ARMY SCIENCE BOARD

Report of the Fiscal Year 2019 Study

An Independent Assessment of the Next Generation Armor/Anti-Armor Strategy

Phase 1: 5th Generation Combat Vehicle Concept and Analysis

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EXECUTIVE SUMMARY

In January 2019, the Secretary of the Army (SECARMY) requested the Army Science Board (ASB) conduct a study entitled "Next Generation Armor/Anti-Armor Strategy" (NGAAS). SECARMY served as the study sponsor and laid out the following objectives:

1. Examine emerging threats, operational concepts, and doctrine necessary to defeat massed armored formations considering the capabilities of the Army's next generation combat capabilities.

2. Assist the Army's senior leadership in developing an understanding of next-generation combat vehicle architectures, technologies, and the tradeoffs between them that support the development of next generation anti-armor strategies.

3. Recommend appropriate investment strategies to field next generation armor combat capabilities.

This report describes the conduct of the study, discusses the threat to the currently fielded U.S. armor platform, the M1 Abrams series tank, addresses the relevance of tanks in current and future warfare, discusses analytical assessment of the M1, offers a conceptual framework for the M1's replacement, and provides a framework for a pre-acquisition technology development program. A comprehensive briefing describing the study in detail was adopted by unanimous vote of the ASB membership in July 2019.

The study team assembled for this study has a broad range of both technical expertise and operational experience pertaining to armor and anti-armor operations. The team made over 20 consultations with Army and other organizations actively involved in the current and future development and employment of armored vehicles.

The study team used the emerging operational concept of Multi-Domain Operations (MDO) as an operational backdrop for future armor operations. Though all near-peer competitors were considered, the team focused on threats to the Baltic States in the 2035-2040 timeframe to focus discussion and analysis.

In developing a concept of the role of armored systems (for the sake of simplicity, a tank) in future ground conflict, the study team identified many important questions:

- What are the technical and operational threats to tanks and armored platforms?
  - What can be learned from conflict in Ukraine and Syria?
  - Considering emerging Russian capabilities and doctrine, what are the threats to the M1 that may reasonably exist in the future?

- Are tanks needed for future warfare, or can their task set be accomplished by other means?

  - What might the battlefield of 2040 look like?
  - Can battles or wars be won through the destruction or servicing of "targets"?
  - How does the U.S. Army move combat power into and around the theater of operations?

- If tanks are needed for future warfare, can the M1 series provide the required capability?

- If the M1 cannot provide the required capability, what capabilities may be needed in 2040? Are robots able to provide that level of capability?

- How does the past trajectory of tank development inform capabilities required in future generation armor systems?
  - What capabilities make a next-generation combat vehicle better than the M1 and fielded threat systems?
  - What is meant by generations of ground combat vehicles?

- What is the technology program to develop a leap-ahead approach to a future system?
  - What is the current level of development and maturation of relevant technologies?
  - What worked or failed in past major platform acquisition programs?
  - How should the development effort be organized?

- What is the analytical framework to assess effectiveness?

In executing its research plan, the study team addressed most of these questions. For example, there are many systems and munitions in the U.S. inventory capable of destroying adversary tanks, such as missiles, Apache gunships, close air support, anti-tank guided missiles (ATGMs), and artillery fire to name a few. However, the act of destroying targets alone cannot win wars. Winning wars requires the offensive capability to compel an adversary to yield to the will of the U.S. In fact, the study steam concluded that historically successful concepts and doctrine at the tactical and operational levels emphasized combined arms maneuver – the ability to close with and destroy the adversary over contested terrain while leveraging the full capabilities of the combined arms team.

