker, a moderate size footprint millimeter wave seeker PGMM (designed for moving targets), and a moderate size footprint IR seeker PGMM. The Strix is fired in two-gun sections at individual targets and small units (targeting is at the centroid of the unit).

Smart 105 is a smart round that replaces the normal HE or ICM round fired by the M-102 105-millimeter towed howitzer. It has an IR seeker and shaped charge warhead. One munition is packaged in each round.

The 155 SADARM is a smart round with two submunitions, and it replaces the conventional round fired by the M-198 towed howitzer. The SADARM submunitions eject over the target area, fall using spinning parachutes, detect targets with a small footprint two-color IR and MMW seeker, and fire at them with an EFP (explosively formed projectile) warhead.



4. ANALYTIC FINDINGS

This section contains our analytic findings. A large number of excursions were run with the LANTCOM scenario, exploring the impact of technology insertions for DRB, comparing antiarmor indirect fire candidates, examining the value of dedicated counterbattery fire, and exploring RSTA coverage needs.

In LANTCOM Scenario, Baseline DRB (FUE 98) Does Not Survive

- Virtually all engagements occur in the direct fire (LOS) battle
- Blue direct fire systems achieve good system exchange ratio ≈3 to 1 (10 to 1 needed to win)
- However, Red massed attack eventually overwhelms Blue
- At range, Blue direct fire vehicles (HMMWV-TOWs & AGS) are first attrited
- Then, dismounts (e.g., Javelin) and indirect fire artillery become vulnerable and fall

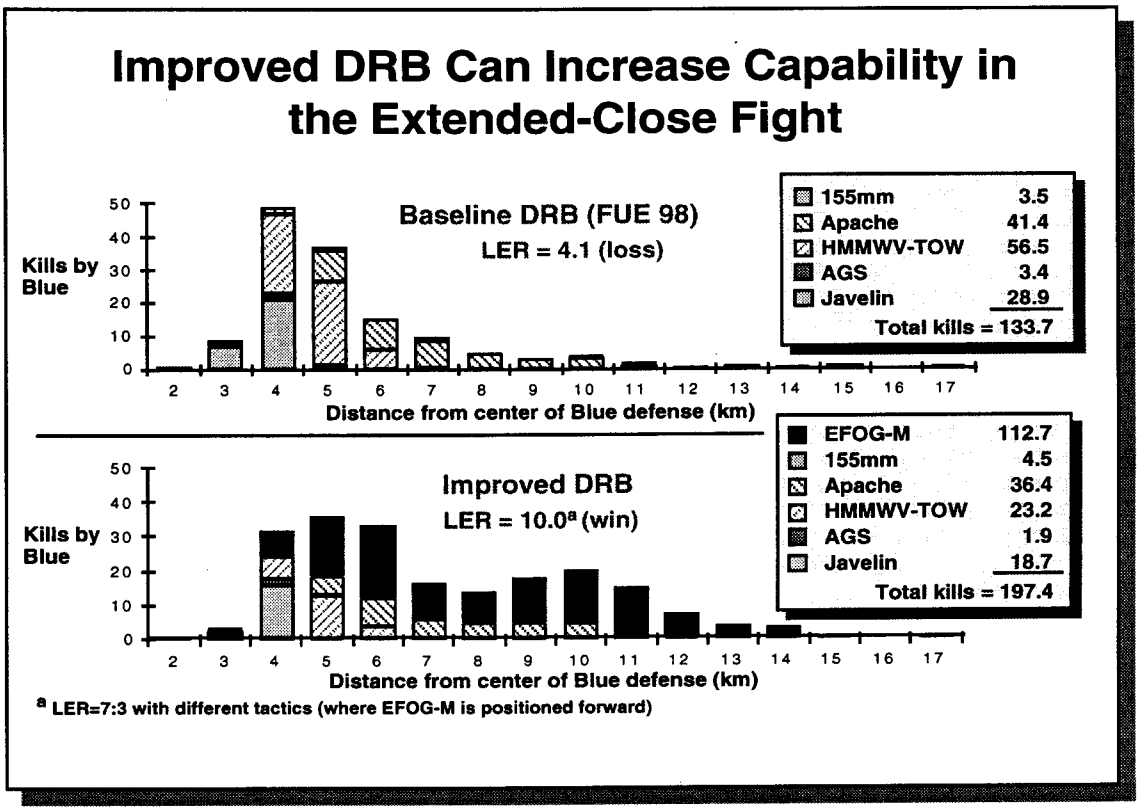


Red force overruns Blue defense

Simulation in the LANTCOM scenario shows that the baseline DRB is unable to destroy the attacking Red force at range, because its only indirect fire assets—towed 105- and 155-millimeter howitzers firing DPICM (dual-purpose improved conventional munitions)—are relatively ineffective against moving armor. Only 3 percent of kills by Blue are attributable to artillery, whereas 30 percent of kills by Red are from artillery firing (preparatory fires) on the fixed Blue positions.

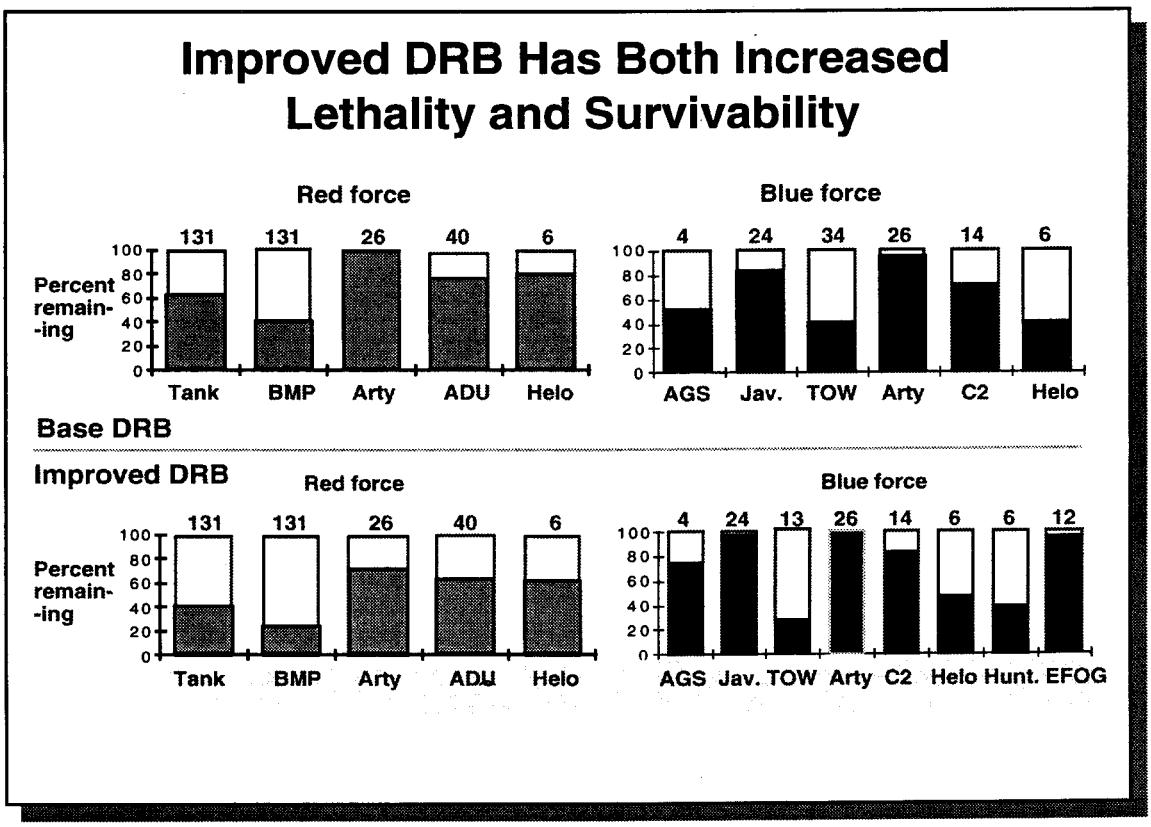
Although the Apaches provide some extended-close (out to 20 kilometers or so) lethal fire, this result is not significant enough to halt the attack. The battle moves quickly to a ground-based direct fire engagement, which favors the defenders initially, with an observed 3-4.1 loss-exchange ratio (LER).[1] However, Red's superior numbers, heavier firepower (including a fire-on-the-move missile), and greater armor protection soon overwhelm Blue. In particular, Red directs massed fires on the Blue vehicles that exhibit firing signatures. Red then penetrates the defensive lines and defeats Blue in detail.

[1]Because of the initial force ratio of about 6.1 in favor of Red and the heavy versus light composition of the two forces, we observed that a win for Blue required a loss-exchange ratio on the order of 10.1 or better. With an LER between 6.1 and 10.1, both Red and Blue forces were typically attrited to a point where they could not continue to fight, which we termed a draw. An LER less than 6 was normally found to result in a Red win.

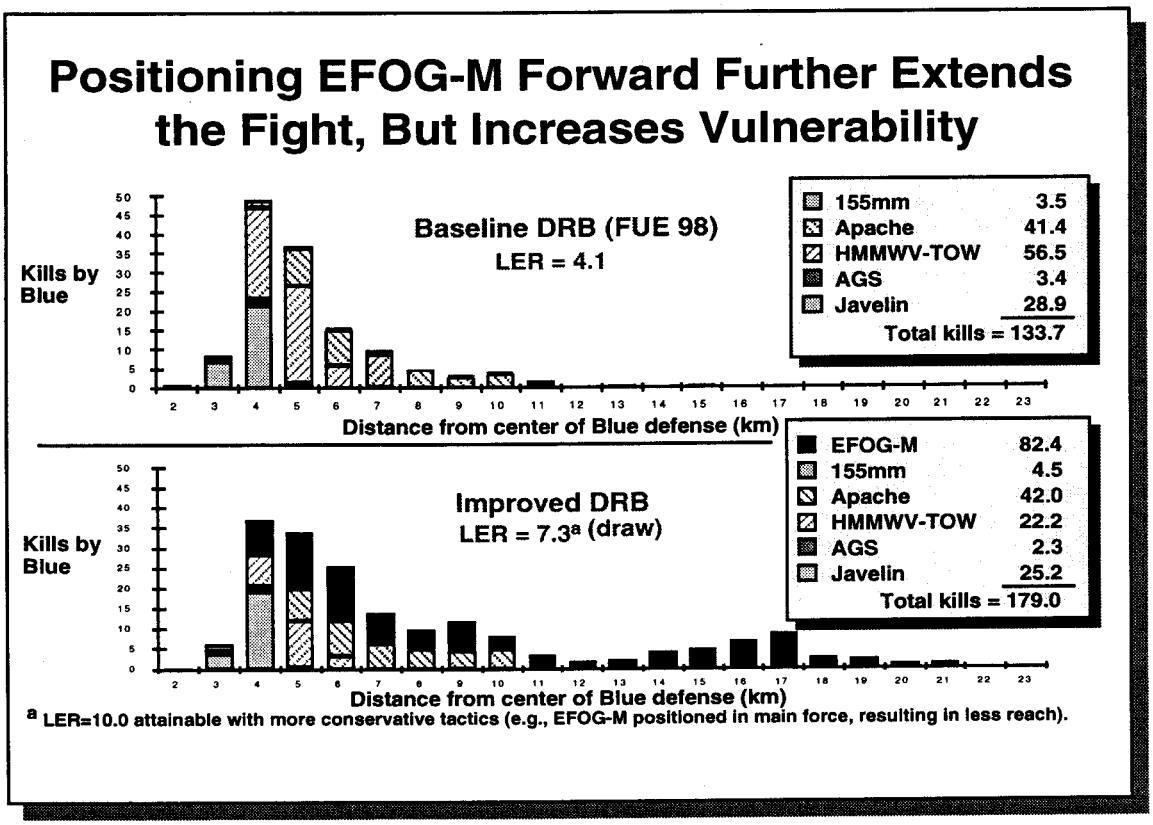


The chart above shows the LER for the baseline DRB at the time of threat breach of the Blue defense. This breach occurs about one hour into the battle, and for comparability, the same time is used as a stopping condition for all subsequent excursions. The outcome may be considered a loss because Red has more than 50 percent of its force intact, whereas Blue has lost more than 50 percent of its mobile assets. For comparison, the LER associated with the improved DRB is shown at the same time in the battle. The improved DRB adds RSTA assets (overwatch sensors, remote sentries, and hunters) and a company of EFOG-M launchers (while eliminating 21 HMMWV-TOW vehicles to maintain constant airlift). Using the hunter/standoff killer concept, the RSTA systems provide target acquisitions at range which are then serviced by the EFOG-M killers. This tactic results in a force lethality that extends significantly farther out than with the baseline DRB.

