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STRATEGY RESEARCH PROJECT

A REVIEW OF SELECTED TECHNOLOGIES AND THE ARMY AFTER NEXT

BY

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Dr Walter LaBerge
Project Advisor

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ABSTRACT

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This paper conducts a survey of future guidance, evolving concepts, and promising technologies and provides recommendations concerning a few of these technologies for the Army After Next 2020 timeframe. Major survey documents include: Quadrennial Defense Review, Report of the National Defense Panel , Joint Vision 2010, Army Vision 2010, Army After Next Study Program; and the Department of Defense and Army Science and Technology Plans.

Following the broad survey, the paper highlights two technologies with the potential to provide leap-ahead capabilities during the AAN time frame. The two technologies are (1) the use of computer simulations to enhance tactical decision-making (planning, preparation, and execution) and (2) a Future Combat System equipped with an Electromagnetic Gun.

A short section of the paper presents, from an outsider's perspective, several observations concerning evolving Army After Next operational concepts. Based on these observations, the paper recommends continued research and efforts to identify alternative Army After Next operational concepts. Additionally, the paper recommends a thorough review of assumptions concerning the potential effectiveness of Active Protection Systems. This is a very important issue because the front running Army After Next operational concept - air-mechanization - relies heavily on Active Protection Systems to provide survivability to a new class of 15-ton fighting systems.

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I owe a special degree of thanks to COL Mike Starry for his efforts in directing the Army After Next study program. COL Starry ensured that I had access to several very important work groups and provided me with several important referrals that made this work possible.

This paper is dedicated to my father whose inspiration and vision guided his son toward an honorable career of service to country.

Finally, I must thank my lovely wife Elizabeth and my beautiful daughter Elizabeth for their continuous love and support.

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INTRODUCTION

The Chief of Staff of the Army and the Commander, Training and Doctrine Command established the Army After Next Project in February 1996 to help the Army Leadership craft a vision of future Army Requirements for the 2020 timeframe.[1] Since its start, the Army After Next (AAN) study team has accomplished a great deal toward identifying future warfighting concepts and opportunities to leverage leap-ahead technologies.

This paper examines the ongoing AAN project and attempts to highlight, through a broad survey, technologies the AAN may depend on. Following the broad survey, the paper highlights two technologies with the potential to provide leap-ahead capabilities during the AAN time frame. The two technologies are (1) the use of computer simulations to enhance automated tactical decision-making tools and (2) a Future Combat System (FCS) equipped with an Electromagnetic Gun (EMG).

Additionally, the paper challenges the effectiveness and potential benefits of Active Protection Systems (APS). This is a very important assumption because the AAN air-mechanized concept relies heavily on APSs to provide survivability to a new class of 15-ton fighting systems. Near the conclusion of this paper, the author discusses this issue along with several other concerns.

Study Assumptions and Limitations:

- Regional threats will continue through the 1998-2015 time frame and a peer competitor may emerge during the period 2015-2025
- Force XXI (2005-2015) timeframe will succeed in providing battlefield awareness

- Legacy systems will provide an important capability well into the 21st century. Maximizing the potential of these systems will be an important factor contributing to the management of the modernization budget. This research effort does not attempt to analyze the cost benefits, or any budgetary issue, associated with how or when these systems should be phased out as new technology takes over
- Due to the classified nature of low-observable technology, no direct research was pursued in this area

PART I: The survey – Where are we now and where do we want to go?

The Strategic Environment

Despite unprecedented levels of recent deployments and imminent concerns with Iraq and North Korea, the United States has been offered a period of relative respite from the prospect of a major war. According to the National Defense University's (NDU) Institute for National Strategic Studies *1997 Strategic Assessment*, three revolutions have transformed the very nature of the global security environment.

These three revolutions include:

- The Geostrategic revolution. The U.S. is currently the strongest global power in a world that is increasingly being driven by market economies.
- The Information Revolution. Access to new information sources support a trend to more open societies.
- The Governmental Revolution. Power shifts from state control toward regional governments and the private sector increase the prospects for more pluralistic societies.[2]

How the US should prepare for an uncertain future during this period of respite is the subject of much debate. The National Defense University - *1997 Strategic Assessment*, the *QDR*, The Institute for Foreign Policy Analysis – *Preparing Now, Alternative Paths to Military Capabilities for an Uncertain Future*, and *The Report of the National Defense Panel* all postulate or predict the possibility of a "peer competitor" during the 2020 timeframe.[3,4,5,6] While each of these studies or reports recommends the need for a full spectrum force, each provides a different recommendation on how future forces should be designed and equipped. They all agree, however, that US Forces must leverage advancements in technology to increase effectiveness of forces that are smaller and lighter.

QDR: Following twelve years of force and budget reductions, the 1997 QDR concludes that we have adequate forces to carry out current missions, but scarcity of resources are preventing us from investing adequately in the modern technologies essential to the future. To compensate for this, the QDR recommends a modest reduction in current force structure in order to balance funding of future readiness with investments in modernization. The plan permits DOD to transition from an acquisition budget of $44 billion to $60 billion by FY02. Total Research, Development, Testing, and Evaluation (RDT&E) will remain steady at about $35 billion over this same period. While maintaining the ability to carry out today's missions with acceptable risk, the primary objective of this plan is to achieve future joint force capabilities described in Joint Vision 2010. [7, 8]

When discussing the Revolution in Military Affairs (RMA), the QDR reports that DoD's long-term Science and Technology efforts are directly linked to supporting the operational concepts outlined in Joint Vision 2010. As an example of this linkage, the QDR offers the Future Combat System as a promising opportunity. "For example, the Future Combat System (FCS) offers the potential of executing future dominant maneuver concepts with smaller, lighter, and more mobile ground forces. FCS technology innovation efforts focus on achieving leap-ahead capabilities for a ground-combat vehicle in the areas of mobility, lethality, survivability, deployability and sustainability." [9]

In general, the QDR addresses service level issues of end strength and program specifics of very major systems. For more specific modernization guidance, the QDR specifies JV 2010 as the execution road map. In response to the publication of the Chairman's Joint Vision 2010, the Chief of Staff of the US Army published complementary guidance in the form of Army Vision

2010. These two blueprints, Joint Vision 2010 and Army Vision 2010, provide operational concepts, operational patterns, and identify enabling technologies required for our future forces.

In providing us these two visions, General Shalikashvili and General Reimer have given us outstanding mission statements – they have told us what to do. They have not told us how to do it. Consequently, a great debate is now underway. The significance of this debate is crucial. For each operational concept or pattern, there are several very diverse opinions as to how to accomplish them. The debate is being vigorously conducted between services as well as within the Army. The crucible of the internal Army debate on this subject – literally, the future of the Army - is the Army After Next (AAN) project.

Following the results of the QDR, the National Defense Panel (NDP) was formed to review the QDR recommendations and submit a separate set of recommendations. The major recommendation from the NDP was to accept more near term risk (reduced optempo, reduced end strength, cancel near term modernization procurements) in return for increased funding of initiatives in intelligence, space, urban warfare, joint experimentation and information operations.[10]

Prior to addressing the AAN effort, the guidance provided by Joint Vision 2010 and Army Vision 2010 must be examined.

JV 2010: Joint Vision 2010 establishes Full Spectrum Dominance as the key characteristic for our armed forces of the 21st century. Building on technological innovations and information superiority, JV 2010 accomplishes Full Spectrum Dominance via four operational concepts: Dominant Maneuver, Precision Engagement, Focused Logistics, and Full-Dimensional Protection.[11]

When discussing advancing technological trends, JV 2010 offers long-range precision capabilities, combined with a wide range of delivery systems as a key emerging factor in future warfare. Additionally, JV 2010 offers the ability to produce a broader range of potential weapons effects, advances in low observable technology, and improvements in information and systems integration technology as means to provide great increases in specific future capabilities.[12]

A theme throughout this document is using information superiority to provide more efficient fires and massed effects with fewer forces. In the context of joint operations, we should be able to provide improved targeting information directly to the most effective weapon system. In this way we will achieve massed effects and potentially reduce force requirements at the point of main effort.[13]

Army Vision 2010: Army Vision (AV) 2010 is the Army's plan to implement JV 2010. In sequence, Force XXI, Army XXI, and AAN define the Army's process to manage change and advance into the 21st century. AV 2010 defines six patterns of operations: Project the Force, Decisive Operations, Shape the Battlespace, Project the Force, Sustain the Force, and Gain Information Dominance. In performing these types of operations, the Army will fulfill its role in achieving full spectrum dominance defined in JV 2010.[14]

AV 2010 states that the Army will pursue the technologies depicted in Table 1 to fulfill its role in achieving full spectrum dominance. The technologies identified are organized in accordance with the six operational patterns.

Project the Force :	*Shape the Battlespace :*	*Sustain the Force :*
• Global Cellular Communications • Smart Pagers • IPB on the move • Lighter Materials • Simulations	• AI Algorithms • Signature Cataloging • Combat ID • Onboard Sensor Processing • Brilliant Munitions	• Inventory Control • More Durable Materials • Over-the air Software Diagnostics & repair • Automated Cross-Leveling and Rerouting
Decisive Operations :	***Protect the Force :***	***Gain Information Dominance :***
• Stealth • Manned Sensors • Unmanned Sensors • Advanced Avionics • High-Speed Vehicular Mobility • Information Warfare • Horizontal Technology Integration • Digitization • Simulations	• Advanced Soldier Technologies • Chemical and Bio Protection • Reduced Signature Enhancements • Situational Understanding • Advanced Identification	• Wireless Communications • Data Compression • Advanced Network Tech • Mobile, Very Small Satellite Transceivers • Multilevel Security Devices

Table 1 – Army Vision 2010 Supporting Technologies[15]

The Army Modernization Plan – Short and Mid-Term: Following guidance provided by JV 2010 and AV 2010 we can depict the Army modernization plan as an orderly and disciplined progression. Our short-term and mid-term force objectives are defined by the evolution of our current force structure to FORCE XXI and then to Army XXI.

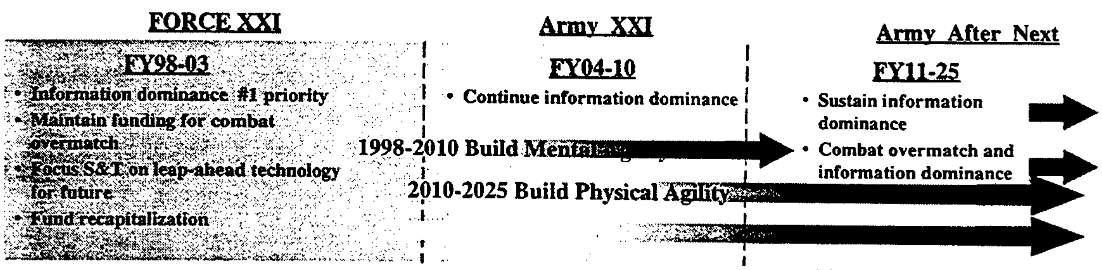

Figure 1 – Army Modernization Strategy[16]

The major goal of Force XXI is to obtain information dominance. In its simplest terms, Force XXI seeks to obtain information dominance by answering the following three questions for each US commander and soldier. Where am I? Where are my friends? Where is the enemy?[17] By sharing a real-time picture of the battlefield, commanders and soldiers alike will have the mental agility to react in accordance with situational awareness and understanding. A key element supporting this concept is the Army's digitization effort and the Army's vision for future battle command as reflected in the Army Battle Command System (ABCS) concept.[18] While this paper is focused on the AAN timeframe, it must be remembered that final achievement of Force XXI capabilities will be a significant technological achievement in its own right. In fact, many concepts for AAN will rely heavily on the accomplishment of these achievements.

TRADOC Pam 525-5, *Force XXI Operations* provides an extensive lay down concerning Force XXI modernization and the concept for evolution to full-dimensional operations. *Force XXI Operations* also establishes a listing of key technologies along with recommendations for future research and development.[19]

Key Technologies with military Impact:

- **Battlefield digitization**
- **Information system security**
- **Anti-satellite jamming**
- **Sensor technologies**
- **Improved survivability**
- **Active hit avoidance**
- **Antiarmor systems**
- **Attack helicopters - extended lethality**
- **Advanced air defense**
- **Smart mines**

Capabilities to Enhance Survivability:

- **Low observables**
- **Lightweight armor packages**
- **Munitions that are insensitive to detonation**
- **Multipurpose sensors**
- **Mounted contamination avoidance detectors**
- **Soldier protection suits with support systems**
- **Active protection systems**

Future Research and Development efforts:

- **Microelectronics and related technologies**
- **Brilliant systems (vice brilliant munitions)**
  - **Autonomous target prioritization and engagement**
  - **Artificial intelligence**
- **Advanced propellants for munitions**
- **Advanced propulsion systems for vehicle mobility**
- **Robotics**
- **Tactical power sources**
- **Molecular engineering - lighter advanced materials**
- **Biological engineering - detection and protection**

Table 2 – Force XXI: Technologies, Capabilities & R&D[20]

Again, the technological and operational capabilities fielded in support of Force XXI are an important stepping stone for AAN. The 1997 *Annual Report on the Army After Next Project* states that the AAN simply seeks to provide the Army of 2020 with the physical agility to complement the mental agility inherited from Force XXI.[21]

Army After Next: In less than two years, the AAN program has accomplished a great deal to forward our understanding of future capabilities and the exploration of futuristic concepts. An extensive study and research plan has led to the development of initial concepts. In addition to the formal program, an ever-growing dialog amongst a broad range of "fellow travelers" continues as an important component of this process.