The study team acknowledged the role of increasing reliance on firepower for both the U.S. and potential, near-peer adversaries. In its final analysis, it concluded that future warfighting concepts, doctrine, and materiel solutions must maintain the capability and capacity to execute combined arms maneuver. Therefore, a ground combat vehicle will be needed in the future, but the M1 has too many technical deficiencies and operational vulnerabilities to provide the necessary maneuver capability on future battlefields with confidence of success. Threat capabilities continue to improve while the M1 approaches the end of its growth capacity. The M1A2 System Enhancement Package (SEP) v3 approaches 80 tons in weight, challenging not only the U.S.' ability to deploy it but also its ability to maneuver on the tactical battlefield (Fig. 1).

Figure 1. Threats to M1 Abrams Tanks

A new ground combat vehicle is required, and the team identified ten design considerations where technology development can coalesce to deliver a potential leap-ahead capability. These considerations, grouped into three categories (Fig. 2), have the potential to restore overmatch to the U.S. Army:

- Core Capabilities
  - Mobility
  - Firepower
  - Protection
  - Command and Control

- Enduring Considerations
  - Reliability and Maintainability
  - Human Factors

- Vital 5th Generation Technologies
  - Computing enhanced with Artificial Intelligence (AI)
  - Masking
  - Networks
  - Robotic systems integration

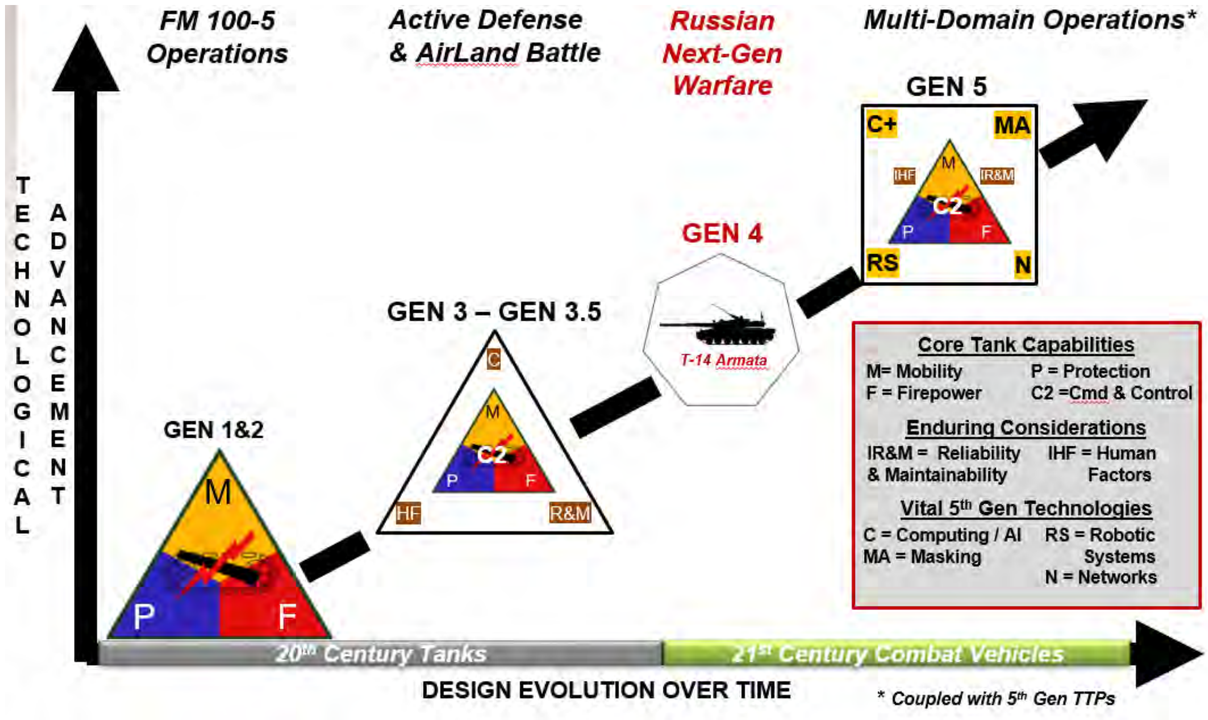

Figure 2. Direct Fire Combat Vehicle Evolution

Future ground combat vehicle designs must continue to focus on mobility, firepower, and protection, coupled with the demand for ever-improving command and control capabilities. These considerations are what have distinguished the tank from all other systems and have been hallmarks of ground combat vehicle design for the better part of a century. The synergy of these four considerations form the core of the tank's capability; all the remaining design considerations serve to enhance the effectiveness of that capability. In addition, future designs must deliver improvements in reliability, maintainability, and human factors engineering. These improvements must come through technologies not available during the 1970s-1980s, when the last generational designs were developed.