When EFOG-M launchers are kept back with the main force, they add considerably to the numbers of kills 5–13 kilometers from the center of the Blue defense. It is evident that the success of this extended-close fight reduces the number of engagements required by the ground-based direct fire system, such as Javelin, AGS, and TOW, resulting in higher survivability (survivability increases by ≈ 40 percent). Thus, the 10.1 loss-exchange ratio is enough to change the course of the continued battle; with outright losses and weakened posture (broken units and loss of mass), the Red force cannot pursue its attack.

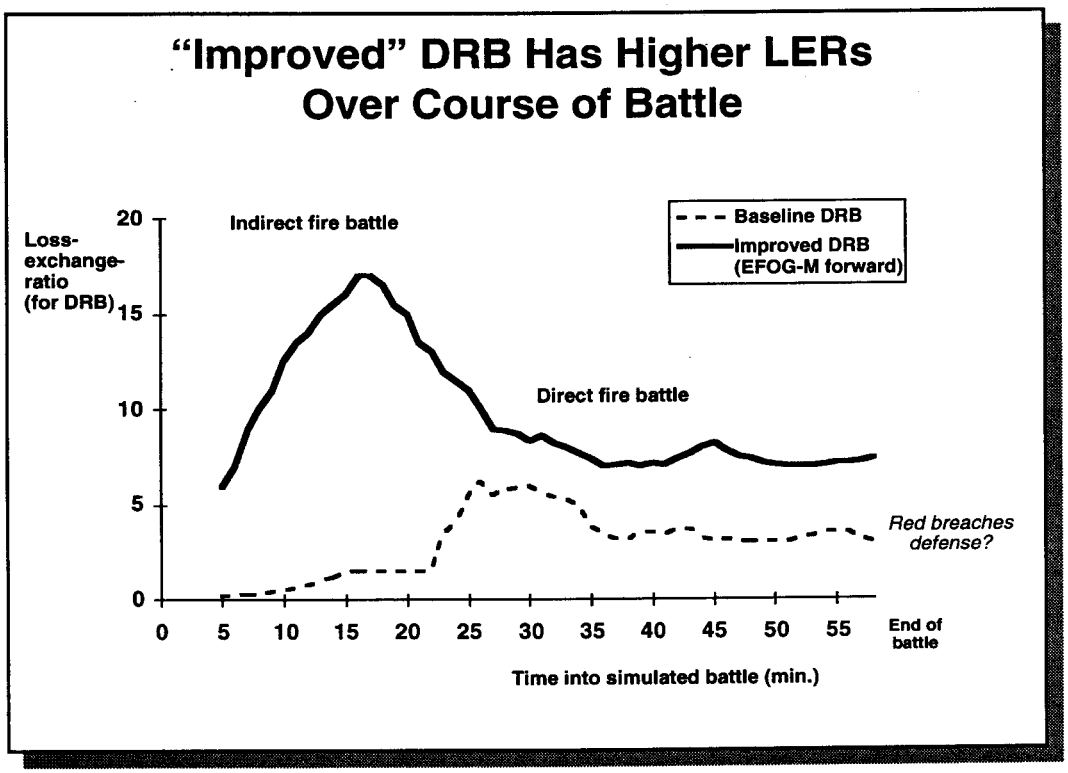


Adding hunter, EFOG-M, and increased RSTA to the baseline light force results in more kills of Red and fewer losses to Blue. Comparing the upper (base DRB) and lower (Improved DRB) portions of the chart, we note that at the end of approximately one hour, Red is left with substantially fewer armored systems, artillery, air defense units, and helicopters when the improved DRB is present. At the same time, the improved DRB maintains much if its fighting capability in AGS and EFOG-M launchers.

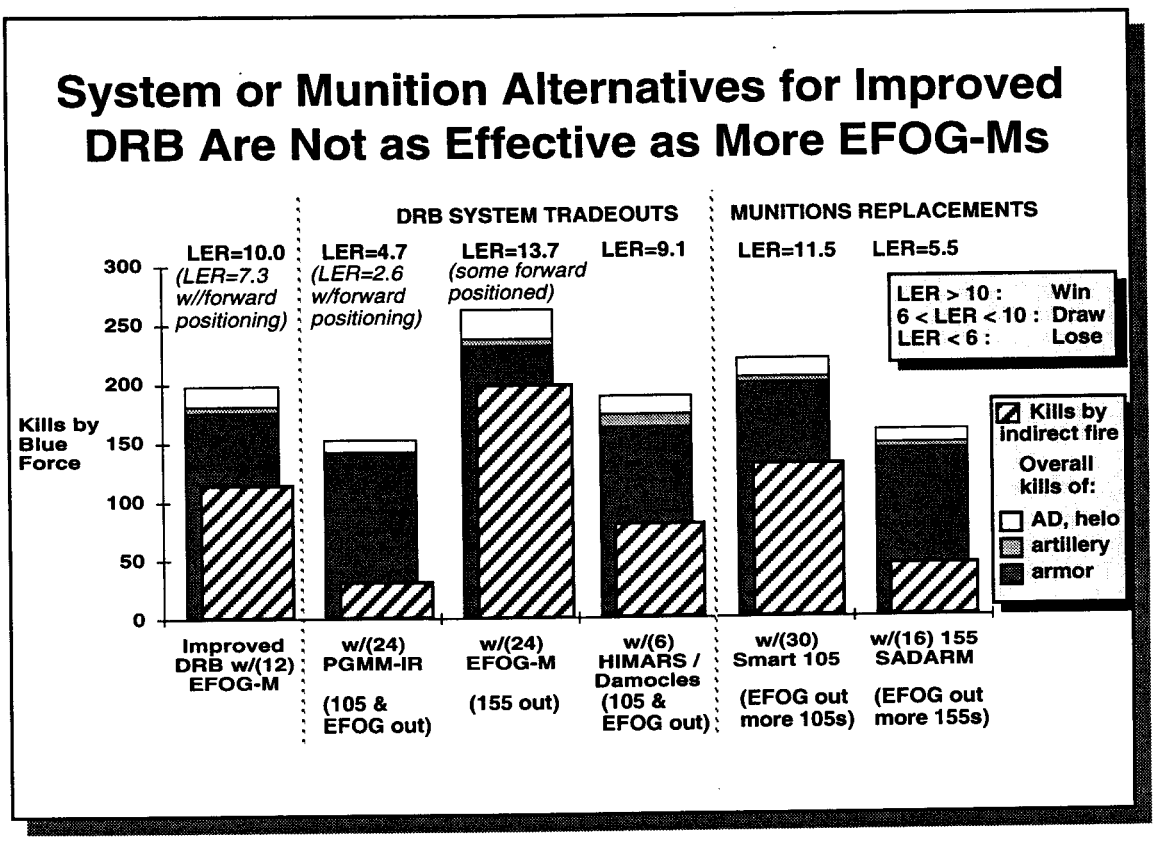


In addition to assessing the effectiveness of the improved DRB with the primary killers (EFOG-M) in a conservative posture, we also considered cases in which EFOG-M launchers would be positioned well forward of the main Blue defensive position (consistent with DBBL TTPs).

By using this maneuver, we found that EFOG-M lethality was extendable to greater distances (kills at ranges of 3 to 21 kilometers). However, the extended range capability does not come without cost. Because of the aggressive posture, more EFOG-M launchers are susceptible to the threat attack without the benefit of direct fire antiarmor protection. That is, some of the launchers are killed by attacking enemy forward-armor units emerging from behind terrain features. Also, because of the added mobility requirements associated with forward positioning and shoot-and-scoot tactics, the EFOG-M launchers are less able to sustain constant fires. The dropoff in kills (shown above) at mid-range is a result of the EFOG-M launchers typically rejoining the main force when the threat is moving within that interval. These launchers must stop and elevate their missile pods to fire their weapons.



The 58-minute snapshot look at the LER on the previous pages provided only a partial picture of the dynamics and outcome of the simulated battle. In the LANTCOM scenario, the baseline Blue DRB shows a very low LER for the first 20 minutes of battle. In effect, it is losing the indirect fire battle against the overmatching Red long-range artillery. The LER increases as the engagement moves into the direct fire phase, but Blue is still penetrated and overrun. With an improved DRB (shown here with EFOG-M forward), Blue begins with a high LER because of EFOG-M kills. The improved DRB then moves into the direct fire phase with a much more favorable force ratio than was present with the baseline DRB.

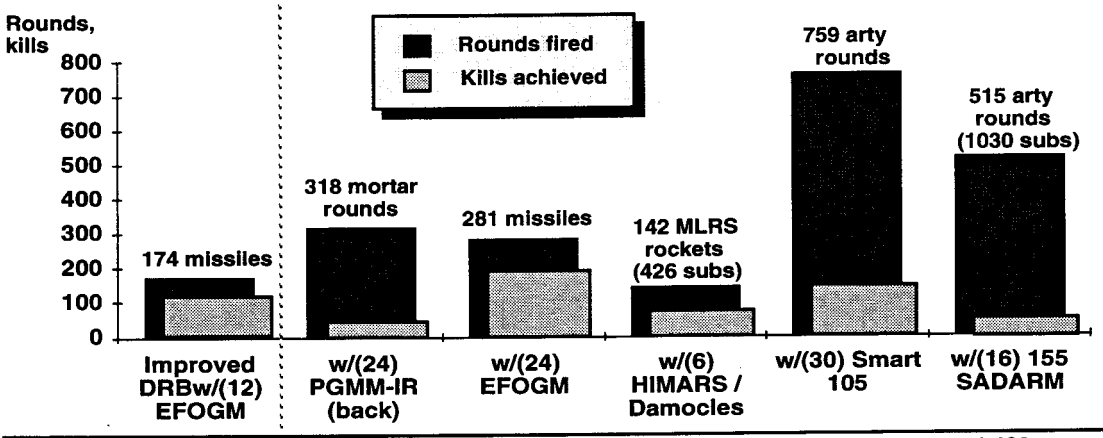


This somewhat complex chart compares the several antiarmor options in terms of force effectiveness and the contributions of the options themselves. The first set of columns is the improved DRB force, with 12 EFOG-M as the primary killer. The next three sets of columns are system tradeouts, in which 105 howitzers or EFOG-M launchers are replaced with other systems. The last two sets of columns emphasize munitions replacements for the 105 and 155 howitzers; here the 12 EFOG-Ms of the improved DRB are replaced with more howitzers, all firing smart munitions. The striped vertical bars indicate the number of kills associated with the indirect fire system being examined, while the gray/white bars show the total number of kills of Red systems, broken down into kills of armor, artillery, and other (air defense and helicopters).