The review of the technologies presented by JV 2010, AV 2010 and Force XXI reveals no shortage of ideas on future capabilities or technological ideas. In the context of projected budgets, it should be obvious that all of these approaches cannot be pursued in an undisciplined manner. In an effort to better manage future investments, the Army modernization strategy includes acquisition reform, leveraging information technologies, horizontal technology integration and a focused tech base.[22] The AAN program is key to developing operational concepts and providing a clear focus and sense of priority regarding necessary research and development activities. In fact, in FY98, the AAN study will attempt to identify the top three to five promising technologies that need to be fostered within the Army's Basic Research program.[23] Additionally, a goal has been established to allocate at least 30% of the Army's 6.1 Basic Research budget to fund Strategic Research Objectives in support of technologies identified by the AAN study program.[24]

Despite the many diverse technologies outlined above, the AAN has established and is beginning to refine several operational concepts which may offer leap-ahead capabilities during the 2020-2025 timeframe. Several of these concepts have been tested in an ongoing series of wargames. At the macro level, the AAN study group recommends pursuing the general attributes of Knowledge and Speed. At a more refined level, The *1997 Annual Report on the Army After Next Project* makes the following recommendations for augmenting existing research and development efforts.[25]

AAN Technology Short List:	*AAN Systems Short List:*
• **Hybrid power systems** • **Fuel efficiency (reduce by 75%)** • **Human/Cognitive engineering** • **Signature control** • **Protection schemes for land systems (Includes active systems)** • **Advanced materials** • **Alternative propellants** • **Bio & Chem Protection** • **Logistics efficiencies**	• **Future Ground Craft** • **Advanced Airframe (Heavy lift/Tactical utility lift)** • **Autonomous and Semiautonomous unmanned systems (air, ground, sensors)** • **Advanced fire support system** • **"Living internet"** • **Active protection**

Table 3 – 1997 AAN Annual Report Short List for R&D Augmentation

The most evolved AAN concept of operations involves the deployment of an Air-Mechanized Battle Force. This concept combines information dominance, long-range precision fires and organic mobility to conduct ambush like engagements. US AAN forces employ an air-ground tactical method of maneuver that combines lighter surface fighting vehicles with advanced airframes (similar to the V-22 but with over five times the payload[26]) capable of transporting them at speeds as great as 200-300 km/hr over distances in excess of 1000 kilometers.[27,28]

The air-mechanized forces utilize a new family of ground combat systems to conduct efficient ambushes from strategic positions on the battlefield. The family of 15-ton (some are less) ground systems includes an advanced fighting vehicle, robotic engagement systems, advanced reconnaissance vehicle, advanced fire support vehicle, advanced command and control vehicle, and the advanced fire support system.[29]

To a large degree, the effectiveness of the AAN force depends on information dominance and enhanced situational awareness provided by Force XXI technology. Benefits of enhanced situational awareness are only beginning to be understood via the Army Warfighting Experiment. Provided Force XXI objectives are fully realized, and we are able to answer the three critical questions (Where am I? Where are my Friends? Where is the enemy?), the use of automated decision aids will take AAN forces to a new level of effectiveness. The key here is how well AAN forces will be able to use the information that is gained from Force XXI technology.

As a first step, automated tools will assist in checking the viability of Courses of Action (COA) to include calculating support and resource requirements, and time distance factors. As a second step, if fully developed, automated tools will provide anticipatory and adaptive execution systems. These systems will anticipate and preempt enemy maneuver like a "chess master" making it possible to plan, adjust and coordinate multiple branched plans as the situation unfolds.[30]

The AAN study team (with the support of many others) conducted an analytical assessment of the air-mechanized concept and the new systems described above during a two-week tactical wargame in November and December 1997 at Ft. Leavenworth. The wargame used hypothesized 2020 organizations and tactics. The official written results of this wargame are in final draft and will be published soon.

From my personal observations during the first week of the two week wargame, the critical enabling AAN technologies included situational awareness (includes intelligence/sensor fusion), UAVs, heavy lift, long range precision guided munitions, and light combat systems (<15 tons) designed to deliver the precision guided munitions. Technologies contributing to light systems included active protection systems, low observable technology and lightweight materials.

Following the exercise I asked the Blue (AAN) Force and Red Force commanders to comment on which technologies contributed the most to their combat effectiveness. The Blue Force Commander LTG (Ret) William G. Carter III made the following observations:

- Speed and dominant knowledge were two immutable precepts for AAN
- The greatest single leverage is probably in UAV technology
- Computer decision aids – which currently do not exist
- The artillery pod system and air-mechanization concepts have great promise

The Red Force Commander Mr. Richard H. Sinnreich made the following observations:

- UAV-based ground location/navigation and broad-band relay mechanisms to augment and back stop orbital platforms
- High discrimination sensors and adaptive munitions enabling the same warhead to attack a wide range of hard or soft targets
- Wide-area non-lethal munitions capable of neutralizing personnel in fortified or urban areas
- Advanced fuels permitting a radical reduction in bulk fuel requirements

Following the receipt of guidance (QDR, JV 2010 and AV 2010) the DoD and Army Science and Technology Plans attempt to develop focused plans to meet the needs of warfighters. Emerging concepts such as Force XXI and AAN are key factors contributing to the focus of these plans. The next two sections provide a brief review of the DoD and Army Science and Technology Plans.

Department of Defense Science and Technology Plan:

The *Defense Science and Technology Strategy* presents the DoD S&T vision, strategy, plan and objectives for the planners, programmers and performers of defense Science and Technology. The DoD S&T Strategy has three supporting components, (1) the *Basic Research*

Plan (BRP), (2) the *Defense Technology Area Plan* (DTAP) and (3) the *Joint Warfighting Science and Technology Plan* (JWSTP). A copy of the DoD Science and Technology plan is located at *www.dtic.mil/dstp/DSTP/index.html* on the World Wide Web. In theory, the Defense Science and Technology Strategy and its three plans are congruent with JV 2010.[31]

An OSD/Joint Staff review of the Defense Science and Technology plan reveals that there are at least 20 Defense Technical Objectives supporting each of the four operational concepts defined by JV 2010 – Dominant Maneuver, Precision Strike, Full-dimensional Protection and Focused Logistics. DTOs are used by DoD to focus the S&T plan. In total, there are nearly 300 DTOs in the S&T plan.[32]

DoD also uses the Joint Warfighting Science and Technology Plan to ensure that the joint capabilities of the war fighting CINCs are being met. For organizational purposes, joint needs are organized into ten Joint Warfighting Capability Objectives (JWCO). A crosswalk between the Science and Technology Plan's ability to meet JWCO objectives and the four operational concepts was conducted by OSD and is displayed in Table 4. Following the conduct of this matrix crosswalk, the *Concept for Future Joint Operations Expanding JV 2010* makes no recommendations for modifications of the Science and Technology Plan.

JWCO Support for JV 2010

Joint Warfighting Capability Objectives	*JV 2010 Operational Concepts*			
	Dominant Maneuver	Precision Engagement	Full-Dimensional Protection	Focused Logistics
1. Information Superiority	●	●	●	●
2. Precision Force	○	●	○	
3. Combat Identification	○	●	●	
4. Joint Theater Missile Defense		●	●	
5. Military Operations in Urban Terrain	●	○	●	
6. Joint Readiness and Logistics	●	○	○	●
7. Joint Countermine	●		●	○
8. Electronic Combat	●	●	○	
9. Chem/BIO Warfare Defense and Protection	●	○	●	○
10. Counter Weapons of Mass Destruction		●	●	

● Strong Support ○ Moderate Support

Table 4 – JWCO Support for JV 2010 [33]

Up to this point, this review of the science and technology plans has concentrated on how well we support the four operational concepts. However, each of these concepts relies heavily on information superiority. JV 2010 states that Information Superiority is a central precept and full spectrum dominance cannot occur without it. Information superiority is defined as "the capability to collect, process and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same." [34]

As discussed previously, the goal of the AWE and Force XXI is to provide improved situational awareness. If successful, Force XXI capabilities will provide vast amounts of information to commanders and soldiers at every level. While Force XXI capabilities will contribute dramatically to force effectiveness, my assessment is that the change in operations, provided by the current science and technology objectives, will be more evolutionary than revolutionary. The revolution in military affairs will occur when we learn how to effectively use this information. Figure 2 depicts a time versus capabilities comparison of the evolutionary and revolutionary approach to the use of information superiority. The graph has been slightly modified from those that appear in *Concept for Future Operations Expanding Joint Vision 2010.*[35]

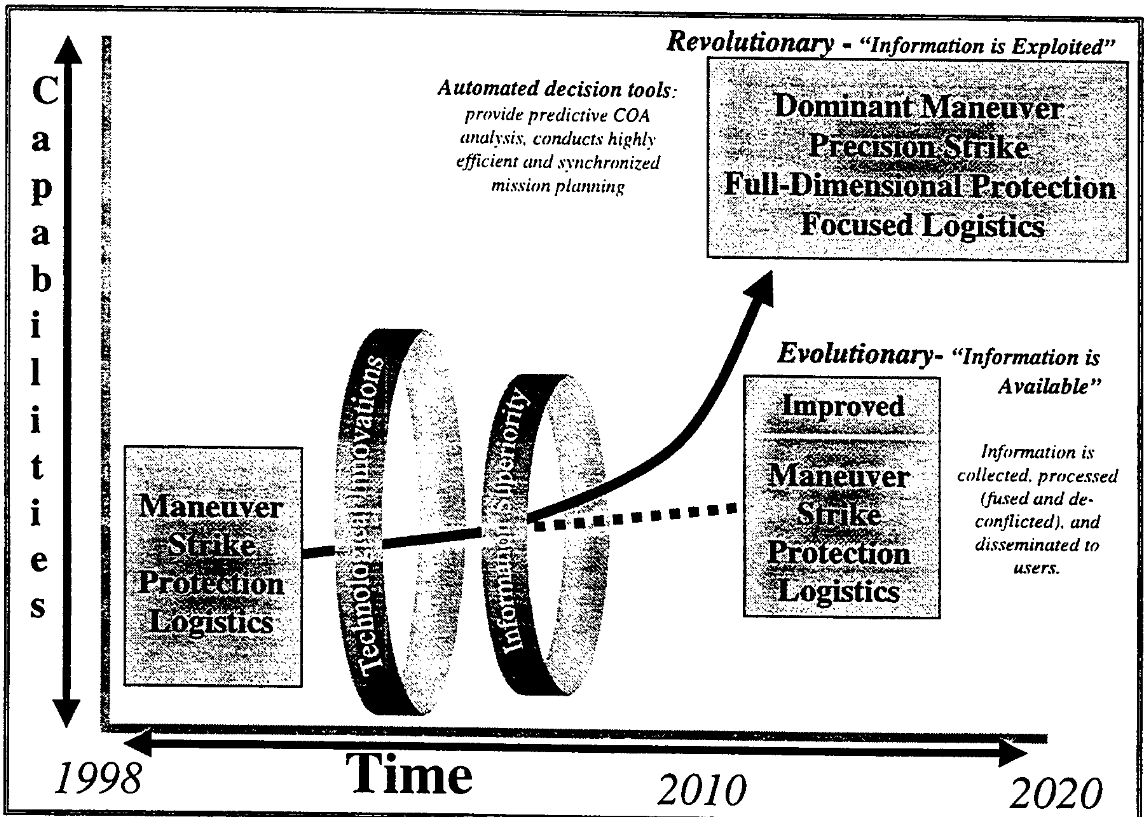

Figure 2 – Information Superiority

A visionary document that addresses revolutionary concepts concerning how to use available information is the Advanced Battlespace Information System (ABIS) Task Force Report. The ABIS report provides a road map that focuses on how to exploit information technology to provide warfighters the knowledge that will permit them to employ forces and mass effects in revolutionary new ways.[36]

The potential for a revolution in combat operations and effectiveness can be directly inferred from envisioned ABIS capabilities. It is important to remember that the ABIS is a concept and not a program. The capabilities envisioned in this concept will never be realized unless a program is created to link information available from Force XXI systems to the appropriately designed decision aids.