The study team's analysis of vital 5th generation technologies concluded that four additional design considerations must be forthcoming to deliver a generational leap-ahead. They include development and fielding of improved networking capabilities, coupled with the incorporation of design features that allow the 5th generation combat vehicle (5GenCV) to command, control, or otherwise leverage the robotic systems envisioned for the future battlefield. Equally important, the study team concluded that surviving on the future battlefield requires combat vehicles and formations to mask their presence and reduce their targetability. Accordingly, the study placed great emphasis on the ability of designers to find substantial improvements in all forms of signature reduction, to include thermal, electro-optic/infrared (EO/IR), electromagnetic (EM), acoustic, and others.

Decisively, the study team concluded that augmentation from advanced computers is imperative for 5GenCVs and their crews to execute both crew duties and mission tasks with a high level of success. Accordingly, the study team concluded that, as a prerequisite for any design of a 5GenCV, requirements authorities should determine in detail all computational requirements needed for successful operation. This includes applications for AI; fire control; automotive and component diagnostics and prognostics; onboard assured position, navigation, and timing (PNT); protection systems; masking systems; target recognition; robotic system employment; and sensor capabilities.[1] The larger point remains, however, that 5th generation designs will demand on-board computing power that leverages decades of exponential improvement in computing speed, capacity, and data integration beyond what exists in the current tank. Moreover, the next ground combat vehicle's computers require the ability to capitalize on rapidly improving processor technology, allowing the force to upgrade computers as frequently as home computer users.

The demands of vehicle computational power are so critical to the successful deployment of the 5GenCV that it will require a radical departure from how tanks were previously designed. Once all the computational and internal network requirements are understood, platform designers and system integrators must focus their efforts to design the vehicle around the internal computer network. The study team acknowledges that this is a radical departure from previous design methodologies, but the team also strongly believes that the pace and acceleration of technological advances in all aspects of tank warfare demand nothing less.

Developing and integrating such an array of technology creates opportunities for risk and program failure. Therefore, the study team conducted a historical review of the main battle tank (MBT)-70, XM-803, M1, Armored Systems Modernization (ASM), Future Combat System (FCS), and Ground Combat Vehicle (GCV) programs to inform the framework of a technology program and to identify successful practices. In particular, the study team's investigation of the M1's development was a central feature of the study effort and yielded several important insights.

First, the M1 program did not depend on any technological breakthrough for the platform's successful development. Although industry, the Army, other government agencies, and Allies all contributed technologies, sub-systems, and components to the final development, what is striking is that both competing contractors offered major technologies, subsystems, and components known to work before incorporation in the final, platform-level design. Only proven and demonstrated technologies found their way into the designs. For example, the Chrysler team offered the AGT-1500 turbine engine, while General Motors' competitive prototype used the AVCR-1360 diesel power pack. Both solutions were proven to meet all system requirements and specifications.

Second, the M1 program did not seek to include the best of every new technology available at that time. As a point of fact, the Chief of Staff of the Army admonished the program manager not to include every "bell and whistle" they could, to keep it simple, and not to try to build the

[1] This listing is not intended to be all-inclusive.

best tank incorporating the most advanced technology possible.[2] Rather, they were instructed to build the best system Soldiers could learn to use, be comfortable with, and be confident in operating. That guidance reduced the per-unit cost that proved fatal to the MBT-70 program and avoided the reliance on breakthroughs that felled the FCS. The M1 Abrams was a tank built for the 1980s but developed in the 1970s using 1960s technology.