Substituting different indirect fire alternatives for EFOG-M, we find that none perform as well as adding more EFOG-M. The low-performing systems and munitions are PGMM and 155 SADARM, which do only somewhat better than the baseline DRB force (LER = 4.1, not shown), and significantly less than the improved DRB with EFOG-M. Because of its range, PGMM is also played in a forward and back position. The reasons that PGMM did not do very well are the following: movement of the targets under the footprint during the flyout, competition with direct fire systems such as TOW and Apache, and multiple attacks on the same target. The 155 SADARM had greater range than the PGMM but was generally not very effective against moving armor targets with its small footprint.

HIMARS-Damocles again showed its added contribution to counterbattery fire even when played in the antiarmor mode and caused an outcome between a draw and a win. Both a Smart 105 and EFOG-M produced win situations. Replacing the 12 EFOG-M launchers in the improved DRB with 12 105-millimeter howitzers resulted in a higher LER than the improved DRB. Much of this outcome is a result of the large numbers of cannons (18 + 12) that can all fire the effective Smart 105 round. However, in a more analogous comparison (the 8 155-millimeter cannons are traded out for 12 more EFOG-M launchers), 24 EFOG-M launchers result in yet a higher LER than the 30 105-millimeter cannons with Smart 105.

Indirect Fire Alternatives Differ Widely in Number of Rounds Expended



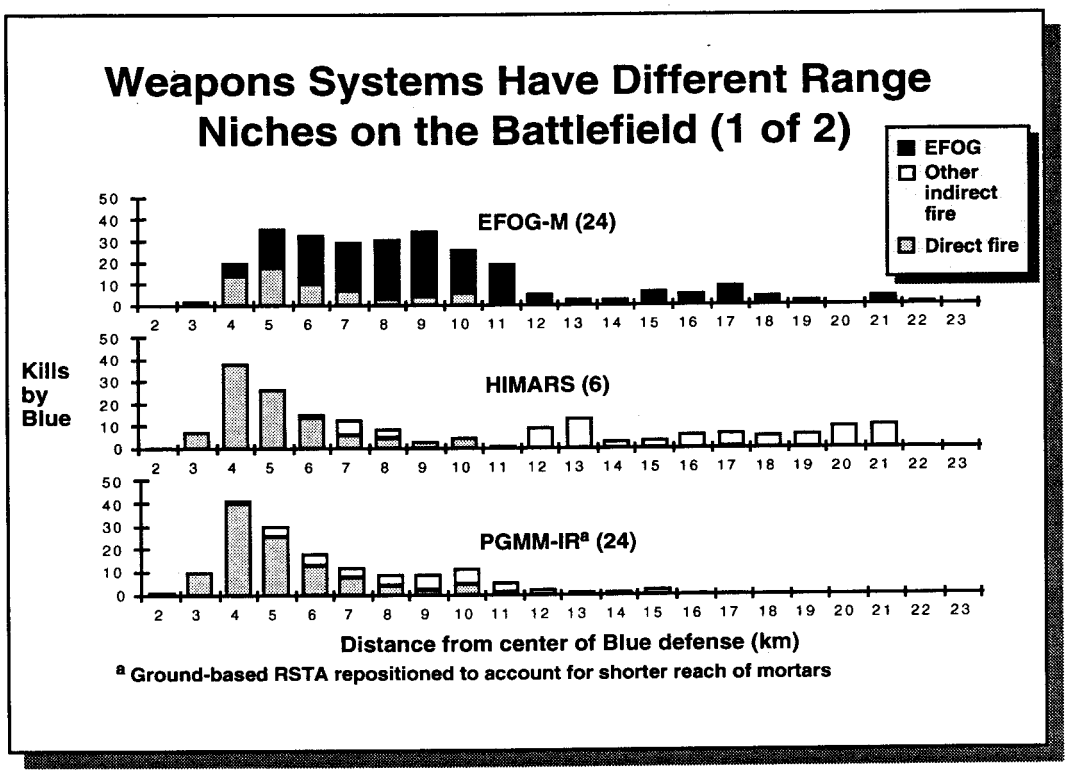
Munition lb/kill:	185	300	170	104	260	1,180
Total tons/kill:	1.7	10.2	2.2	5.5	12.8	19.6
C-141 sorties[a]:	9	21	22	24	88	51

[a] Per unit, e.g., EFOG company; assumes Desert Storm planning factors (20 tons per C-141); 360 sorties for 7,200 ton DRE

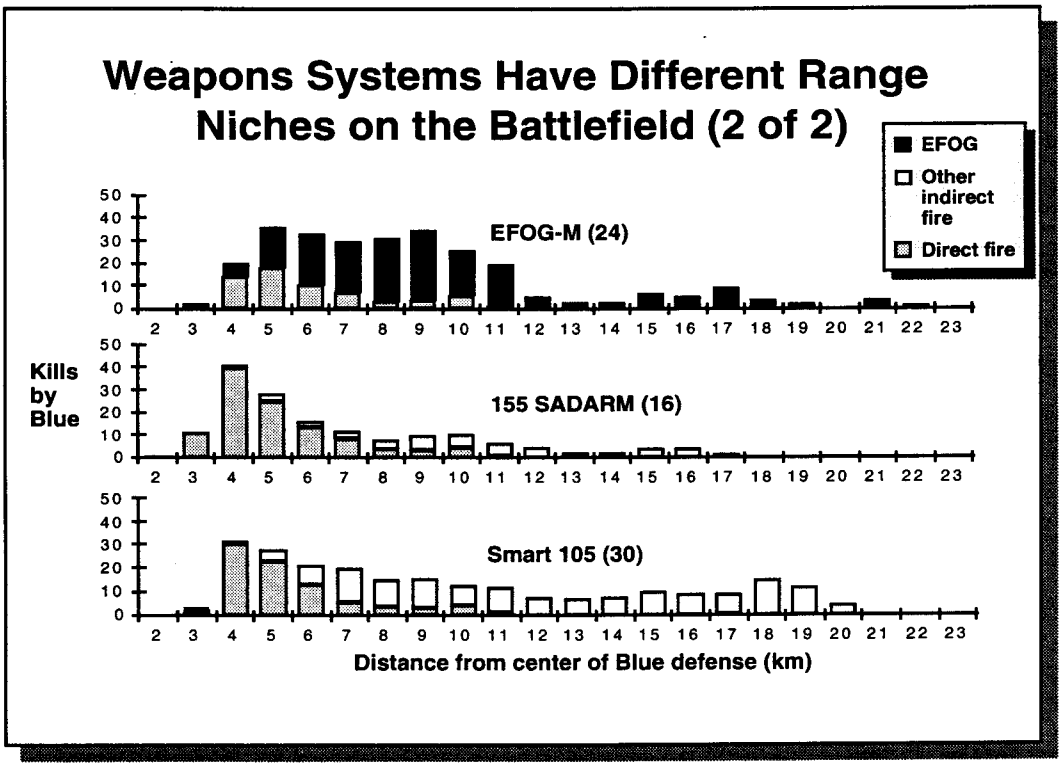
We can begin to make some comparisons of efficiency of the different systems and munitions by looking at rounds or missiles fired and targets killed. EFOG-M, with its man-in-the-loop control, was by far the most efficient. The other systems varied widely in efficiency. PGMM and 155 SADARM fired large numbers of rounds but killed few targets. HIMARS-Damocles achieved a high percentage of kills per rocket, but each rocket contained three submunitions. Smart 105 achieved a substantial number of kills but fired almost three times as many rounds as EFOG-M launchers fired missiles. (TTPs on rounds fired per target were designed to yield high expected probability of kill, ≈1.0.)

In addition to total rounds fired and kills, the chart (bottom portion) shows the munition weight per kill, the total tons per kill of the indirect fire alternatives' slice including launcher, ordnance, and support vehicles, and the approximate number of C-141 equivalent sorties for that alternative's slice. Some of these factors require additional explanation. For example, the number of tons attributed to 24 PGMM and 24-EFOG-M were each more than twice that of the 12 EFOG-M, even though all of these systems are HMMWV-mounted. This result is because each 24-system, two-company section adds a headquarters unit not present in the 12-system force. Smart 105 and 155 SADARM have an even higher weight burden, because we have to include the standard ordnance (smoke, illumination, high explosive

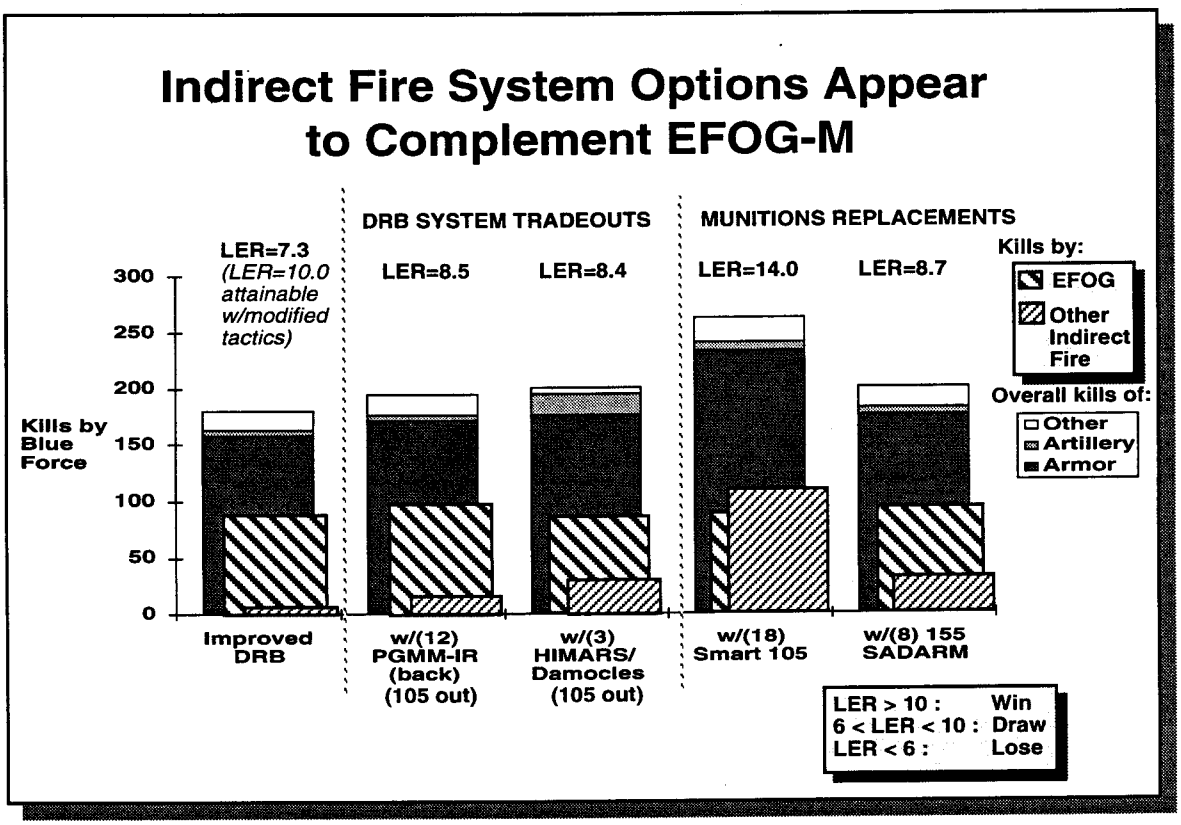
rounds, etc.), along with their trucks and handling systems. When these systems were traded in against HMMWV-mounted EFOG-Ms and PGMMs, only the launchers and smart munitions components and support were considered.