Selected ABIS capabilities include the following. Although this list is detailed, it is worth study and review. It does not take much imagination to envision revolutionary increases in combat effectiveness that will result from this type of decision and execution support system.

- **Situation Projection.** Use of automated Model and Simulation (M&S) tools to project from present situation to likely alternatives into the future.
- **Support Simultaneous Engagement and Coordinated Operations.** Automated support to optimization of allocation and deconfliction to maximize combat power against target set. Dissemination of the execution plans and loading of target sets into weapons in a timely manner. Retask forces and systems as status of targets changes. Real-time coordination between combat elements. Objective: 50 simultaneous coordinated missions, dissemination and retasking in less than one minute.
- **Shared, Dynamic, Distributed, Continuous Collaborative Planning.** Shared dynamic plan representation linked to central strategy with distributed, collaborative plan generation and refinement. Includes automated M&S and tools to reduce time for critical nodal analysis, alternate COA evaluation and BDA analysis. Includes a look-ahead, opportunity planning capability and collaboration with a streamlined logistics planning system. Objectives: Increase effectiveness and reduce planning cycle by 50 percent.
- **Rapid, Accurate Targeting.** Detect, identify, locate and track critical targets and associated infrastructure. Automatically pair targets with weapons. Objective: 500 targets per hour.
- **Rapid, Accurate Battle Damage Assessment.** Assess damage to attacked targets. Objective: Tens of minutes for most targets and less than 30 seconds for fleeting high-value targets.
- **ISR and C3 System Management and Integration.** Integrated management and tasking of ISR assets, national and theater tied to central strategy. Objective: Retask ISR in less than one minute.
- **Force Status and Execution Following**. Provision of common shared understanding of commander's intent, strategic attack priorities, force status, readiness, friendly damage, and execution status. Objective: 50 simultaneous coordinated missions.
- **Parallel Dissemination of Intelligence/BDA to C2 and Shooters.** Provision to rapidly disseminate intelligence and BDA to C2 and shooters in parallel.

- **Rapid, Accurate Target Information (Target Location and Recognition, Situation Awareness in Target Area).** Provision for customized and streamlined automated target detection, recognition, and location and dissemination of local situation awareness to the designated shooters.
- **Automated Mission-to-Target and Weapon-to-Target Pairing.** Rapid, automated pairing of missions to target sets and weapon to target to support the kill of high-value fleeting targets.[37]

A potential road map of key ABIS conceptual capabilities is depicted in Figure 3. In general, this proposed timeline parallels our modernization timeline from Force XXI to AAN.

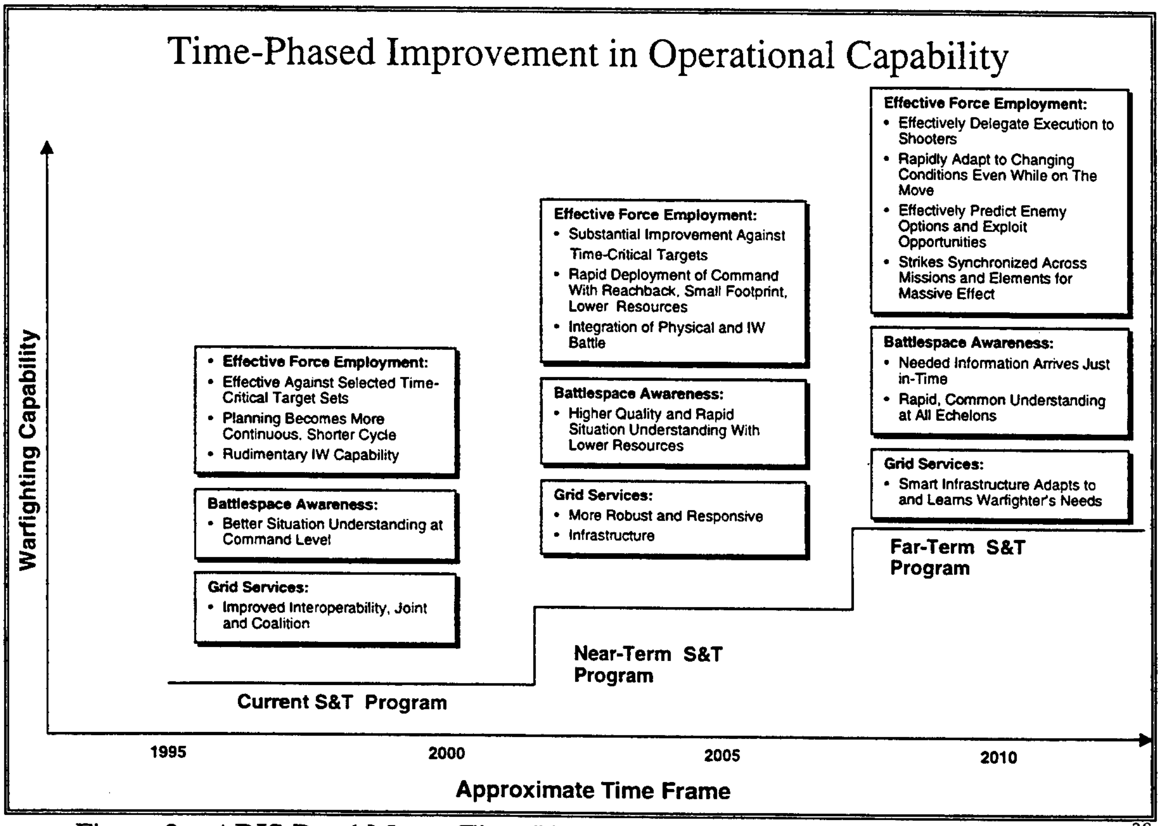

Figure 3 – ABIS Road Map – Time Phased Improvement in Operational Capability[38]

Army Science and Technology Plan:

Army Science and Technology Objectives (STO) are the Army's top science and technology efforts. Approximately 200 Army STOs are published in the Army Science and

Technology Master Plan (ASTMP). An objective of the ASTMP is to support Army XXI, Army Vision 2010 and the emerging long-term concepts from the Army After Next Program.[39] The challenge of translating operational concepts into capabilities (i.e., managing the ASTMP) becomes obvious when you review the scope of *TRADOC PAM 525-66 – Future Operational Capability* (FOC). The 1997 FOC establishes 479 desired future capabilities. In order to ensure compliance with top level guidance, the FOC provides an extensive crosswalk between JV 2010 Operational Concepts and the desired Future Operating Concepts.[40]

Each year, TRADOC reviews ongoing research programs (6.1, 6.2, and 6.3) and evaluates them directly against each FOC to determine the adequacy of current efforts. Input from the TRADOC Science and Technology Review is used by the Army Science and Technology Working Group to develop the ASTMP. Following the last review, the *1997 S&T Review* identified 52 FOCs as potential Science and Technology Objectives in the ASTMP. A cursory review of these 52 recommendations reveals that 18 of them have direct connection to emerging AAN concepts.[41] The 4-step process resulting in the ASTMP and the approved STOs is depicted in Figure 4 below.

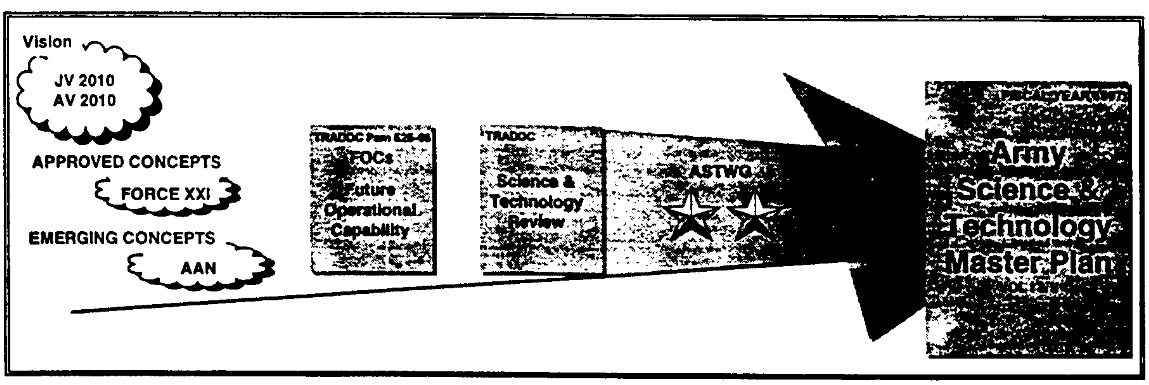

Figure 4 – Science and Technology Review

At this point in the research process, we have identified the strategic geopolitical rationale for modernization and we have identified high-level modernization guidance for the near and midterm (FY99-FY10) – QDR, JV 2010 and AV 2010. We have introduced the evolving concepts for the long term as identified by the AAN effort. And, finally, we have reviewed highlights of DoD and Army Science and Technology Plans tasked with providing the technology and systems required to support these evolving concepts.

During this review, we have identified dozens of technologies and several mutually supporting operational concepts. The task now is to focus our resources on promising technologies that provide true leap-ahead capabilities and maximum increases in combat effectiveness.

Part II: Analysis and Recommendations

Based on broad review of guidance, operational visions, and evolving concepts, two technologies capable of providing AAN forces with leap-ahead capabilities can be identified. I assess the developmental risk associated with each of these technology recommendations to be high. However, because the time frame for AAN is still twenty plus years in the future, we have been given a tremendous opportunity to identify and develop leap-ahead concepts, technologies and systems on a long-term basis. Given this relatively long lead-time, I am very confident that if we give these two technologies adequate emphasis and resources, our science and technology base will fully meet the challenge.

The first recommendation is to put information superiority to work. The opportunity exists to fully leverage situational awareness provided by Force XXI in a revolutionary manner. To do this, we must develop automated decision making tools to assist commanders and their staffs during the planning, preparation and execution of combat operations. These tools, most likely based on models and simulations, will benefit future forces in combat regardless of future force structure or operational concept decisions. While this research project was able to identify several requirements for automated decision-making tools, it was not able to find a program designed to support the requirements.

Automated decision support is an important technology and capability to pursue because it provides any deployed force increased effectiveness. This will be true regardless of the operational concept or force structure selected. It will not matter if AAN forces are air mechanized forces, very dispersed special operations forces, a more traditional mix of a modernized combined arms team or even Force XXI legacy systems.

The second recommendation is the development of a Future Combat System (FCS) equipped with an electromagnetic gun. As the analysis will show, the EMG provides a potential breakthrough in the continuous and costly trend toward heavier and heavier tanks. The analysis will also show that other lethality upgrades such as missile technology or electrothermal-chemical (ETC) systems either continue the trend toward heavier systems or greatly exacerbate survivability and logistical concerns.

Following a more detailed analysis of these two recommendations, I will present a listing of supplemental recommendations and a short listing of issues and concerns relevant to the AAN process.

Recommendation #1 – Automated Decision-Making Tools:

Force XXI and digitization initiatives are leading our forces and their command and control systems toward a goal of information superiority. Clearly, increased situational awareness will provide our forces a tremendous advantage. Many of these advantages have already been demonstrated during the Army Warfighting Experiments. However, we can do much more. We can make the information derived from Force XXI technology work harder for us. But we must start now if we are to realize this potential by the year 2020.

Major recommendations presented in this section include:

- Initiating a program to develop Automated Decision-Making tools required in Force XXI and AAN concepts
- Linking Force XXI technologies and capabilities to the appropriate automated decision making tools that will provide capabilities such as those envisioned in the OSD ABIS concept
- Continuing to support Force XXI technology initiatives that must be in place in order to provide the basic components required to establish information superiority
- Identifying an appropriate agency as the proponent responsible for defining, developing and fielding automated decision-making systems
- Organizing a data collection effort from the NTC, the Gulf War and other sources to validate and calibrate simulation results.

The analysis supporting the recommendation to support automated decision technology is organized as follows:

- Description of Concept
- Current Simulation Efforts – JWARS & WARSIM
- Advances in Computer technology and Science
- Summary and Recommendations.