Accordingly, the study team believes the Army should develop a 5GenCV following a methodology similar to the M1's development. All technologies, prototyping, sub-system development, and component testing should be proven with high levels of confidence that they will work before attempting to integrate them into a platform-level design. This contention forms the basis upon which the study team recommended the creation of a series of testbeds[3] to mirror the design characteristics it believes are essential to the development and fielding of a 5GenCV. In formulating testbed recommendations, the team considered current and planned research and development (R&D) efforts within the Army (Fig. 3).

Subject	Specifics	Cost	Duration	Comments
Core Capabilities				
Mobility	Hybrid-Electric	$450M	5 Years	Multiple Platforms
Firepower	Autoloader & Gun	$625M	5 Years	Turret Integration (Includes Initial Design)
	Advanced Munitions	$300M	5 Years	GLATGM, Hypersonics
Protection	APS; Adv. Armor; Underbelly	$320M	4 Years	Integrated, Layered Suite
C2 and Network	C2 and Network Capability	$180M	3 Years	Leverage Related Ongoing Activity
Enduring Considerations				
Reliability & Maintainability	Prognostics and Analytics	$50M	5 Years	Integration into C2 Systems Reliability Analysis
Human Factors	2&3 Man Crew Enablers	$50M	3 Years	Operational Architectures
Vital 5th Generation Technologies				
Computing	AI Applications	$85M	3 Years	Platform Integration
Masking	Vehicle Test	$60M	5 Years	Platform Integration
Robotics	Wingman, RSV	$150M	5 Years	Multiple Platforms Remote and Autonomous Ops
Testbed Subtotal		**$2,270M**	**7 years**	
Competitive Systems Prototyping		**$700M**	**4 years**	
Testbed and Prototype Program Totals		**$2,970M**	**7.5 years**	

Figure 3. Recommended Testbeds

These considerations, the guiding research questions, and the objectives set by SECARMY led to the study team's findings (Fig. 4) and recommendations (Fig. 5).

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[2] Kelly, Orr, King of the Killing Zone, W.W. Norton & Company, New York, 1989, p. 133.

[3] In line with DoD 500-series definition of testbeds, they would have some, not necessarily all, of the actual hardware that will comprise the system. Testbeds typically provide a great deal of the system evaluation information used during the middle part of a systems development cycle.

1. Russian “New Generation Warfare” and emerging Chinese capabilities have contributed to a new U.S. operational concept, Multi-Domain Operations. The threat and MDO require a 5th Generation combat vehicle that is significantly more capable than current systems.

2. The Russians have demonstrated the following in their operations in Ukraine in both open and urban environments:

- Tanks dominate close combat. More tanks were killed by other tanks than other anti-armor weapons.
- Increased anti-tank weapon lethality
- Massed precision and area fires
- Cyber and Electronic Warfare
- Employment of UAVs

3. Threat analysis (Ukraine lessons learned, T-14 development, Russian modernization, Scenario 7, etc.) assist in determining the essential requirements for a new system.

- The threat helps to establish the need for armor as part of a combined arms force.
- Reducing weight and improving reliability will have the effect of reducing the sustainment tail and strategic lift requirements. Reduced weight also allows air movement of small numbers of 5th generation combat Vehicles for limited contingency operations.
- M1A2 SEP v3/v4 tactical mobility is challenged in Eastern Europe
- Advanced ATGMs, top-attack, and emerging KE are future protection problem.
    - i. Unmanned turret mitigates several issues (crew protection, silhouette, weight, mobility)
    - ii. Integrated CE/KE/EFP hard & soft kill active protection systems improve protection

4. The M1 is approaching the end of its product improvement cycle.

- All product improvements add weight to an already too-heavy vehicle.
- There is inadequate space and power for computational capability to accommodate modern information systems.