The reach of the weapon systems was determined by a combination of their range and their position on the battlefield (the TTPs assumed), whereas the effectiveness of the weapons, by distance, was determined by simulation. HIMARS/Damocles and PGMM-IR exhibited very different distributions of kills by range. In the three graphs above, kills by the advanced system are shown separately from the kills by all other systems combined. All results are cumulative over time up to the same stopping point, approximately one hour after initiation of the battle. EFOG-M (24) was able to fire at longer ranges (with some of the systems placed forward) and at danger close, resulting in kills spread over the battlefield. HIMARS was primarily a mid- to long-range system, unable to fire close to own troops because of its large munition footprint and its MLRS rocket ballistic error. PGMM-IR, finally, was a close-in system and often competed for targets with other systems in the force.



Continuing the range comparison of systems, we see that the munitions replacement excursions varied widely in effect. Again, we show the EFOG-M (24 launchers) distribution of kills for comparative purposes. Unlike EFOG-M, the cannon-fired artillery rounds have extremely fast response at range (thus, reducing errors associated with target movement). Even so, the 155 SADARM resulted in a low level of mid-range kills primarily because of the small footprint's ability to encounter the attacking mobile armor targets. This result contrasted sharply with the broad range of kills by the conceptual Smart 105 system, which had a much larger footprint combined with the fast response.



In addition to comparing the systems side-by-side, we also compared the added benefit of the alternative systems in conjunction with some EFOG-Ms (where EFOG-Ms are positioned forward)[1]. Because we are including two types of advanced indirect fire systems, fewer numbers are available than before.

Generally, we found that the alternative systems and munitions replacements tended to complement EFOG-M in different ways. PGMM-IR and 155 SADARM both contribute a small but significant number of kills, without stealing from the EFOG-M kills. PGMM kills are closer in than 155 SADARM and tend to fill in some of the interval when EFOG-M launchers are moving.[2] 155 SADARM kills are farther out and actually increase EFOG-M kills slightly, apparently from killing Red systems that threaten EFOG-M launchers and hunters during the pull-back.

HIMARS/Damocles has two effects. It kills targets at range, and it results in counterbattery fire, reducing losses from Red artillery. This results in a higher LER than would be expected from the number of kills by Blue.

Smart 105 is a very lethal system, with its moderate range and high probability of acquisition and kill. The 18 105-millimeter howitzers are able to achieve more kills than the 12 EFOG-M launchers.

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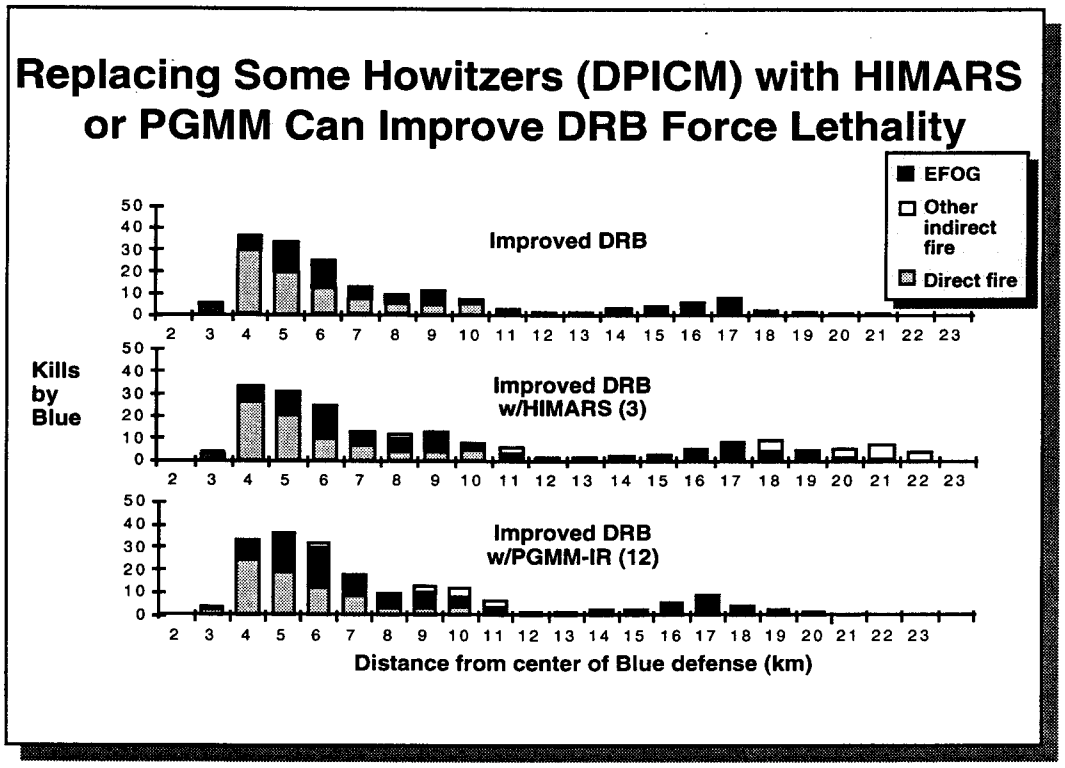
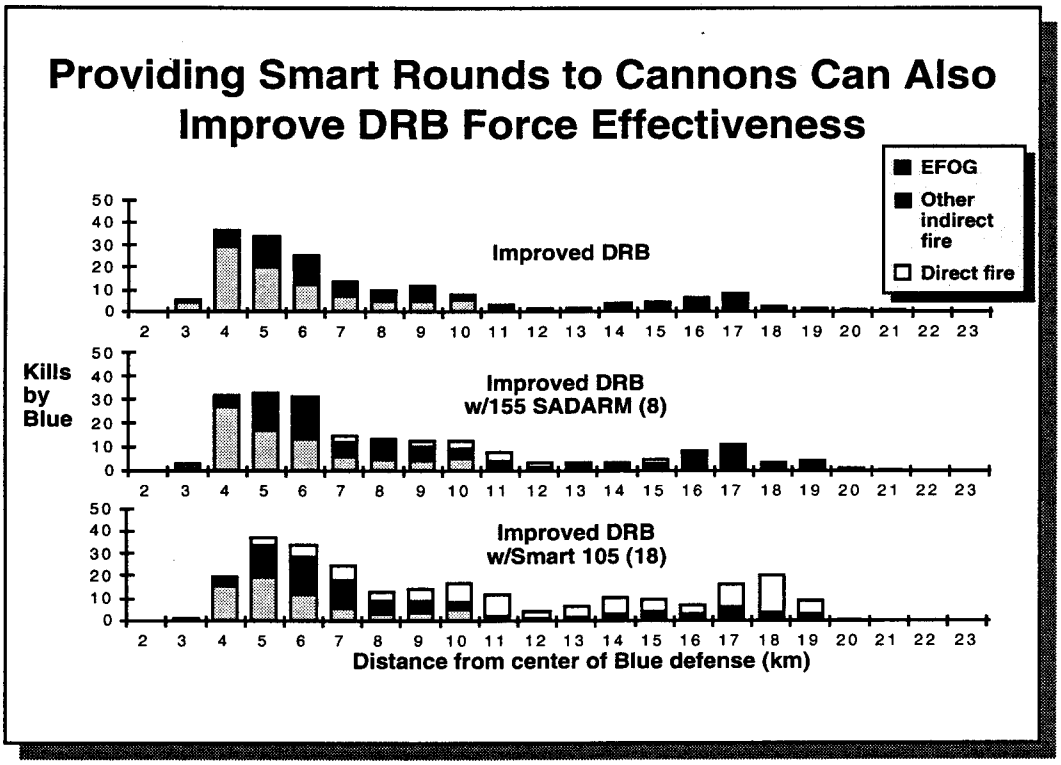
[1]Forward placement of EFOG-M was used in this instance because of excursion sequencing; later runs showed rear placement to be superior.

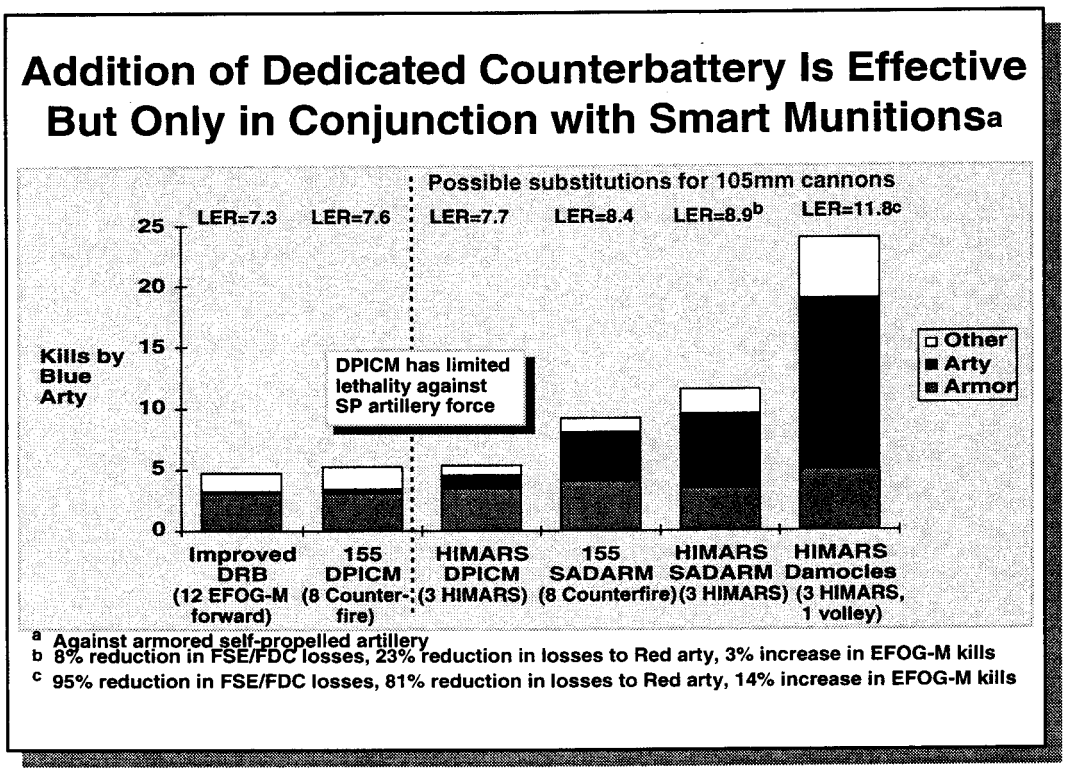
[2]PGMM-IR is one of several smart mortar cases examined; the most effective of these cases occurred when it was placed back in the force.