Many systems and concepts state the requirement for automated decision-making capabilities. For example, the AAN study team has identified the need for "anticipatory planning and adaptive execution systems".[42] Other examples include TRADOC Pamphlet 525-5 *Force XXI Operations,* which discusses the development of brilliant systems and the use of artificial intelligence to significantly improve Army battlefield management.[43] *The Operational Requirements Document (ORD) for the Maneuver Control System (MCS)* defines a system that provides automated command and control support to commanders and staff. The system envisioned shortens the duration of the decision-making cycle and provides the capability to analyze alternative courses of action with predictive analysis capabilities. The MCS is the Army command and control system for corps, divisions, brigades and battalions.[44] *The Capstone Requirements Document for the Army Battle Command System (ABCS)* and Operational *Requirements Document for Force XXI Battle Command – Brigade and Below (FBCB2)* both have requirements for automated decision aids. [45,46]

When fielded, these automated systems will link the ability of future indirect fire systems with long range precision guided munitions and should allow commanders to target key enemy nodes in a very efficient and debilitating manner. However, this is easier said than done. The shear number of sensors, shooters and targets make the problem very complicated. An even greater level of complexity evolves when you try to optimize the effectiveness of all systems (artillery, long range rockets, NLOS, etc.) in the fight against each various target type. An additional layer of complexity occurs when you attempt to debilitate and paralyze the enemy with synchronized fires against essential nodes throughout his combat organizations. Quite simply, a fire plan of this complexity, efficiency and effectiveness cannot be planned let alone executed using manual methods. The plan continues to get much more complicated when you integrate direct fire systems, counter-mobility systems, suppression of enemy air defenses, attack helicopters, EW and close air support.

There are many science and technology efforts such as target identification, target tracking, intelligence fusion, UAVs, broadband communications and standard simulation architectures that will contribute to the final system. While each of these enabling technologies will contribute to increased combat effectiveness independently, there is significant developmental risk associated with each of them. Again, these enabling technologies must be in place in order for automated decision-making tools to work. The 2005-2010 timeline for fielding most of these capabilities is associated with Army Vision 2010 and Force XXI.

Description of Concept:

The concept I envision takes data available from Force XXI systems (Where am I? Where are my Friends? and Where is the enemy?) and feeds that information directly into a very high resolution combat simulation. The simulation tracks individual combat systems on high-resolution dynamic digital terrain. With minimal user input such as a mission statement, the simulation wargames thousands of potential courses of action and provides two or three recommendations to the commander and his staff.

The most significant benefit of this iterative approach is the production of a highly refined, efficient and effective fire and maneuver plan. Following a battlefield update of current information, the first step of the process determines an initial plan to defeat the enemy. The simulation determines, via a nodal analysis, enemy strengths and weaknesses and determines the most effective means of destroying his combat power. The second step is the allocation of combat power - US AAN and/or Force XXI forces. During this step, the simulation designs a fire-and maneuver plan that incorporates all available fire and maneuver assets and uses each in the most effective role in terms of timing and mission.

If properly developed, this approach will be vastly superior to our present doctrinal system. Under our current system, the commander prioritizes his fires during each phase of the operation. A common plan might designate enemy indirect fire systems as the first priority target. Second and third priority targets might be ADA followed by command and control elements. While this system is effective at massing fires, it leaves major elements of the enemies organization untouched by effective indirect fires. This method is effective, but more importantly it is manageable under our manual planning and execution system. We can do better.

There are two important caveats concerning the concept for this system. The first, and most important, is the fact that the automated decision tool is not intended to replace the commander. Rather it is intended to support the commander in the management of many diverse and complex systems. The commander will always be responsible for making combat decisions.

The second important point to consider concerns the design of the combat simulation. The simulation tool should not be designed to produce optimal solutions. A highly effective plan does not need to be optimal. This approach will greatly simplify the development of the tool and contribute to decreased computation time and complexity.

Current Simulation Efforts:

Current simulation efforts are impressive. Much work has been done to define M&S requirements, prioritize investments, establish standards and supporting technology, develop education and infrastructure plans and to provide a management system.[47] Both DoD and the

Army have established Modeling and Simulation offices to oversee these efforts. The two most ambitious ongoing simulation efforts are the OSD Joint Warfare Simulation (JWARS) and the Army's Warfighters' Simulation 2000 (WARSIM).

However, these two models are being designed to support force development and training requirements. Neither is intended to support combat operations. Additionally, COL David Hardin, Deputy Director Army Model and Simulation Office and LTC Daniel Maxwell, from the OSD JWARs office, confirmed in separate interviews that no significant modeling or simulation effort was ongoing to meet the operational requirement for automated decision support.

JWARs will be a state-of-the-art representation of joint warfare at the theater-level. JWARs will assist in implementation of Joint Vision 2010 by providing a vehicle to assess current and future military capabilities. At a very aggregated level, JWARS will provide support for Course of Action development and risk assessments for US Forces. For crisis action planning, time required for preparation. execution and analysis should be no more than 18-24 hours when scenario data is available. Potential users of this simulation include the Joint Staff, Services, CINC's and Joint Task Force Commanders/Staff.[48]

Warfighters' Simulation 2000 (WARSIM) is designed to be an enhanced training system. It is designed to increase the effectiveness of commander and staff training during exercises and staff mission rehearsals by dramatically increasing the realism and scope of available training environment. Primary WARSIM system capabilities include:

- Support training of unit commanders and their staffs from battalion through theater
- Track individual platform locations in the simulation environment
- Model cognitive processes to include the ability to reason on the factors of METT-T
- Course of action analysis and comparison by wargaming friendly courses of action
- Monitor the execution of plans by subordinate, supporting and adjacent units replanning, and issuance of fragmentary orders or new orders
- Build scenarios from scratch within 80 labor hours for division/corps and 16 labor hours for brigade/battalion

- Provide an unconstrained view of the battlespace
- Process, merge and display information collected from unit command and control equipment
- Interact/communicate directly with units over real C4I equipment using real message formats
- The ability to use, manipulate, input data to and extract data from a variety of data bases to include organizational system databases
- The ability to link directly to Army Battlespace Command Systems (ABCS) such as MCS and able to upload data to and download data from this equipment.

Advances in Computer Technology and Science:

Many of the capabilities we need for the envisioned automated tools are being incorporated into the JWARS and WARSIM simulations. Portable computing power to handle these large problems is on the near horizon. IBM announced in February 1998 the development of a 1000 MHz processor. In 1999, readily available PC architectures will migrate from 32-bit to 64-bit systems. This migration will increase addressable memory from 4 giga-bytes for 32-bit systems to 18 billion giga-bytes for 64-bit systems.

Other advances such as Reduced Instruction Set Computing and (RISC) and Parallel computing will contribute to additional increases in computing power. [49]

Summary and Recommendations: The challenge now is to link the emerging Force XXI capabilities with automated decision making tools and back to our AAN warfighters and their combat systems. Several experts working on current systems have told me that this concept is simply "pie-in-the-sky". They state that they are having problems just making digitization work.

There are many technological challenges that must be overcome in order to develop and field a system such as the one described in the ABIS concept. Developmental risk for this concept is high. Many problems from simulating cognitive processes to managing vast amounts of data in real time are among the most significant.

For once, time may be on our side. If we start soon. we have approximately 20 years to develop a revolutionary decision support system. The system will translate information dominance into revolutionary increases in combat effectiveness. Based on this research, I recommend the following actions:

- Initiate a program to develop Automated Decision-Making tools required in Force XXI and AAN concepts.
- Link Force XXI technologies and capabilities to the appropriate automated decision-making tools that will provide capabilities such as those envisioned in the OSD ABIS concept
- Continue to support Force XXI technology initiatives that must be in place in order to provide the basic components required to establish information superiority
- Identify an appropriate agency as the proponent responsible for defining, developing and fielding automated decision-making systems
- Conduct a thorough data collection effort from the NTC, the Gulf War and other sources to validate and calibrate simulation results.

Recommendation #2 – Future Combat System Equipped with EMG Lethality:

As a preface to this section, I readily admit that it is outside the scope of this research project to justify the need for a tank-like system during the AAN timeframe. Despite early AAN conclusions, I do believe that the ongoing AAN analysis will eventually conclude the following requirements for AAN forces.

- A direct fire system, similar to the description of the Future Combat System (FCS), will be necessary in the 2020-2025 timeframe in order to provide combat lethality, mobility and survivability necessary to close with and destroy a determined enemy.
- Advances in Active Protection Systems (APS), low-observable technology and the development of light weight materials will not lead to the fielding of a survivable direct-fire close-combat system as currently envisioned (approximately 15 tons) by the AAN force. Support for this statement is offered later in the paper in the section outlining issues and concerns.

The primary advantages supporting the development of an EMG gun are based on increased lethality with much smaller tank killing ammunition. Smaller ammunition leads to: smaller turrets, smaller tanks, reduced power requirements, increased survivability, increased strategic mobility and decreased logistics. Based on this survey, the EMG gun is the only evolving technology with the potential to support a lethal and survivable Future Combat System that is lighter.

Dr. Walter LaBerge, a former Undersecretary of the Army, is also a strong advocate for the EMG technology. Dr. LaBerge submits the following reasons for why EMG technology is important to the FCS:

- Only way to get hypervelocity and HV may be one of few ways available to deal with emerging ERA threat
- EM Gun allows efficient metering of propellant energy applied to target being attacked optimizing mission load
- Significantly reduces vulnerability of FCS by replacing explosive propellant charges with less volatile JP 10 and by vitiating active defense by producing minimal firing signatures

- Apparent significant growth potential through HV novel penetrator development and hyper energy options
- Can be synergetic to all electric FCS concept.

While the technology survey and analysis presented in this paper was derived independently, many of the derived conclusions directly support Dr. LaBerge's positions. Major recommendations along with supporting analysis presented in this section include:

- EMG lethality technology (a high-risk technology) offers the best leap-ahead potential for the AAN direct fire combat system.
- Revise FCS user and the Defense Technology Objective requirements. A few recommendations that offer a balance between user requirements and technological challenges are offered at the end of this section. I believe these recommendations have the potential to contribute to a FCS below the current 40-ton design.
- The applied research program supporting the EMG power source should be increased. This is the most significant remaining technological challenge and must receive priority support, money, organization and time.
- Fabrication of the EMG power supply should be expanded to at least two highly proven contractors.
- The applied research program supporting the full scale EMG and the full scale Integrated Launch Package (ILP) should be expanded and returned to US control and responsibility.

The analysis supporting the recommendation to support EMG technology is organized as follows:

- Synergistic benefits of EMG
- Requirements for Increased Lethality
- Description of EMG technology
- Update on EMG program accomplishments
- Recommendations for further EMG investigations.

Synergistic benefits of EMG: The primary justification for developing EMG technology is derived from the synergistic linkages between increased lethality and the elimination of propellant charges. The use of electric energy to eliminate propellants on the EMG round results in a cascading set of important efficiencies. Key among these efficiencies is the opportunity to reverse the continuing spiral of increasingly heavier tanks. Reduced system weight, when coupled with reduced logistic requirements has the potential to enhance strategic deployment capabilities.

Other technologies such as a 140-mm cannon, Electrothermal-chemical (ETC) and LOSAT offer increased lethality. However, each has significant drawbacks when compared to the application of EMG benefits in a direct-fire close-combat system. Because future systems need to be lighter, no one is currently considering a 140mm solution for increased lethality.

ETC technology offers a near-term solution for increased lethality and should be easier to develop. However, the increase in lethality is only expected to meet near term requirements and leaves little margin for growth to accommodate developments by our adversaries. Additionally, the ETC solution still requires a 120mm cannon and a cartridge containing even more chemical propellant charges. This solution does nothing to decrease volume or weight requirements on a tank. In terms of deployment and Class V logistical support, there is no benefit to deploying ETC technology.

The Army Science and Technology Objective (STO) to create the next generation Line of Sight Anti-tank (LOSAT) is called the Compact Kinetic Energy Missile (CKEM). The object of this STO is to deliver a KE projectile with more than 20MJ of energy at 4Km [50] (A discussion concerning lethality and energy follows shortly). Clearly, this technology must be pursued. It is very impressive and offers a long-term solution for direct fire lethality. However, due to the size and cost of each missile and its inherent problems with survivability, the CKEM may not be a cost-effective solution for a FCS type system. The role of the CKEM could be similar to that of the current TOW missile. The CKEM has the potential to be a highly efficient system in an over-watch direct fire role.

Quantitatively, the size and weight reduction from a 120 mm round to an EMG round is significant. A smaller EMG round (no propellant) reduces the weight of 40 rounds (number of rounds stored on-board an M1A1) from 3100 lbs. to 800 lbs. Furthermore, the volume of these same 40 rounds is reduced from 20 ft^3 to 9.5 ft^3.[51]

The following graphic, Figure 5, depicts the relative size of each projectile and provides a clear example reflecting potential volume, weight and logistical benefits or burdens associated with each projectile.