5. As during the start of the M1 development program, the current Army tank development program is behind the Russian development program. The potential inability of the Russians to produce in quantity its prototypes offers the US the opportunity to move beyond their advancements. However, the Russians are upgrading existing vehicles with technology proven by their prototyping activities. Threat analysis (Ukraine lessons learned, T-14 development, Russian modernization, Scenario 7, etc.) assist in determining the essential requirements for a new system.

6. The technology base to support the development of a 5th generation combat vehicle is not sufficiently mature to begin EMD (Milestone B).

- Critical Component and Systems technology have not reached TRL 6.
- Current analytics capability is insufficient to develop employment concepts and assess supporting hardware approaches.

7. This study group believes that the precedent set with the development of the M1 offers the best approach for development of a 5th Generation combat vehicle.

- Critical component development maturation and competitive system prototyping before commitment to system acquisition (Milestone B).
- Doctrine development conducted in parallel with hardware activity
- Conducted in parallel with current systems product improvement

Figure 4. Study Team Findings

1. A 5th generation combat vehicle technical program should follow precedent set by M1 program.
   - 6-8-year pre-acquisition program
   - $2B to complete technical maturation; $3B to complete technical maturation and competitive systems prototyping.
   - Experimentation for both component and system prototyping
   - Red Teaming employing national intelligence capabilities
   - Program balances initial cost and time with reduced risk, time, and money savings post-Milestone B (EMD).

2. Army Futures Command (AFC) should manage the pre-acquisition effort employing the approach used by the M1 pre-acquisition program.

3. AFC should, in parallel with the pre-acquisition effort, determine the requirement for the 5th Generation combat vehicle informed by (among other considerations) the above technical effort. This team believes a stand-alone activity should be established for this effort. This effort should include an analysis of alternatives (AoA).

4. Any program to establish the technology base for a 5th Generation combat vehicle should ensure a competitive industrial base.

5. The Army should, as it did in the pre-acquisition program for the M1, look outside the Army for technology that would further the capabilities of a 5th Generation combat vehicle. It should investigate technical areas (e.g. energetics, materials, modeling, and simulation) where increased investment would significantly improve the development and employment of a new vehicle.
   - Allies (Israel, Great Britain, France, Germany, South Korea, Japan)
   - Department of Energy
   - Industry / Commercial Sector
   - DARPA

6. DARPA should be engaged to help the Army explore high risk technology advancements and assist in assessing technical characteristics of the future battlefield. MOUs and programs between Army and DARPA are already in place.
   - Information Science
   - Robotics
   - Smart Munitions including Hypersonics
   - Artificial Intelligence

Figure 5. Study Team Recommendations

1. INTRODUCTION

This study was intended to inform Department of the Army leadership on a potential decision to replace the M1 Abrams tank with a next-generation combat vehicle. In 2017, the ASB began identifying and assembling subject matter experts to support the effort.

1.1 TERMS OF REFERENCE (TOR)

In consultation with SECARMY and the Deputy Under Secretary of the Army (DUSA), the ASB's office of administrative support, subject matter experts developed initial parameters for the study terms of reference (TOR). Once the intent of the study was clearly established, three broad objectives were established to provide the study team with sufficient leeway for investigation:

1. Examine emerging threats, operational concepts, and doctrine necessary to defeat massed armored formations considering the capabilities of the Army's next generation combat capabilities.

2. Assist the Army's senior leadership in developing an understanding of next-generation combat vehicle architectures, technologies, and the tradeoffs between them that support the development of next generation anti-armor strategies.

3. Recommend appropriate investment strategies to field next generation armor combat capabilities.

In short, the TOR directed the study team to identify threat armor capabilities, identify how to defeat those capabilities, understand and explain the emerging technologies relevant to next generation armored vehicles, and provide a recommendation on investments needed to field those capabilities.