Replacement of the 105-millimeter cannons by advanced systems (HIMARS/Damocles and PGMM-IR) resulted in moderate improvements, because the systems acted in complementary ways. The 12 EFOG-M launchers in the improved DRB case provided kills throughout the range of the extended close battle but had some drop-offs at long and midrange. The long-range dropoffs occurred because the systems could not be deployed far ahead of the main body and because the EFOG-M has a 150-second or so flyout time to maximum range. The mid-range dropoff was due to movement back into the main body and reloading. HIMARS/Damocles was able to fill in some of the long-range kills, whereas PGMM-IR was able to contribute somewhat to the mid range.



Keeping the towed 105s and 155s in the force and replacing the DPICM munitions with smart rounds showed even larger effects. The 155 SADARM was able to fill in some of the mid-range dropoff, whereas the conceptual Smart 105 system contributed large numbers of kills at the same ranges that EFOG-M did and even competed somewhat for targets. Nevertheless, the combination of Smart 105 and EFOG-M showed the highest LER, partly due to increased overall kills and partly due to greater survivability.



Counterbattery fire showed the overarching importance of large footprint weapons, along with the need for killing enemy artillery. Relatively small numbers of artillery kills had a sizable effect on LER, because these kills silenced weapons with the highest kills per system of any in the Red force. In the improved DRB case, between 8 and 9 of the 25 Blue losses are due to Red artillery, including all FDC, FSE, and towed 105 losses.

The left side of the chart shows that use of dual-purpose improved conventional munitions was relatively ineffective with all types of delivery platform—towed 105, towed 155, and HIMARS. Here HIMARS with DPICM is shown as a possible addition to the force because there are only 105- and 155-millimeter howitzers in the current force. Few kills were seen even with AN/TPQ-36 Firefinder radar directing the counterbattery assets.

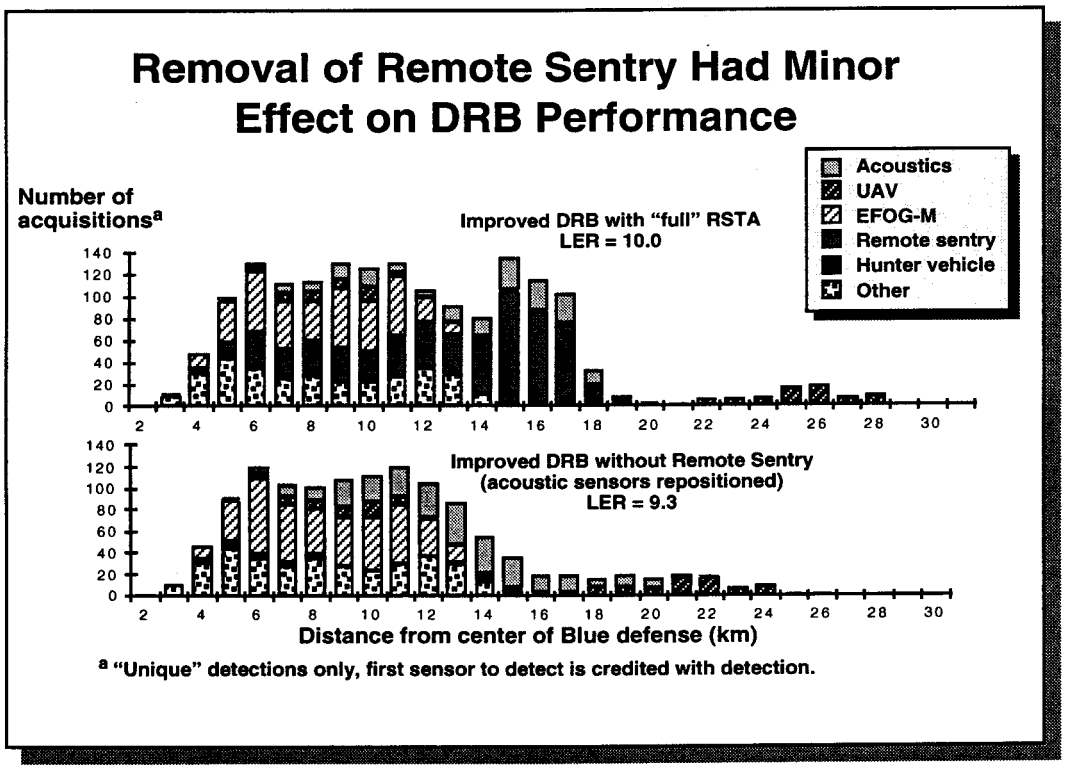
The right side of the chart shows that as we move up in footprint size from SADARM to Damocles, the number of counterbattery kills goes up. The final HIMARS-Damocles case is so effective that virtually all enemy artillery is killed in the first volley. Blue could shift its next two volleys to antiarmor but was directed in this instance to wait and respond to any additional enemy artillery fires.

Reducing RSTA in Improved DRB Only Modestly Degraded Force Performance (LER)

- **Removing UAVs resulted in decreased LER (15%)**
  - **However, some loss of deep area coverage (visual)**
- **Keeping UAVs and halving ground RSTA (repositioned around critical areas) resulted in decreased LER (8%)**
  - **However, gaps in noncritical areas increase overall force vulnerability (potential to be blindsided)**
- **Removing all Remote Sentries resulted in fewer numbers of detections but minor decrease in LER (7%)**
  - **However, acoustic sensors which fill some of the gaps provide lower quality information (nonvisual)**

The set of RSTA systems specified for the improved force was quite extensive—UAVs, forward observers, hunters, remote sentries, and overwatch sensors. We checked to see if redundancy occurred between sensors—first by removing the UAVs, then by removing the remote sentries, and finally by keeping the UAVs but reducing the number of all other sensors by half. All actions had minor effects.

The reason for this result is fairly straightforward. Substantially more target acquisitions were made than those converted into kills. Reducing the improved DRB RSTA (which included both a wide coverage area, including null space coverage, and a fair amount of sensor overlap), resulted in less coverage of null space (and possibly increased vulnerability to surprise avenues of attack) and an increased reliance on single sensors to call fires. Thus, even though the total number of acquisitions might have been reduced when parts of the DRB RSTA were removed, this could often be compensated for by repositioning the remaining RSTA assets.



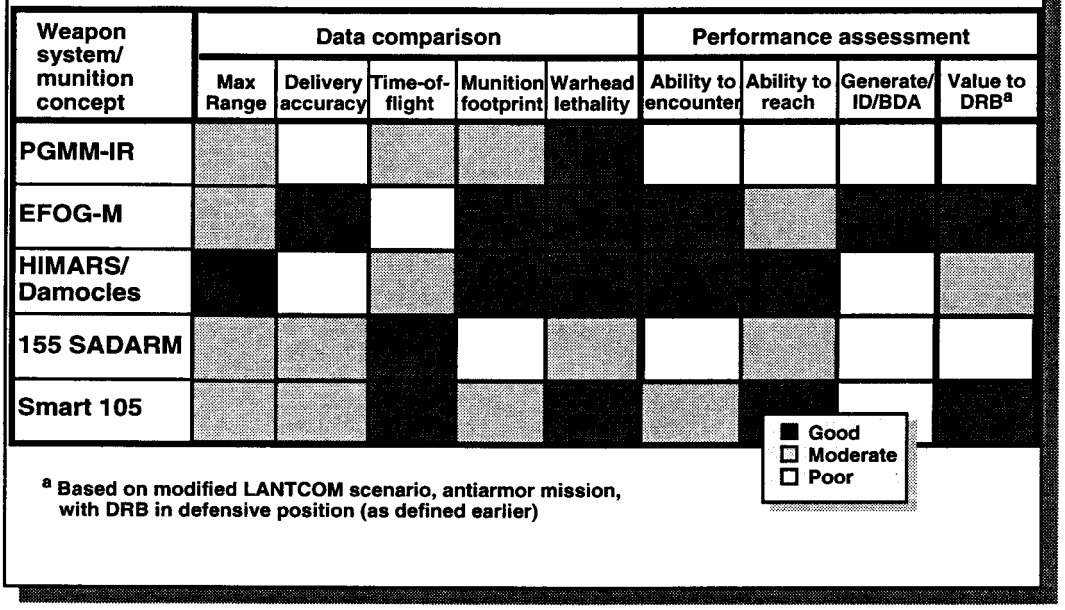
As an example, we show the target acquisitions as a function range for two RSTA environments: (1) complete set and (2) without remote sentries. Throughout the study, we noted that early detections of Red forces were never fully exploited. Part of this outcome is due to the limited number of launchers available, part appears due to movement of the vehicles out of the footprint of the weapon during flyout, and part seems attributable to the cascaded time delays of C2, weapon launch, and flyout. The number of target acquisitions was relatively high, but the weapons were not able to service them. Removal of the remote sentries (one of the more prominent RSTA assets) did not have a dramatic effect on the LER, simply because the remaining RSTA was adequate to perform the "hunter" part of the hunter/standoff killer concept. With some minor repositioning of only the overwatch sensors, most of the target acquisitions maintained (with the exception of the 11-to-14-kilometer band).

Because of the large number of acquisitions obtainable at range, the situation appears to be ripe for use of additional long-range systems and for in-place weapons such as the intelligent minefield.

Outline

- Scenario and forces
- Operational concepts
- Analytic findings
- **Conclusions**

Comparison of Indirect Fire Alternatives' Characteristics and Performance



[a] Based on modified LANTCOM scenario, antiarmor mission, with DRB in defensive position (as defined earlier)

In our analysis, the data we used to characterize the indirect fire systems generally originated from the developer. Although we questioned the validity of certain data, ultimately we used the data that we were provided. In some cases, it was apparent that systems in conceptual or early development stages incorporated more-optimistic projections than those proven in testing. Nonetheless, using the data as provided (a comparison of the attributes is shown on the left side of the above chart), in conjunction with TTPs recently discussed with the user/developer, allowed us to assess the performance of the different indirect fire concepts in the context of the stressing LANTCOM scenario.

The combination of data, TTPs, and interactions with other systems on the battlefield (including C2 network/delays) provided the opportunity to quantify performance at a higher level. For example, the ability to encounter targets was partly determined by the data (sensor capability, time-of-flight, etc.) but also was influenced by the C2 interactions. Another example, the ability to reach, was determined partly by the range of the weapon but also by the placement (using inherent mobility) on the battlefield. EFOG-M was the only weapon that could generate targets on its own, identify targets after launch (increasingly important in lower intensity conflicts), and provide a means for BDA (battle damage assessment). Both EFOG-M and Smart 105 appeared to be high-leverage weapons for the DRB, especially against mobile targets. On the other hand, both PGMM and 155 SADARM did not fare as well. These outcomes are explained in greater detail on the following page.