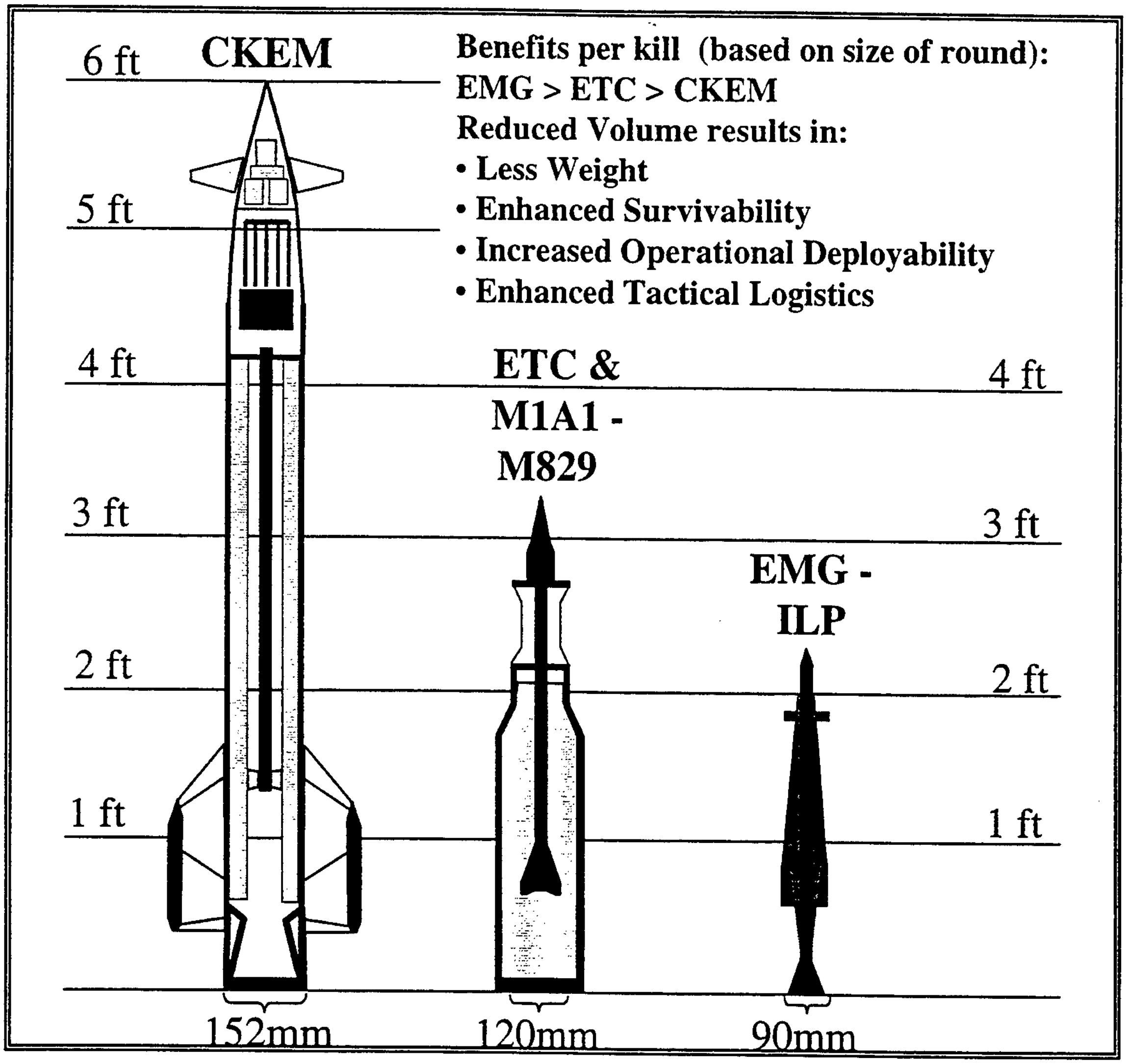

Figure 5 – Relative Sizes of Direct Fire KE Systems

A more detailed, and yet very simplistic, depiction of EMG synergies and the relationship between these factors is presented in Figure 6 below.

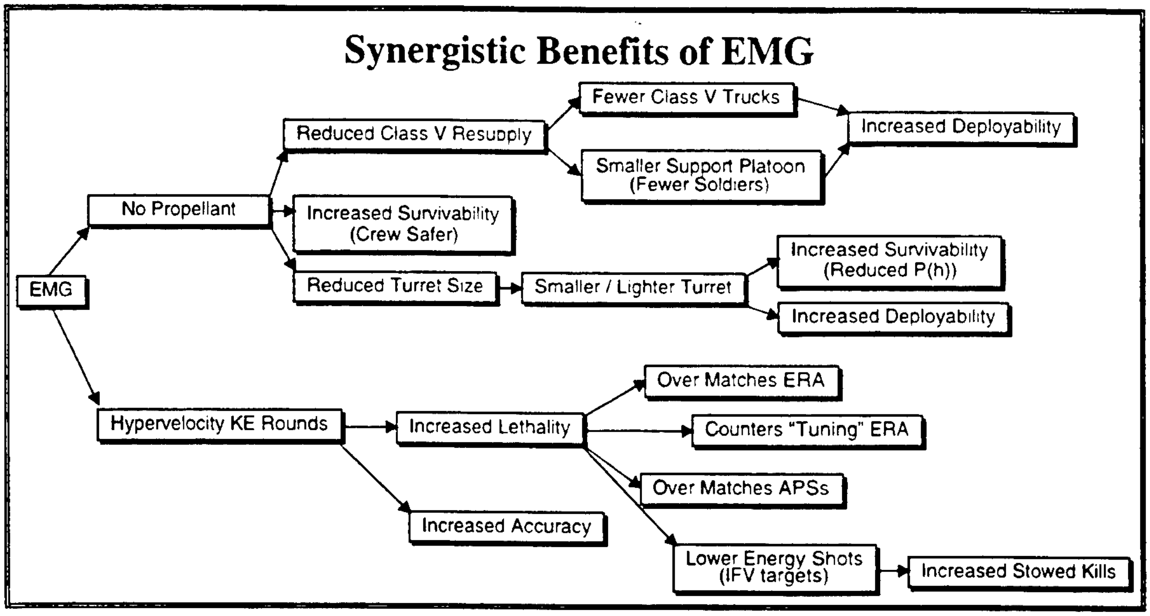

Figure 6 - Synergistic Benefits of EMG

The following discussion elaborates on the benefits that may be derived from a smaller round that does not rely on propellant charges.

Enhanced Strategic and Operational Deployment: The transition from a forward based force to a power projection force places increased emphasis on the requirement for lighter combat systems and smaller more lethal units. The current M1A1 tank weighs approximately 70 tons. Clearly, a lighter easier to support weapon system would enhance our deployment capabilities.

The Air Force C5-A/B strategic transporter is designed to carry 291,000 pounds (145 tons). In practice, to include overseas wartime deployments, only one M1A1 is transported during each flight.[52,53] Likewise, the C-17 can carry one M1A1 with a design payload of 85 tons.[54] Feasible designs for an EMG equipped FCS have emerged at or near 40 tons. At 40 tons, it would be possible to transport three FCSs on a C5 or two FCSs on a C17. While the ability to deploy first in "heavy" combat power 2-3 times faster does not solve the complete deployment problem, it is still a dramatic improvement.

Increased Survivability: EMG technology offers increased survivability in two important ways. The first is due to the reduced size of ammunition storage space. Reduced storage space (20 ft^3 to 9.5 ft^3) should result in a smaller turret design. A smaller turret is harder to acquire and much harder to hit. For similar levels of protection, if a system is harder to hit, it is more survivable on the battlefield. Quantifying the exact benefit of this size reduction will depend on evolving turret designs and the conduct of high-resolution combat modeling and simulation. The results may be significant. High resolution CASTFOREM simulation results conducted during the Army Systems Modernization Program - Cost and Operational Effectiveness Analysis (COEA) determined that nearly 75% of all tank losses were the result of direct fire hits (missiles and KE rounds) to the tank turret.

The second benefit of the EMG round results from the absence of a propellant on each round. Secondary explosions are a significant danger to armor vehicle crews. Secondary explosions occur when stored ammunition is hit and explodes. Current tank turret designs include physically separating the crew from most of the ammunition. This method of protecting the crew is called compartmenting and requires additional space and weight to design. The compartmented design of the M1A1 is very effective but there is still a danger from secondary explosions.

Requirement for increased lethality: The growth of tank guns from 90mm, 100mm, 105mm, 115mm, and up to the current US 120mm and Russian 125mm guns has been driven by the need for increased killing power. Larger guns permit tanks to shoot larger projectiles at the same or slightly higher velocities at increasingly heavier and more survivable tanks. With the application of Explosive Reactive Armor (ERA) the trend toward heavier more survivable tanks continues. In fact, there is considerable evidence that second and third generation ERA produced by Russia. China and others has already marginalized the effectiveness of our 120mm tank rounds. Russia is also advertising a program to develop ERA systems to defeat future 140mm rounds.[55]

Today's best tank rounds use kinetic energy (KE) to kill other tanks by shooting "long-rod penetrators" at very high velocities. From basic physics, we know that KE is defined as $\frac{1}{2}MV^2$ (M is the mass of the projectile and V is the velocity of the projectile). From this equation, it is readily apparent that increasing the velocity of a projectile is the best way to increase its energy and effectiveness.

As a reference point, a 120-mm (fictional but realistic round) departs the gun tube at 1700 meters/sec and weighs 9 kg (22.05 lbs). This is the total launch weight. The muzzle energy is therefore $\frac{1}{2}(9kg)(1700m/sec)^2$ or 13MJ (Mega Joules). At a range of 2000 meters, the penetrator portion of the projectile now weighs 6kg (3kg was discarded with the sabots after the round left the muzzle) and has slowed down to 1550 meter/sec. Penetrator energy at this point is now 7.2 MJ.

As mentioned previously, Russia is currently marketing an application package of explosive reactive armor. The advertisement claims that their ERA package provides 150mm – 200mm of overmatch protection the US M829 KE round.[56] The M829 is the best 120mm KE round shot by the US M1A1/A2 tank. Because several countries are retrofitting their tanks with advanced ERA protection technology today, it can be argued that the effectiveness of our front line anti-armor systems is already marginalized.

For purposes of this study, assume that the Russian advertising claim is true and that it will take an 8MJ shot to destroy the tank. At 2000 meters range, our 120mm 7.2MJ tank round is no longer effective. To get an 8MJ impact at 2000 meters, we must increase the velocity by 83 meters/sec, or increase the mass of the penetrator by .66kg (1.5 lbs.). Of course, this limited increase in lethality simply places the effectiveness of the new round right on the margin.

In short, at 13MJ (1700meters/sec), the 120mm cannon is operating very close to its maximum effectiveness. One of the Army's Science and Technology Objectives (not ETC) is spending over $3 million in an effort to increase propellant efficiency to increase the 120 mm gun velocity by 5-10%.[57]

A summary of these points is simple. Increased direct fire lethality is a near term requirement. A very efficient means to increase lethality is to increase projectile velocity. Currently, the only technology that offers increased lethality with reduced projectile size and weight is Electromagnetic Gun technology.

Description of Electromagnetic Gun Technology: This section of the paper describes the function of the railgun and the power supply. The basic technology behind the EMG is best described by the simple railgun. Operation of a simple railgun is depicted in Figure 7.