Conclusions
(LANTCOM Scenario)

With new indirect fire weapons as part of the hunter/standoff killer concept, the DRB can be enhanced to fight and survive, even against an advanced threat

- **Among indirect fire options, EFOG-M provided the highest loss-exchange ratio—DRB effectiveness can be further improved with additional long-range counterbattery fire**
- **Projected Smart 105 and HIMARS with Damocles offered next-highest LERs with several favorable characteristics**
- **Small footprint weapons (SADARM and PGMM) yielded lowest LER and were least attractive against mobile targets**

Extensive RSTA assumed in improved DRB provided more than adequate coverage for indirect fire systems examined

With respect to the first question posed in this study, we found that with new indirect fire weapons used as part of a hunter/standoff killer concept, strong improvements to the planned (FUE 98) DRB performance can be achieved—although the different alternatives varied widely in the level of improvement.

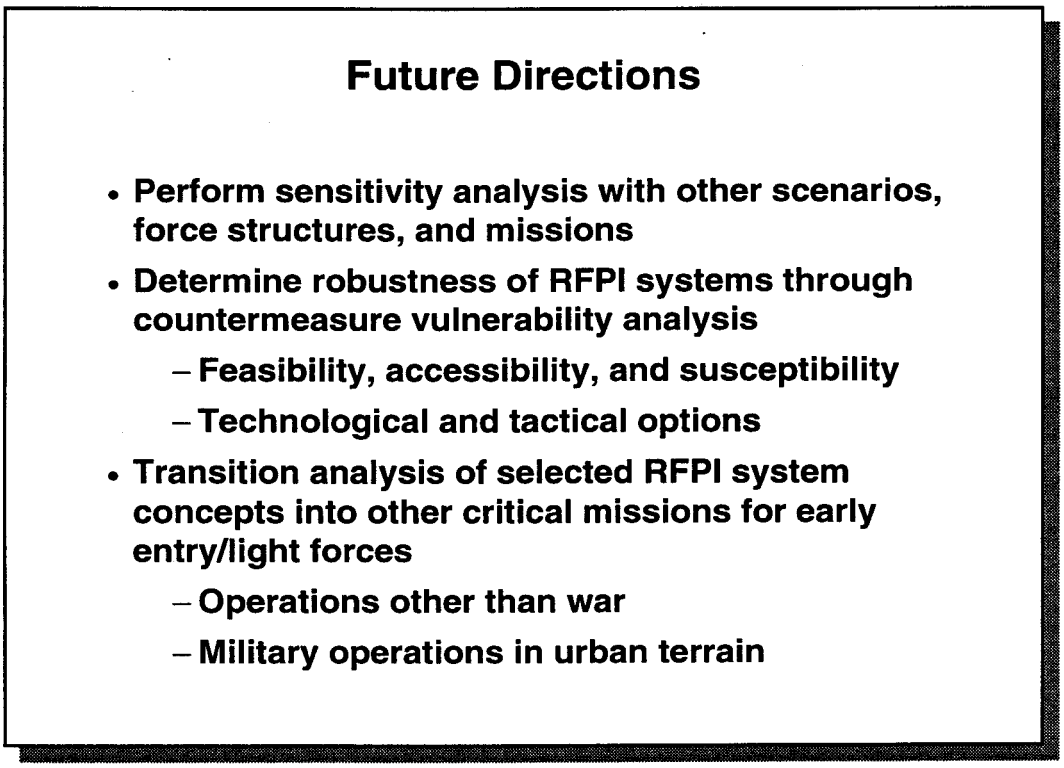
The different indirect fire systems varied widely for different reasons. The smaller footprint smart munitions (PGMM and SADARM) did not do well against moving armor because the targets would often move out of the encounter zone of the munition. PGMM was further penalized because its short range and long flyout time resulted in frequent competition with Apache, TOW, and other direct fire systems. HIMARS was relatively efficient in terms of kills per rocket with the large footprint Damocles munition, but it was restricted to company-sized targets and, with its substantial system weight, had only a few launchers to work with. Smart 105, because of its large numbers, long reach, large footprint, fast response, and high lethality, was an attractive system.

The second question in the study was whether other systems or munitions could substitute for EFOG-M. We found that was not the case in this scenario. Although it was slower to get to target than Smart 105, the EFOG-M's large footprint was able make up for the longer flyout time, still affording very high probabilities of "encounter." And, usually, when the primary target was not within the footprint, a secondary target

was addressable—resulting in high probabilities of engagement. In addition, the EFOG-M's sensor was able to cue attacks by trailing missiles when not performing fire missions originating from the RSTA assets. Other attributes include an ability to perform both BDA and identification of target after launch (which can be especially important for lower-intensity conflicts).

The third question in the study concerned the usefulness of counterbattery fire for the improved DRB force. Long-range counterbattery fire with large footprint munitions (notably HIMARS with Damocles) was found to be highly effective in itself and complementary to the shorter-range indirect fire systems such as EFOG-M.

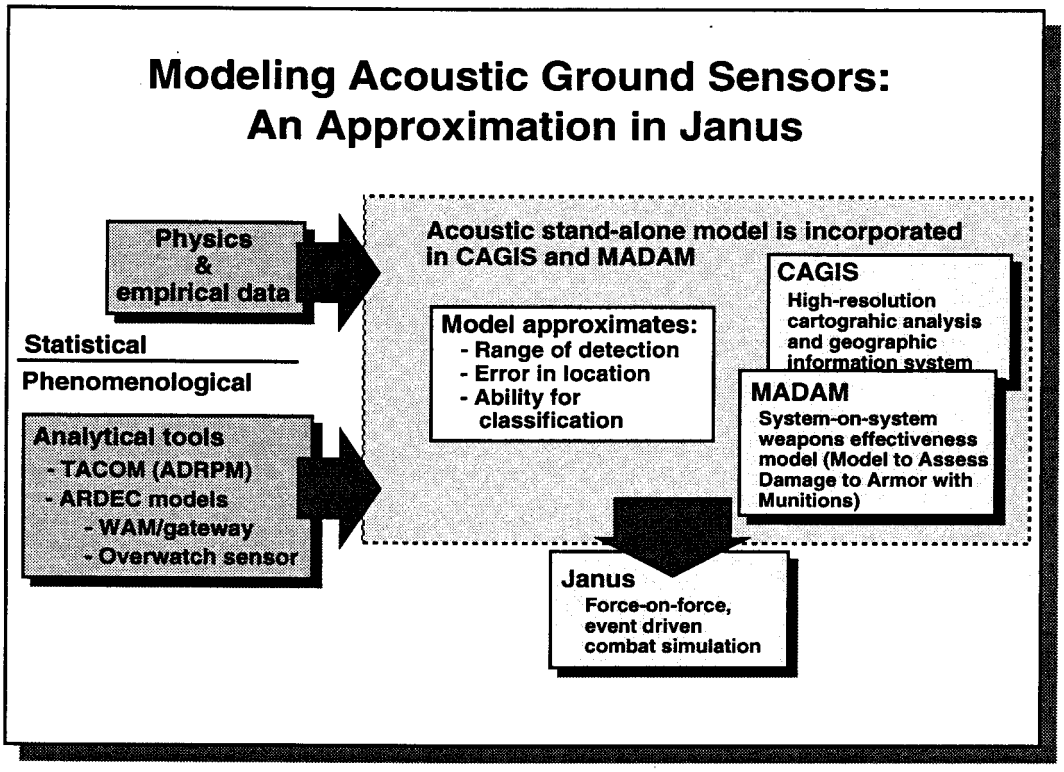
The final question posed was the sufficiency of the assumed RSTA for calling indirect fire. In answering it, we found that the coverage of acoustic sensors, unmanned imaging systems, UAVs, FOs, and EFOG-Ms was easily enough for calling fires. In fact, many of the long-range contacts were not engaged because of weapon availability problems.



5. CONCLUSIONS

Currently, we envision the RFPT project to move along three inter-related avenues. We plan to perform sensitivity analyses to build on this work. For example, our previous work (see DB-168-A/OSD) indicated some of the impact of close terrain on effectiveness of RSTA and indirect fire weapons systems. Future work should expand the scenario and conditions to include a wider range of terrain, weather, tactics, and threat types. We also need to include upcoming advanced systems such as the RAH-66 Commanche helicopter with Longbow and F-16s with tactical munition dispensers. On the threat side, we have been tasked by the RFPI team to transition our effort to exploring possible countermeasures to and counter-countermeasures of an RFPI force. Of particular importance will be issues of RSTA and C2 vulnerability. Finally, we hope to explore the utility of selected RFPI systems in other critical missions for the light forces (OOTW and MOUT).

Appendix A
Modeling Acoustic Ground Sensors



To analyze emerging RSTA technology (ground-based acoustic sensors in such RFPI systems as the advanced overwatch sensor and remote sentry), we needed to make important modifications to our simulation tools. We started off with a two-prong approach that involved understanding the physical phenomenology (theoretical and empirical) and acquiring other analytic tools already being developed (from TACOM and ARDEC) for assessing ground-based acoustic sensor performance. From these two different angles, we constructed an estimation-based model for representing acoustic sensor performance in our simulations. Important measures include range of detection, azimuth error associated with location (through sensor fusion), and capability for classification.

Underlying Physics for Approximating Range of Acoustic Signal Propagation

- **Attenuation in the intensity level *IL* is due to the inverse square law and absorption**
- $I(r) = I(0) \cdot e^{-2\alpha r} \cdot r^{-2} \Rightarrow \frac{I(0)}{I(r)} = e^{2\alpha r} \cdot r^{2}$
- $Attenuation = IL(0) - IL(r) = 10\log_{10}(I(0)/I(r))$

$$= 10\log_{10} r^{2} + 10\log_{10} e^{2\alpha r}$$

$$= 20\log_{10} r + 8.7\alpha r$$

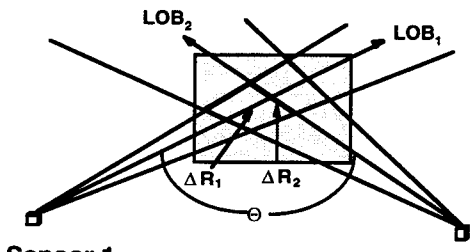
- attenuation coefficient: $a = 8.7\alpha$

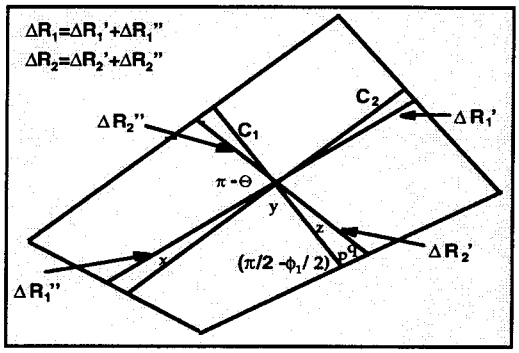
where: $\alpha = \sum \alpha_i = \alpha_S + \alpha_K + \alpha_M$

{α_s = viscous dissipation, α_κ = heat conduction, and α_M = molecular relaxation comp.}

Basic physics was used to approximate range of detection associated with acoustic sensors. The equation for calculating acoustic signal attenuation (thus, range of detection) is shown above. Many of the criteria for calculating attenuation are highly dependent on the environment. Surprisingly, some "first-order" criteria such as temperature and humidity levels are not necessarily critical; however, perturbations and gradients across the propagation path can be. Other factors that can be important include ground surface roughness, flow resistivity, thermal gradients, and wind, for example. We are using the TACOM ADRPM model to provide some quantification of attenuation; in some cases, we are referring back to basic theory. Also, we are currently interacting with developers to obtain empirical data that may be more appropriate to obtain the range capabilities of the different acoustic sensor concepts. At this point, the model is not validated because there is no truly representative hardware.