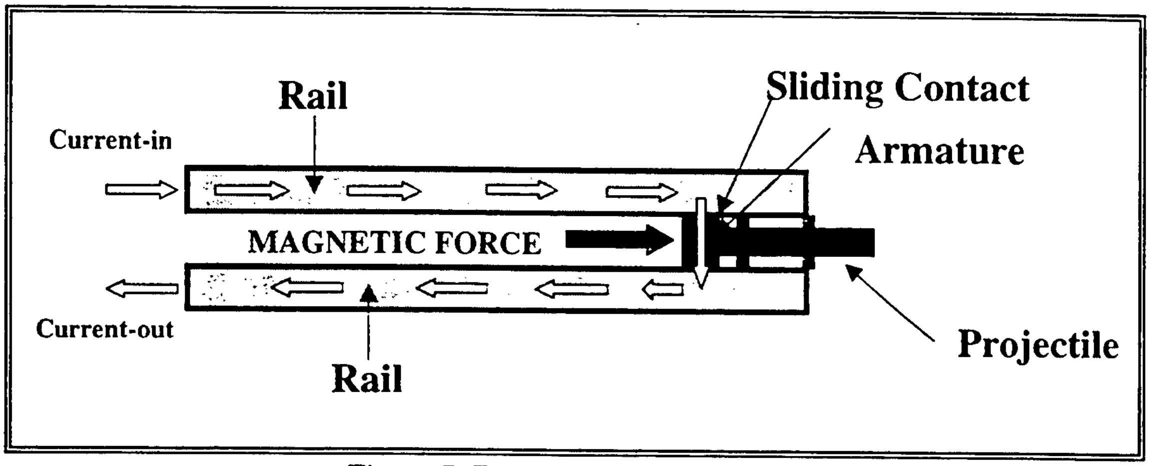

Figure 7. The Simple Railgun

As depicted here, the electric current flows from rail to rail through the armature and a sliding contact. The current flowing through the rails creates a magnetic field between the two rails. Because the armature is free to move, this force propels the armature to high velocity. Laboratory railguns have launched small projectiles in excess of 7km/sec.[58] In 1993, the U.S. EMG program fired a 2.77 kg projectile from a 90mm railgun at 2.38 km/sec. This militarily significant shot created 7.85 MJ of energy at launch.[59] The Director of the US Electromagnetic Gun Program reports that the UK has recently fired a 2.2kg launch package at 2600 m/s. This equates to an energy of 7.44MJ. [60]

Aside from a portable power source, which will be discussed later, the three remaining challenges associated with rail guns are: (1) reducing the weight of the rail gun structure required to rigidly contain extremely large forces along the length of the rail; (2) reducing armature conductor mass since it is typically discarded with the sabots; and (3) maintaining metal to metal contact at high launch speeds while minimizing metal gouging along each rail.[61]

Various international programs are making progress in each of these tough areas. In fact, recent research at the Institute for Advanced Technologies (IAT) at the University of Texas has led to design techniques, which should significantly eliminate high velocity rail gouging.

A US Army Science and Technology Objective (#IV.I.13) has been established to demonstrate leap-ahead technology to defeat future threat targets such as explosive reactive armor and active protection systems using an Electromagnetic Gun (EMG) in the 2015 time frame or an Electrothermal Chemical (ETC) Gun in the 2002 timeframe.

In direct support of this effort, the Army Research Lab's (ARL) Weapons and Materials Research Directorate invested $19.3 million in FY 1997 into the electric armaments research and development. The railgun portion of the program is led by the University of Texas Institute for Advanced Technology (IAT). Science Applications Technology Corporation (SAIC), the prime contractor, is teamed with the University of Texas Center for Electromechanics (CEM) to provide a pulsed-power system design and fabricate a power supply. The funds devoted to the IAT and CEM programs were $4.0 million and $10.0 million, respectively.[62]

Update on EMG Program Accomplishments*:* Worldwide, a great deal of research is being expended in an effort to harness the potential of hypervelocity EMGs. This section provides an overview of worldwide EMG technical achievements. No fewer than 11 countries made formal presentations at the 8th Symposium on Electromagnetic Launch Technology in 1996. Following the United States, the next major contributor at the Symposium was Russia.

The 9th Symposium on Electromagnetic Launch Technology will be conducted in May 1998 in Edinburgh, Scotland. International participation in this technology is on the increase. China, for example, is presenting ten separate papers at this symposium.

- **UK electric Gun Research Program**: The UK program has concluded that EM technology offers the potential to accurately fire hypervelocity KE projectiles from a sensible length barrel. "Though the risk is high, so is the pay-off, including significant battlefield logistic savings coming from the lack of tons of chemical propellant to be moved around the battlefield".[63]

- **UK 90mm EMG**: In 1996, the UK program reported on the ability of their 90mm EMG to hit targets at a range of 2000 meters. Using this gun, a 3.51 kg projectile was fired at 1700 m/s thus producing a 5.1 MJ shot.[64]

The Director of the US Electromagnetic Gun Program reports that the US Army has placed the UK in charge of full-scale development of the Integrated Launch Package (ILP). The University of Texas will work on a design of the ILP at 40mm model scale. Furthermore, the Director reports that the UK has fired a 2.2kg launch package at 2600 km/s. A joint US-UK effort is underway to design more efficient ILPs.[65]

- **Effectiveness of Hypervelocity KE rounds against Solid Targets**: Two independent studies from the U.S. Army Research Lab[66] and the Israeli Rafael Company[67] have demonstrated that Hypervelocity penetrators (greater than 2km/sec and 3km/sec respectively) produce penetrations greater than predicted. Each of these studies suggest a "secondary" penetration created by the energy contained in the displaced material created by the initial penetration.

- **Novel penetrators:** Experimental and simulation work at IAT and the Sweden National Defense Research Establishment reports increased effectiveness of novel penetrators. Two promising designs are the segmented and telescoping penetrators. Both simulations and tests show that these two penetrators have better penetration capability than a homogeneous projectile with the same initial geometry. At hypervelocity, these projectiles offer an excellent opportunity to provide increased lethality for smaller projectiles.

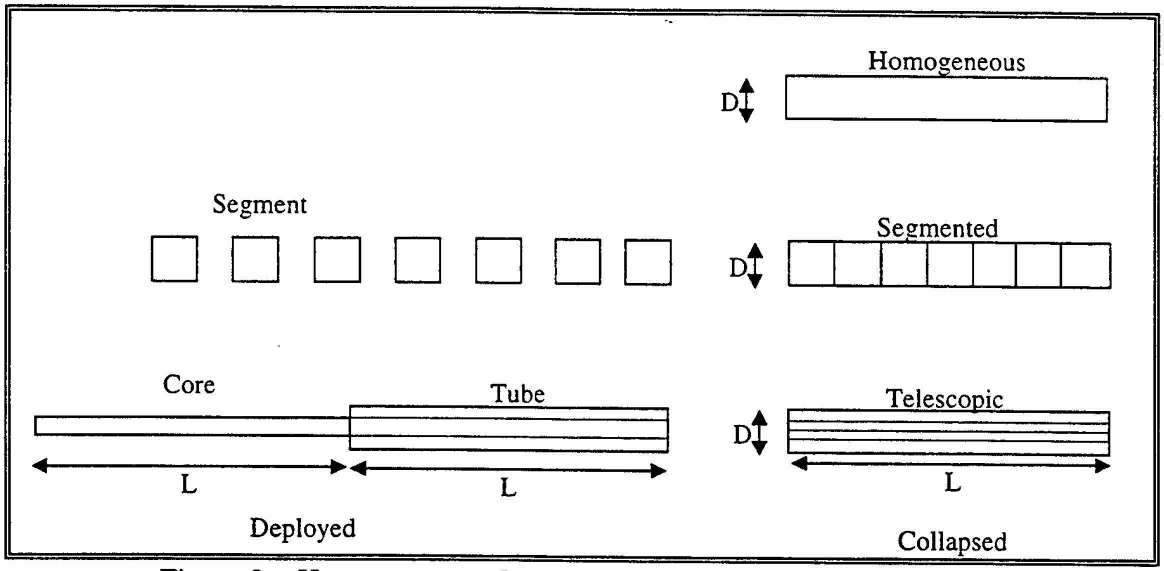

Figure 8 – Homogeneous, Segmented, and Telescopic Penetrators

- **Integrated System Design:** No one has ever doubted our ability to build an EMG capable of launching full-scale combat projectiles at hypervelocity. The challenge has always been our ability to integrate the components of an EMG (gun, power supply, and projectile launch package) into a reasonably sized combat system. Although many problems remain to be solved, recent developments in pulsed power, advanced materials and penetration physics have enabled systems engineers to design size competitive systems.[68]

System engineers at SAIC have determined that "smart integration of EM gun, EM armor, hybrid electric drive, and a myriad of other electrically powered subsystems will result in a system that will be lighter, more survivable, and cheaper to sustain than its conventional counterpart".[69]

Clearly, this is a complex system integration problem and many technological problems ranging from medium to high risk remain. The following figure depicts both the complexities of the system integration problem and a potential design solution that provides 15 MJ of energy to a projectile.

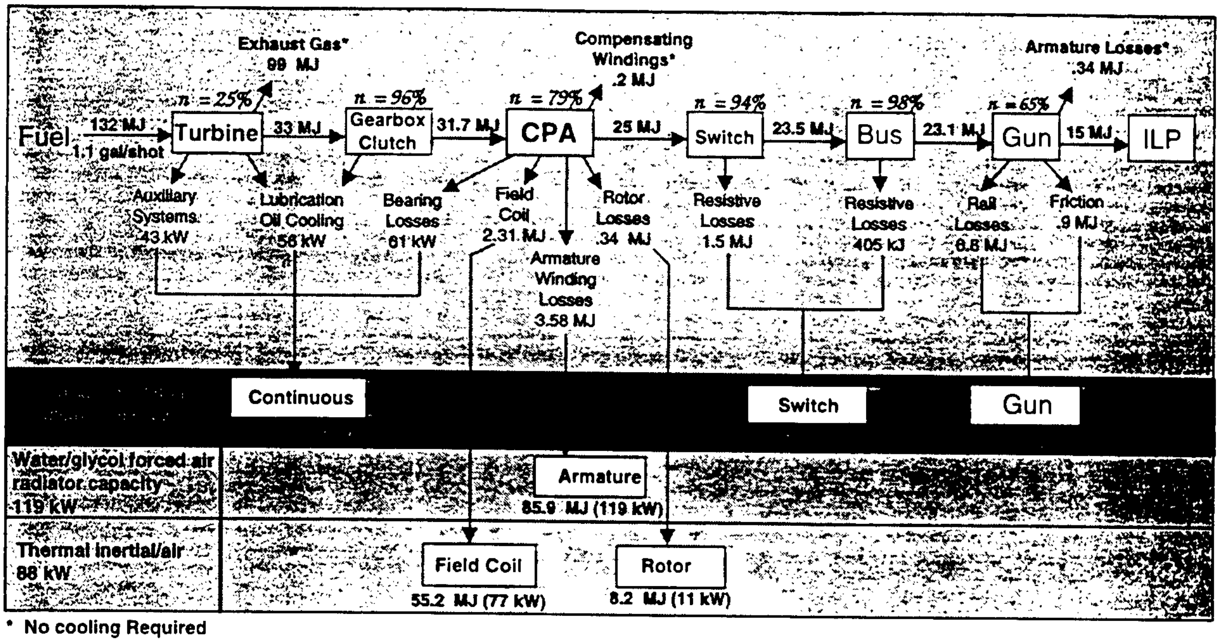

Figure 9. System Energy Flow and Cooling Requirements

A second area of system integration being developed offers the potential for significant power savings during direct fire engagements. This benefit is derived by the system capability to control the power supply provided for each projectile launch. The EMG can adjust its power consumption to match the target and its range. In addition to saving fuel, the most important benefit of controlling power results in the conservation of available electrical energy which may be needed for subsequent shots or for mobility. The extent of these savings and efficiencies can be significant. Figure 10 illustrates the range of savings against MBT and IFV type targets.[70]

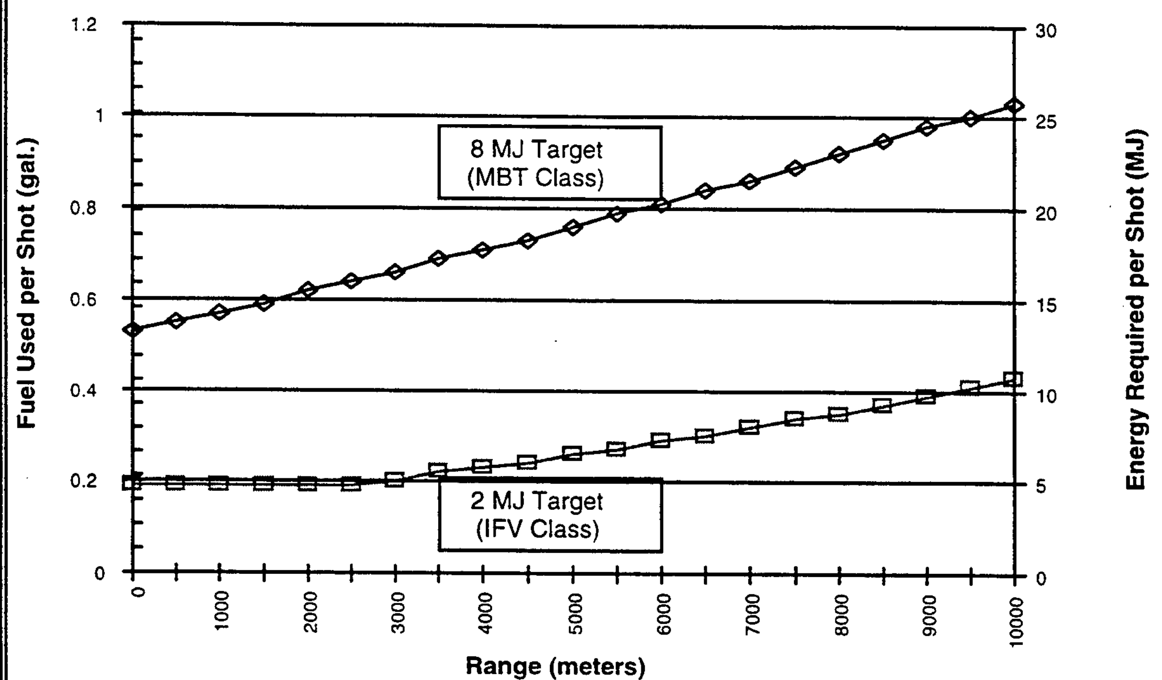

Figure - 2

EML LAUNCH ENERGY AND THE FUEL REQUIRED TO PRODUCE IT

Are Determined by the Range and Projectile Energy Needed for the Target

Figure 10 – EMG Launch Energy

Another important area of systems integration analysis is on going at IAT. This effort, led by Dr. Scott Fish, has developed a simulation tool designed to assess energy requirements for an all-electric combat system. The simulation represents an energy management controller that monitors energy requirements and energy status for a combat system as it conducts various combat mission tasks such as moving and shooting. This tool has demonstrated the potential to assist in design decisions for sizing prime mover and pulsed power energy storage requirements. The basic system architecture represented by this simulation tool is depicted in Figure 11.

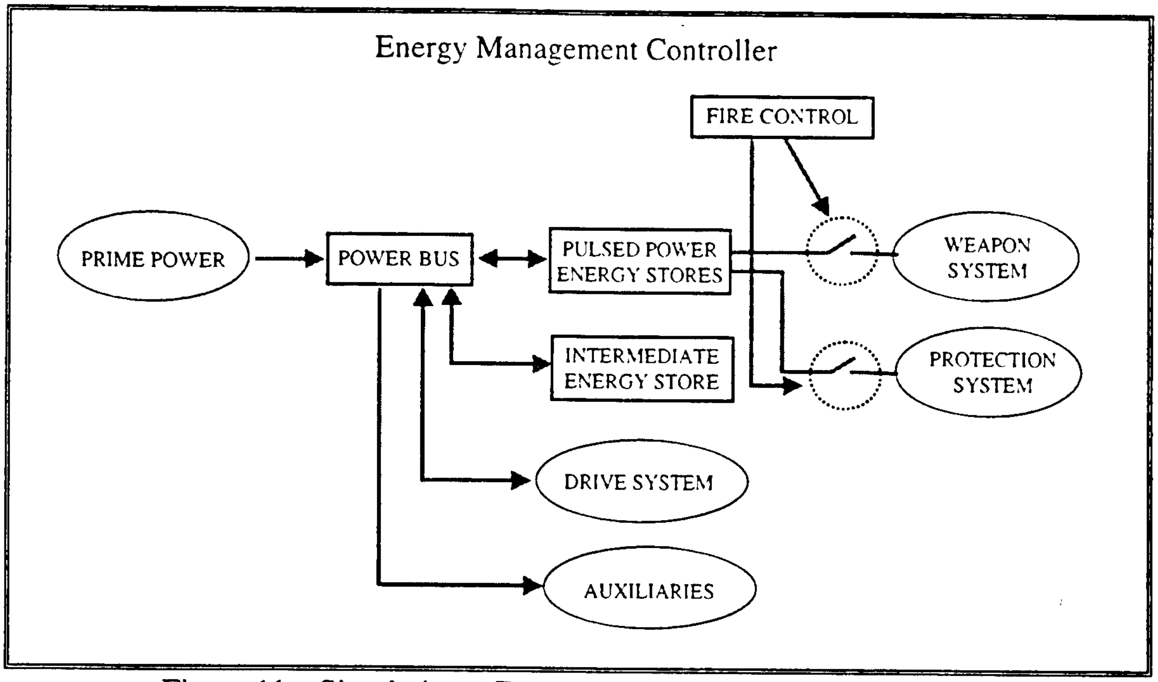

Figure 11 – Simulation – Energy Management System Architecture

Power Supply: Designing a reliable power supply that fits within the constraints of a combat system remains the toughest technological challenge associated with a tactical EMG. Power requirements of an effective combat scale EMG are impressive. For example, if a railgun were just 50% efficient, it would need 8000 MW of power to accelerate an 11.15 kg launch package to 2049 m/s. The power to produce this 23.41 MJ shot is equivalent to the power delivered by four large utility power stations. It is only feasible in practical equipment sizes because the power is only needed for less than 6 millionths of a second.[71]

Progress on the development and design of a practical energy source has been slow and painful. Much work remains to be done. The most promising technology being pursued as a power source is the Compensated Pulsed Alternator – or Compulsator. The compulsator was invented in the late 1970s. By the early 1990s, the EMG Weapon System Program was building a compulsator capable of producing a 21.3 MJ shot. Due to its large size (19.84 tons and 8 m^3)

and impending technological advances, this program was terminated in 1992 when it was approximately 95% complete. Current efforts by SAIC and the University of Texas Center for Electromechanics (CEM) are focused on the design of a compulsator designed to produce a 29.8 MJ shot. This machine is projected to weigh 2.78 tons and occupy just 1.6 m^3.[72]

A subscale version of this machine has been built and has begun testing. Tests undertaken in November and December of 1997 demonstrated power outputs in agreement with theoretical predictions up to 7,500 rpm. These results represented an important milestone because some important R&D players had predicted power output an order of magnitude less than predicted and accomplished. The next major milestone occurred on March 29th 1998, when the sub-scale machine demonstrated the capability to "self-excite" its own magnetic fields at 7000 and 8000 rpm. The test of this machine is schedule to proceed up to 12,000 rpm during the month of April 1998.

Although the subscale system has performed to expectations up to 8000 rpm, problems persist. Despite tremendous efforts, the team of SAIC and CEM has experienced setbacks and the testing phase of the subscale system is now several months behind schedule. Informed sources closely associated with this effort have told me that assembly configuration problems have led to at least two testing malfunctions resulting in minor damage to the subscale system. Budget constraints and schedule pressures have led to a new testing schedule. As a result, the subscale system is being tested before all repairs were made to the system. Despite these shortcuts, the team hopes it will work this time.

- **US EMG Basic Research Programmatics**: The two most significant ongoing efforts to develop the EMG and the Future Combat System (FCS) are part of the DoD and Army Science and Technology plans. The EMG program is defined by the Army Science and Technology Objective (STO) IV.I.13. The FCS program is defined by the DoD Technology Objective (DTO) # GV.02.06.

The EMG program is being managed by ARL and has established the following goals and milestones as part of STO IV.I.13.

- By FY97, complete and test the sub-scale pulsed power compulsator (CPA), perform structural mechanics analysis of ILP candidate
- By FY98, add SOA switching to CPA, perform ILP scale model shoot-off
- By FY99, demonstrate 3 J/g in a pulsed power CPA system mated to an EM gun, enhanced accuracy ILPUs at 7MJ:2.5 km/s launch energy: velocity, with less than 50% parasitic mass and no accuracy barriers, and from a 120-mm XM291.[73]

Additionally, the Institute Executive Advisory Board (IEAB), a DA oversight board for the Electric Armaments program at IAT, established the following FY99 EMG "exit criteria" for transition to Applied Research (6.3) development.

- Defeat an advanced threat armor package with 25% less energy than a conventional 140mm round.
- Show a 7MJ, 2.5km/s launch with greater than 50% projectile mass.
- Demonstrate EMG tube life greater than 100 war rounds
- Demonstrate no accuracy barriers
- The IEAB also specified that the pulsed power supply must demonstrate a 3 J/g capability along with a road map to a 10J/g system. The power supply must also show self-excitation and field energy recovery

Progress on each of these objectives is being made. Some are lagging behind; several are proceeding up to a year ahead of schedule. The potential delays involve the power control switches and problems testing the sub-scale compulsator. Problems relating to the switches and compulsator are likely to lag a year behind the current milestone schedule. Design for a 75mm sub-scale integrated launch package (ILP) is proceeding well. An IAT conceptual design has resulted in a package containing 56% projectile mass.[74] The EMG KE projectile presented in Figure 5 was based on this design.

Dr. Harry Fair, the Director of IAT, reports that the hypervelocity utility program should meet the FY 99 "exit criteria" one year early. Once the exit criteria are met, much work will remain but the most important challenges remain those associated with the weaponization of the power source. A summary of program status is presented in Table 5.

IAT Program Summary

- No show stoppers in following areas:
  - Rail gouging
  - Plasma-arc erosion of rails
  - Selection of materials to satisfy rail life requirement
  - Agreement between experimental data and computations
  - Advanced composite materials for next generation rotor successfully tested to 600 m/s
- Increased understanding of advanced ERA leads to conclusion that:
  - Conventional long rods are very vulnerable to ERA armor
  - ERA is the most serious threat if it can be tuned to any given velocity
  - HV introduced to a battlefield that already has OV weapons, forces a reduction in overall protection level of the ERA
- IAT is close to demonstrating the HV utility exit criteria a year in advance

Table 5 – IAT Program Summary

The current Defense Technology Objective (DTO # GV.02.06) is the Future Combat System (FCS). Approximately $138 million is programmed toward this effort during the period FY98 to FY03. Nearly $70 million of this is programmed during the period FY99-FY01 for the development of mobility and survivability technologies.[75] While these are important technologies, our ability to field a leap-ahead FCS that significantly breaks the trend toward heavier systems relies more heavily on the addition of EMG lethality.

This section of the paper has presented a brief description of U.S. and international accomplishments. These results are a small representative sample of the achievements of several national level programs. Many other significant accomplishments could not be discussed due to the limited length of this paper. Some of these accomplishments include increased understanding of hypervelocity impact physics, railgun wear. hypersonic aero-ballistics, control mechanisms for large electric pulses, recovery of unused electrical energy, design for integrated launch packages, and effectiveness of hypervelocity KE rounds against explosive reactive armor.

Recommendations for Further EMG Investigations: While conducting this research effort, several ideas for further analysis have evolved. These recommendations are offered in an effort to help design a FCS system less than 40 tons. Potentially, the most significant recommendations involve several modifications to the Mission Need Statement for the Future Combat System. The other recommendations include modifications to the physical design of the gun and projectiles. These modifications provide the opportunity to reduce the size of the turret while maintaining the same number of stored kills on-board.

When considered in total, these recommendations and proposed compromises with system design characteristics offer the opportunity to make a significant reduction to system size, weight and power requirements. Obviously, these recommendations need to be subjected to a much more thorough quantitative examination.

- **Modify FCS Operational Requirements:** Much of the current debate concerning direct fire systems is directly related to the weight of these systems. Again, while it is beyond the scope of this study to analyze the requirement for direct fire systems, I can propose for consideration several recommendations that might lead to a lighter FCS than that currently proposed. The current Future Combat System (FCS) Mission Need Statement (MNS) is the US Army Armor Center's requirement statement for meeting the requirement for a direct fire system. In order to meet these robust requirements, recent system designs presented by the Tank and Automotive Command's ARDEC (TARDEC) result in a system that weighs at least 40-70 tons.[76] If not for deployability issues, this system might be very close to the most cost-effective system we could field for the direct fire close combat role.

A summary of FCS requirements from Version 1.2 Draft Mission Need Statement (MNS) for the Future Combat System follows:[77]

- **FCS Lethality Characteristics**:
  - Defeat armored vehicles equipped with advanced ERA and APS
  - Defeat material targets (bunkers, buildings, etc)
  - Defeat aerial systems
  - Defeat exposed personnel
  - Fire on the move at max vehicle speed
  - Destroy non-line of sight targets (including tanks) out to 10 km
  - Automatic target acquisition and identification
  - Automatic fire planning and execution
  - Automatic tracking of multiple targets

- **FCS Survivability Characteristics:**
  - Defeat threat direct fire CE and KE munitions
    - Without reliance on heavy armor
    - Residual effects must not exceed medium caliber projectiles
  - Ballistic protection against medium caliber cannons
  - Defeat smart munitions sensors
  - 100 km/h cross country dash speed

- **FCS Mobility Characteristics:**
  - 100 km/h level cross country dash speed, sustained for 500 meters
  - 70 km/h sustained cross country speed
  - 100 km/h sustained road speed

As AAN capabilities (situational awareness and precision long range fires) become integrated into an effective fighting concept, the opportunity may exist to trade off some of the

FCS requirements described above. The following trade-offs offer the potential to field a lighter FCS for the AAN force.