Sensor Fusion Error Can Be Estimated with Basic Trigonometry



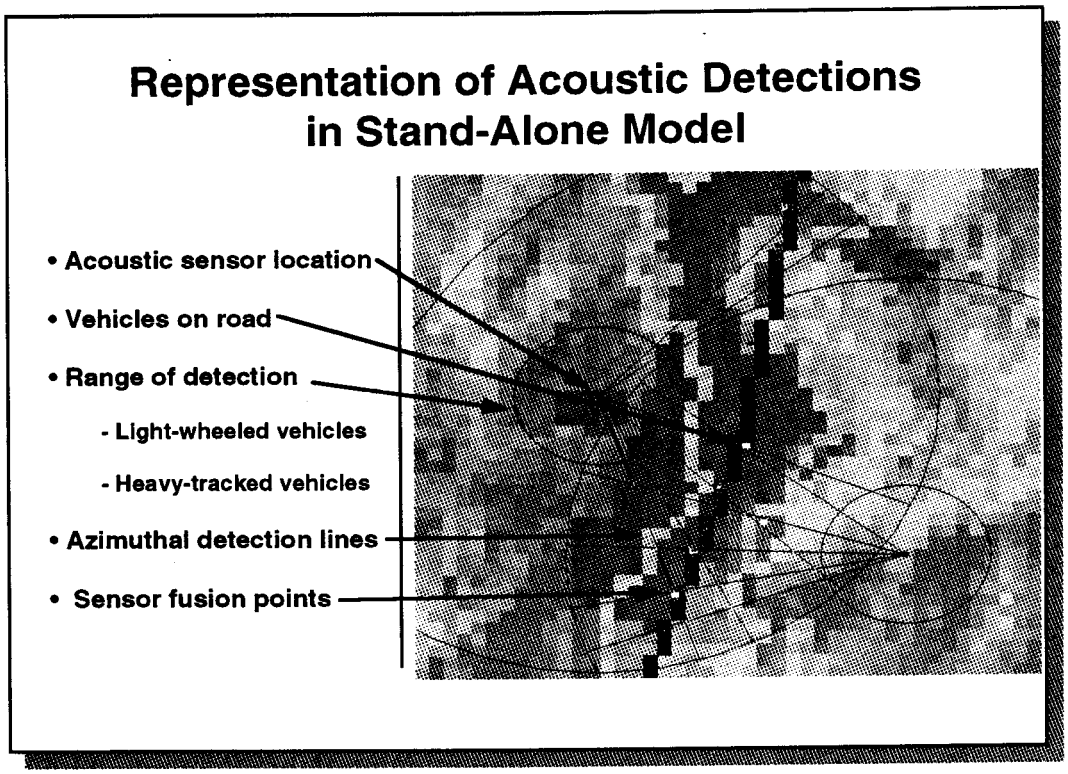


$$\Delta R_2 = \{C_1 \cos(\phi_1/2) / 2\}\{ 1/V + 1/V'\}$$
$$\Delta R_1 = \{C_2 \cos(\phi_2/2) / 2\}\{ 1/V + 1/V'\}$$

where,
$C_1 = 2 R_1 \tan(\phi_1 / 2)$
$C_2 = 2 R_2 \tan(\phi_2 / 2)$
and,
$V = \sin[\Theta + \phi_1/2]$
$V' = \sin[\Theta - \phi_1/2]$

To estimate target location, we took a more fundamental approach than that which might exist in other analytic tools. Presuming that the acoustic wave/sensor directionality or azimuth can be determined, the accuracy from fusion between multiple sensors can be approximated using elementary trigonometry. We show the equations that can be used to estimate the error (ΔR_1 and ΔR_2) in the above chart.

Currently, we do not account for multipath, which is an important consideration in assessing acoustic sensor performance. Additionally, we presume that the classification of vehicle types consists of light-wheeled, medium-tracked, and heavy-tracked vehicles.



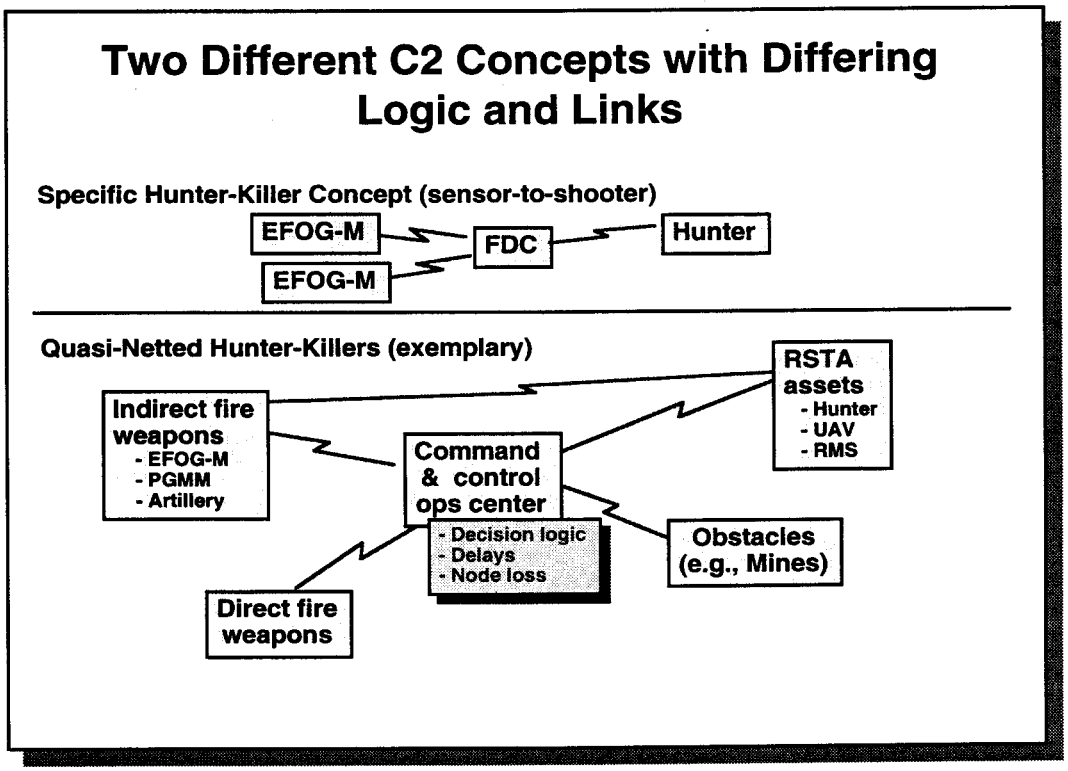
The above chart shows the type of information our estimation-based acoustic model provides. The rings show the range of detection for a given sensor for different types (loudnesses) of vehicles. The range of detection for light-wheeled vehicles is represented by the inner ring, and the range of detection for heavy-tracked vehicles is shown by the outer ring.

Given a limited "resolution azimuthal band" for acoustic sensors, we also implement a criteria to limit the number of available detections per unit degree. Additionally, a limit is set for the number of vehicles that can be tracked at a given time. Both of these criteria are inputs into the model which can be derived from the attributes of the sensor.

In the above chart, we also show the detection lines (generally based on the loudest signal within the resolution band at the frequency of interest). When multiple sensors are covering a given area with a fusion of information, we account for some target "fingerprinting" (defaulting to a less-pronounced degree but with a distinct signature) for an increased probability of fusing on a single target, thus allowing for triangulation to determine location. For the case above, detections generated by the model are shown as either white squares (heavy-tracked vehicles), white triangles (medium-tracked), or circles (light-wheeled), and their estimated locations are shown by the positions of the respective icons.

Appendix B

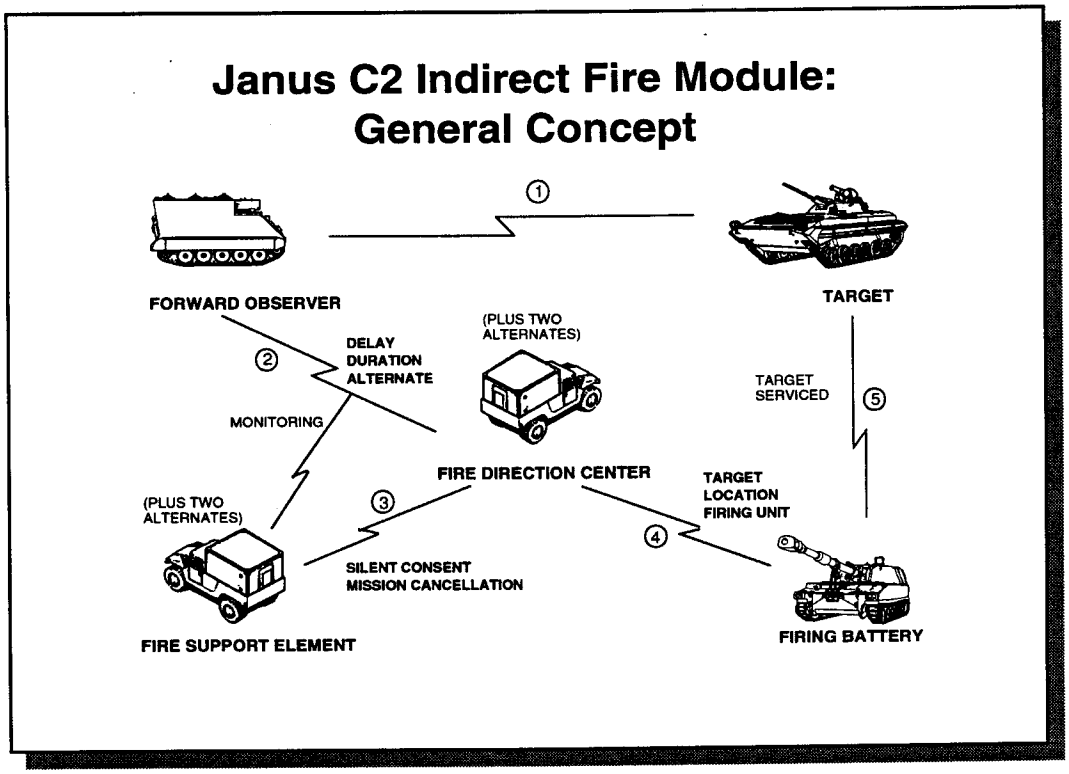
Representing Command and Control in Janus



One of the important areas of exploration within the RFPT project has been an assessment of the possible benefits associated with near-automated command and control concepts. The chart above depicts, in a highly simplified fashion, two different yet possible philosophies for command and control. In the first (upper part of the figure), we show an exemplary RSTA system (hunter) linked to indirect fire shooters (in this case, EFOG-M). The basic concept of operation is theoretically straightforward and is already implemented in Janus: the hunter detects targets, determines if they are of interest, determines their location, and submits a call for fire. This call for fire is passed through the fire direction center (FDC) which alerts the closest available (e.g., functional, loaded, and ready to shoot) EFOG-M launcher, which subsequently launches an EFOG-M to service the target. Delay times associated with specific weapon system operations are embedded into the launch sequence.

While the above concept represents a highly streamlined command and control process, the linkage to a single system (EFOG-M) may provide only limited response. That is, different targets detected by hunter systems may be better serviced by other indirect fire weapons. Thus, an alternative automated command and control system might involve a decision node and logic (with manned silent consent) for determining the

"best" weapon to service the detected target—referred to the quasi-netted system, shown in the lower part of the figure. This system would provide flexibility for different RSTA assets to draw from a large pool of possible indirect fire systems. On the downside, it would likely decrease responsiveness and increase system vulnerability.



The implementation of the aforementioned sensor-to-shooter concept is now programmed in Janus in the form shown above. The basic functionality is fairly straightforward:

(1) The forward observer (e.g., hunter) detects potential targets, determines their location, and submits a call for fire.

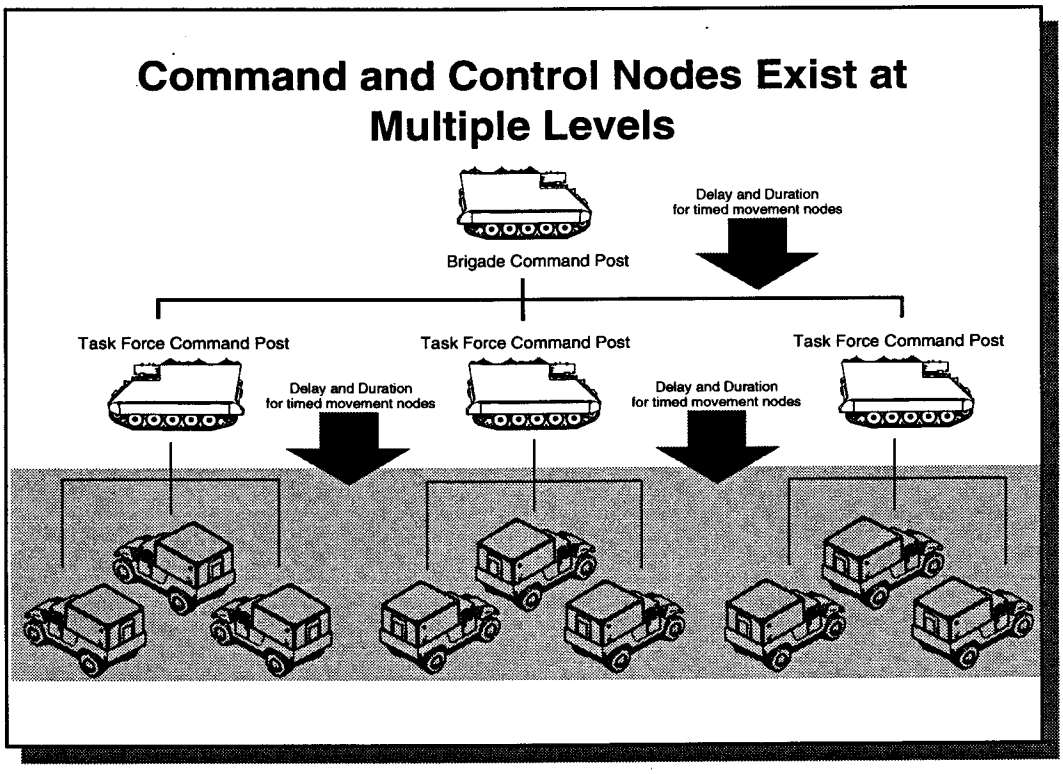
(2) This call for fire is passed through the fire direction center (FDC) which alerts the closest available, functional, loaded, and ready-to-shoot launcher (e.g. EFOG-M).

(3) The fire support element (FSE) monitors information to the FDC through a silent consent mode.

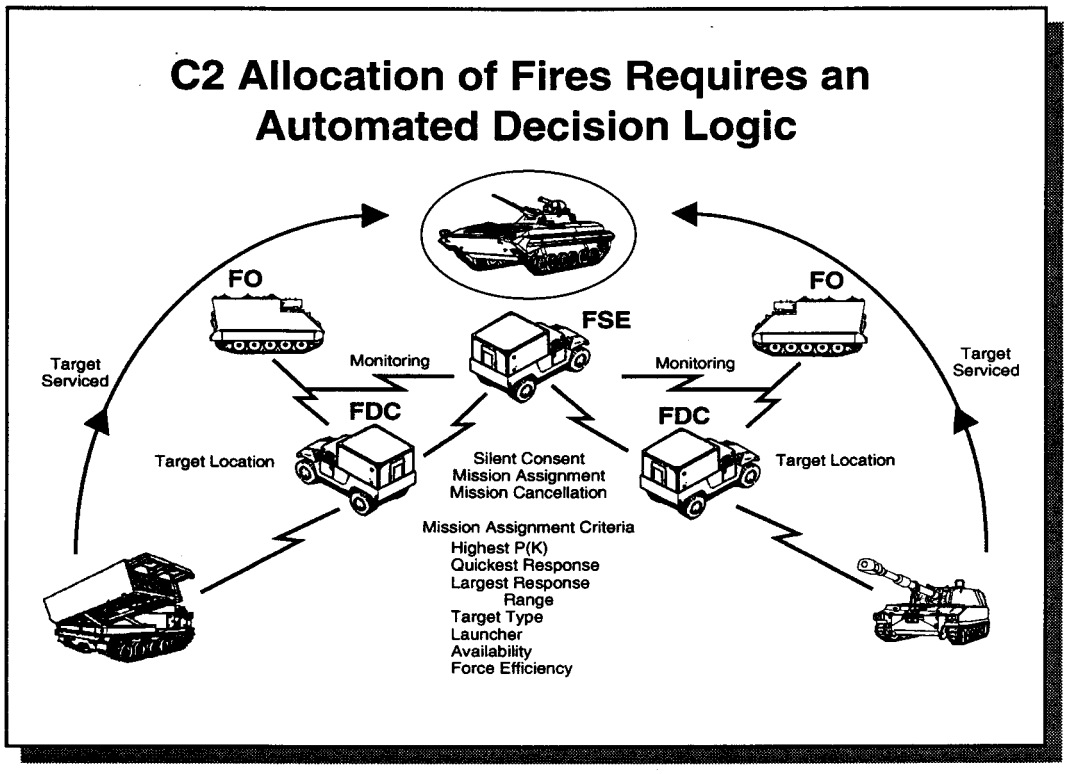
(4) The fire mission is tasked to the closest EFOG-M launcher which meets the aforementioned availability criteria.

(5) The tasked EFOG-M launches weapon to service the target.

(6) The FSE cancels all subsequent calls for fire against the target allocated to the EFOG-M launcher until the engagement is completed.

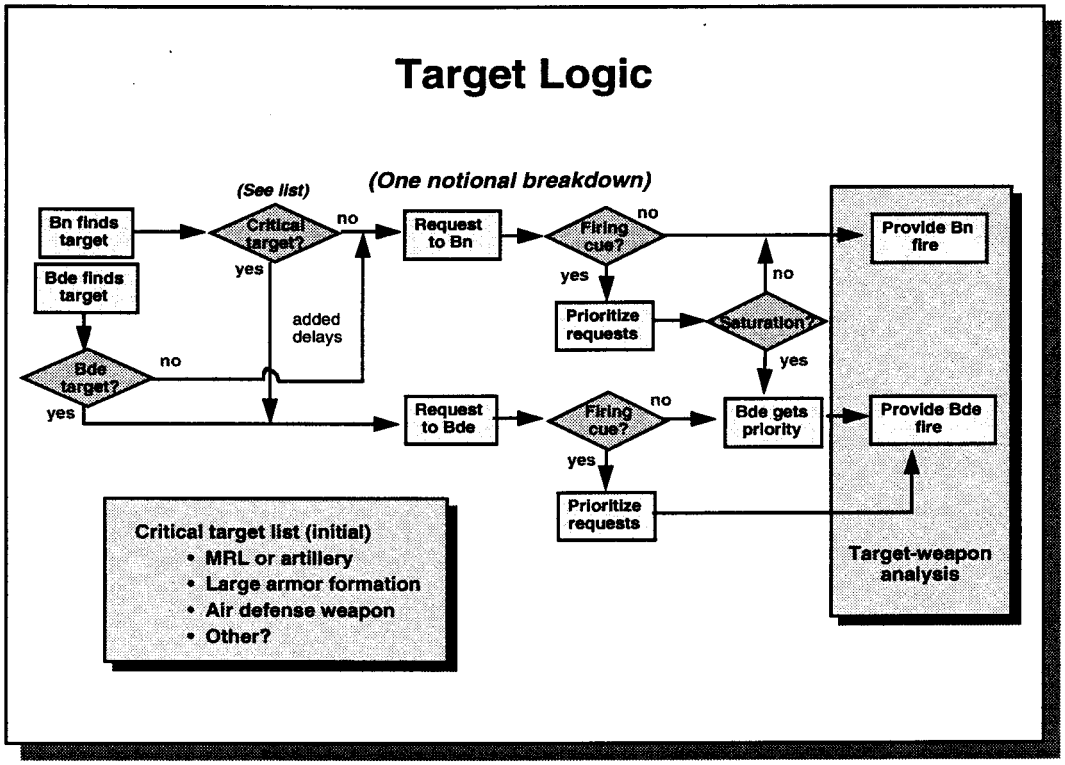


In addition to modeling the sensor-to-shooter C2 process, we have added a hierarchical C2 model with corresponding fire support elements (FSE) and fire direction centers (FDC) to Janus. These "nodes" are represented as actual entities in the Janus scenario, complete with representative vulnerabilities. If a C2 node or link is lost, delays commensurate with an alternative pathway (or reconstitution of the C2 node) are invoked.



The current logic is predominantly based on first-in, first-out logic, given the overwhelming need for antiarmor missions in the scenarios we have considered so far. Nonetheless, this model can be easily modified as needed to service priority targets as identified by the "decide, detect, and deliver" doctrine. For some cases examined, we have created a command structure to handle a dedicated counterfire network in conjunction with the antiarmor missions. In most cases, we have divided the network to correspond to different locations of the battlefield. Delay times associated with the FSE, FDC, and specific weapon system operations are included.

The model is limited in that it is primarily composed of logic rules and time delays. No explicit representation exists of such important aspects as channel occupancy, signal degradation, or poor decisions associated with the "fog of war." Modeling of some of these aspects is planned to be included in the next version of the C2 module.



One architecture to handle the prioritization of different targets with a tiered command structure might be represented by the above flow chart. Since different RSTA assets have different "ownership" levels, the availability and passage of information originating from these systems (and the corresponding delays) should be accounted for when modeling C2 process. Certain targets might be serviced at different levels, as well. As long as the "rules" can be defined prior to battle, an architecture with a streamlined flow can be envisioned.

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