- Eliminate the requirement for destroying targets out to 10 Km. (Reduces size of required power supply)
- Design a fightable system for a two-man crew. (reduces size and weight of system, thus further reducing size of power supply)
- Reduce the requirement to destroy multiple targets while on the move at maximum speed.
- Re-evaluate the combat utility of 100-km speeds on the battlefield.

When combined, these trade-offs should result in the design of system that is considerably smaller and lighter than the most current designs. The key is to get the system smaller. A smaller system is inherently more survivable, takes less armor to protect and less power for mobility. A significant size and weight breakthrough will occur if we can reduce the crew size and design a system that requires only one engine instead of two. This breakthrough will only occur if trade-offs are made simultaneously across each component of lethality, survivability, mobility and fightability.

- **Dual Use Rectangular EMG Tube:** A second recommendation applies directly to the tube portion of the design of an EMG. Although the exact dimensions of the EMG tube have not been determined, some modeling and experimental data exist to indicate that a rectangular tube will be efficient.[78,79] The following recommendation offers an additional advantage for a rectangular tube.

I recommend that two different sized rounds be developed for the same rectangular EMG tube. The larger of the two rounds is the primary long-range tank killing round. If a 90mm rectangular gun is developed, this round would be integrated into a 90mm integrated sabot package. This round, or ILP, is the same round depicted earlier in Figure 5.

Then second round is a smaller round designed to kill IFV type targets. Because these smaller IFV targets are the most common targets encountered on a typical battlefield, we may be able to replace 50% or more of the onboard rounds with this smaller round.

We have already shown that we can save energy with the launch of an IFV killing round by reducing power and launching the round at a slower velocity. The advantage of using a smaller round is reduced turret storage space for the same number of stowed kills and even less power. A comparison of these two rounds and a very simplified view of required modifications to the tube is depicted in Figure 12.

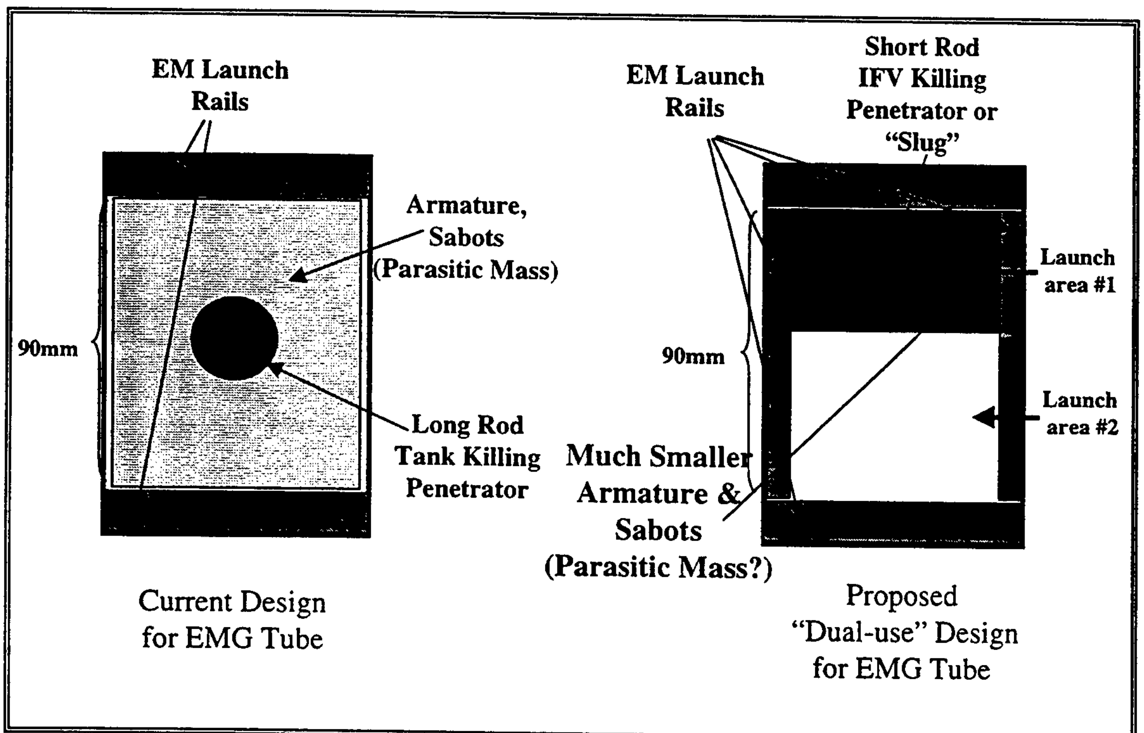

Figure 12 – Alternative Tube Designs for EMG

If this configuration, or something similar, were developed there would be at least two significant benefits. The first comes from the smaller IFV killing round – probably less than 1/6 the size of the tank-killing round. If a high-velocity "slug" round is found effective against IFV targets, the size IFV killing round could be further reduced. A smaller round has reduced volume claims in the turret for the same number of kills (reduced weight, enhanced deployability, reduced power, reduced logistics). Because this design uses three sets of launch surfaces instead of one the potential exists to increase in the life of the tube by at least a factor of three. Drawbacks to this configuration could include increased complexity, cost and tube weight.

Supplemental Recommendations:

Current research efforts in support of DoD and the Army are impressive. The DoD has organized 300 Technology Objectives and the Army has 200 Science and Technology Objectives to focus their research efforts. Based on the survey conducted during this research project, the following supplemental recommendations are offered in an attempt to help focus scarce resources toward technologies in support of the AAN force.

- **Analytical support for the AAN project**. The most important step in this process is to correctly identify the correct operational concepts for our AAN forces. Focus of our technological efforts depends on correctly identifying these new concepts. TRADOC along with its own TRADOC Analysis Command (TRAC) have formed an impressive study team and effort. However, the simulation used to support the tactical wargames in November and December of 1997 were not capable of representing several important aspects of the new concepts and equipment. Examples include inadequate representation of RED counter tactics (use of dispersion, concealment, and ADA) and use of joint forces. Prior to making any decisions concerning an approved operational concept for AAN forces, the AAN study and analysis effort must be given access to a simulation that better reflects the strengths and weaknesses of these concepts.

- **Support for Force XXI technologies.** The physical agility envisioned by the AAN study group depends on the mental agility and situational awareness provided by the Force XXI technologies. We must do everything possible to ensure that Force XXI objectives are achieved.

- **Support for important enabling technologies.** Regardless of decisions concerning AAN operational concepts, we can identify several technologies that have the potential to contribute to increased effectiveness. Two of these promising technologies include improved UAVs and semi-autonomous robotics. Support for many information technologies is also critical. Information management systems with enhanced storage capacity, intelligent content processing, compressed data and data throughput, increased portable computational power and intelligent displays need to remain priority research and developmental efforts.

- **Support for Strategic Mobility.** A national military strategy based on power projection must have the requisite strategic mobility assets. While our strategic air-lift assets (C5 and C17) are the best in the world, they were never designed to fully support large contingency operations. Using current technologies, ship builders report it is now possible to build a new class of very fast ships. These new ships would be capable of hauling 20,000 tons of cargo at 57 miles/hour to a range of 8000 miles.[80] Clearly, such a system would provide a tremendous strategic capability. Even if not used for the first elements of the AAN force, this capability would enhance the strategic effectiveness of legacy forces that will still be around. Peacetime commercial use of this technology would help make this capability cost effective.

Issues and Concerns:

The following comments are not intended to be critical of the ongoing AAN study effort. They are intended to contribute to the ongoing discussion and analysis in an effort to contribute to the current process. As a "fellow traveler", I fully support the efforts of the AAN study group and look forward to a continued dialog with the study team. Full discussions concerning these issues are not possible in a paper of this length but can be addressed later in alternative forums.

AAN operational concept selected prematurely: As evidenced in *the AAN FY98 Study and Research Plan* and high level briefings coming from the office of the SARDA, the AAN study group has already determined the basic operational concept for AAN forces.[81,82] The new AAN Operational Concept is based on an Air-Mechanized force equipped with large tiltrotor aircraft and a new family of 15-ton combat systems.

I believe that this operational concept was decided upon prematurely and that the concept is very vulnerable to several asymmetric threats. Threats such as SOF, highly mobile and dispersed wheeled ADA, and wheeled medium cannon units would be very effective and economical to field against this AAN force. Analytical support for this concept failed to portray several reasonable threat responses to this new concept. The concept was tested in a simulation environment incapable of realistically portraying threat tactics. And finally, the analysis supporting effectiveness of blue systems such as Automatic Protection Systems (APS) and Advanced Heavy-lift Air Frames was overly simplistic and may lead to flawed conclusions concerning very important operational concepts.

There is another aspect of this concept that should concern the Army. If the concept is approved, I expect the Air Force to say that the AAN Air-Mechanization concept and its use of long-range precision fires is a great concept. They will also present impressive evidence that the Air Force can already perform this mission. Since the Air Force already has this capability, there will be no reason to develop and procure the AAN force. Support for the Air Force solution will be significant due to the huge cost savings.

Overreliance on Active Protection System Technology (APS): The evolving AAN air-mechanized concept depends on the development and fielding of a new class of 15-ton combat systems. These systems depend on a combination of situational awareness, rapid tactical maneuver, low-observable technology and APSs to provide survivability. Briefly, once detected, these systems rely on a thin layer of passive armor to protect against small arms and the APSs to protect them against larger threats.

APSs effective against ATGMs have already been developed and fielded. In fact, a Russian and German joint venture is currently marketing an APS. Furthermore, APS experts predict that an effective system against KE projectiles may be developed in the future. However, the consensus of over 50 of the US government's leading experts on APS agree that an effective APS will never be developed against medium caliber high rate of fire systems.[83]

Medium caliber automatic cannons (25mm and 30mm) are already among the most prevalent weapons on the battlefield. Armed with the intelligence that US systems were vulnerable to medium caliber cannons, we should expect potential adversaries to procure many of these types of systems.

Before committing new systems to this design for survivability, a realistic assessment concerning how the system will survive against medium caliber cannons, artillery shrapnel and the residual components of ATGMs and KE rounds after they are "shot out of the air" by the APS needs to be conducted.

Self-deployment: An AAN goal is the deployment of the AAN force to theater in 120 hours (5 days).[84] This goal becomes possible if AAN airframes can self deploy to theater while carrying the new lightweight combat systems. Claims that AAN systems self deployed during the Leavenworth Tactical Wargames cannot be replicated in a European, SWA or Korean Scenario. During the Tactical Wargames, the force leapfrogged to a fictitious land mass placed (created) in the middle of the Atlantic. The AAN force reached this fictitious landmass after refueling in Bermuda.

CONCLUSIONS:

We are too early in the AAN process to select a warfighting concept or make specific system decisions. As this research suggests, we can focus a portion of our research and development efforts on two technologies that have the potential to provide leap-ahead capabilities, regardless of the operational concepts approved via the AAN process. Each of these technologies is high risk. I am confident, however, that if program decisions are made now, we can field these leap-ahead capabilities in the 2020-2025 timeframe.

Support for the creation of automated decision-making tools may require the initiation of a new program to build the links between Force XXI systems and appropriate automation tools. The fielding of an automated system such as that envisioned in the OSD ABIS system will ensure we effectively leverage investments and information obtained through the current digitization and Force XXI initiatives. Finally, this investment will better ensure that information dominance envisioned in JV 2010 and AV 2010 will result in revolutionary changes in US Military capabilities as opposed to evolutionary changes.

The Army After Next program has identified "Knowledge and Speed" as important characteristics for AAN forces. Because of deployment and support considerations (speed), it is imperative that we field a more lethal direct fire system at reduced weight. This research paper has compared the potential benefits of other lethality enhancements and has determined that EMG technology offers the best opportunity to meet both these needs. It is the only technology under development that offers a survivable and lethal close system solution at reduced weight. Because this technology has great potential to produce important benefits to the AAN force, the program must receive more support and resources on a priority basis. In particular, and most importantly, program support for weaponizing the power source must be increased. Although still considered high risk, much progress has been made. If the program is properly energized, we have nearly 20 years to solve the remaining technological problems and field an effective leap-ahead system.

Finally, the TRADOC AAN study group should be commended for their ground-breaking work and efforts aimed at developing future operational concepts. Looking forward 20-25 years and predicting the best use of available concepts and technologies is a tremendous challenge. It is also a very important challenge and task.

I hope that the two recommendations presented in this paper, along with several issues and concerns, will receive appropriate consideration from the study group. I look forward to the opportunity to participate in a continued dialog and contribute to this effort as a fellow traveler wherever possible and appropriate.

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