To meet these objectives, the study team was assigned supporting tasks:

a. Assess relevant emerging threats, operational concepts, and doctrine.

b. Determine how organizations will fight with new technologies.

c. Suggest next-generation combat vehicle and supporting system design parameters.

d. Investigate ways to increase lethality, improve survivability, and address strategic, operational, and tactical mobility while also reducing sustainability demands across all next generation combat capabilities.

e. Report on other factors and considerations as deemed appropriate.

The TOR was signed by then Secretary of the Army, Dr. Mark Esper, on January 4th, 2019.

1.2 STUDY TEAM AND VISITS

To address the TOR tasks, the ASB selected study team members with the expertise and experience in the following areas (see Appendix B):

- Armor and Mechanized Operations
- Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR)
- Directed energy systems
- Metallurgy and Materials Science
- Mechanical Engineering
- Program Management
- Logistics
- Signal Processing
- Vehicle and System Protection
- Doctrine
- Computer Engineering
- Operations Analysis
- Systems Engineering
- Physics
- Ground Combat Systems Programmatics
- Military History

In addition, several team members were retired Army officers with significant operational experience in major conflicts from Viet Nam to the current counter terrorism operations. Study team members were also directly involved in previous major armored vehicle development programs, to include the M1, FCS, and GCV.

Data gathering efforts included individual research conducted by study members as well as visits and interviews with organizations involved in armored vehicle development and operations, including:

- Ground Vehicle Systems Center (GVSC, formerly TARDEC)
- C5ISR Center
- Aviation & Missiles Center
- Armaments Center
- Army Research Laboratory (ARL)
- Data and Analysis Center (DAC, formerly AMSAA)
- National Ground Intelligence Center (NGIC)
- Missile & Space Intelligence Center (MSIC)
- Center for Army Analysis (CAA)
- The Potomac Foundation
- Maneuver Center of Excellence (MCoE)
- Defense Advanced Research Projects Agency (DARPA)
- Engineer Research & Development Center (ERDC)
- Army Geospatial Center
- Space and Missile Defense Command (SMDC)
- National Training Center (NTC)
- Army Combined Arms Support Command (CASCOM)
- Next-generation combat vehicle Cross-Functional Team (NGCV CFT)
- Program Executive Office Ground Combat Systems (PEO GCS)

The study team also reviewed previous ASB reports on pertinent subject matters, including Tank Modernization (1998), Full Spectrum Protection of 2025 Era Ground Combat Vehicles (2000), Future Armor Anti-Armor Competition (S) (2016), Disruptive, Innovative Concepts for the Future Army (2016), Robotic and Autonomous Systems-of-Systems Architecture (2016), Manned Unmanned Teaming (2018), Multi-Domain Battle (2017), and Multi-Domain Operations (2018).

1.3 BACKGROUND

In the late 1990s and early 2000s, the confluence of several events served to slow the U.S. military's development of heavily armed and armored direct fire ground combat systems. First was the "peace dividend" following the end of the Cold War in 1992. Second was the Army's transformation to a lighter "Objective Force" in 2000. Third was the protracted Global War on Terror, which prioritized current combat operations over future modernization efforts.

Subsequently, the Army initiated but later canceled several projects to replace the M1 tank, including FCS (started in 2001 and canceled in 2009 due to cost overruns, schedule risk, and technology risk) and the GCV Program (a successor to FCS, canceled in 2013 for similar issues).

While the U.S. was at war in the Middle East, Russia initiated its own modernization programs to field new tank capabilities and modernize its existing fleet. As a result, U.S. overmatch in the area of armored vehicles has been significantly reduced.

To regain its overmatch in armor, the U.S. must take steps to prepare for the development of next-generation combat vehicles that not only meet this challenge but provide true leap-ahead capability. The future battlefield promises to be dominated by sensors and firepower enhanced by AI systems, all of which will serve to contest the Army's ability to conduct maneuver. To preserve its ability, the Army will require a 5th generation, direct fire, ground combat system capable of closing with and destroying its near-peer competitor's most lethal and advanced ground combat systems.

2. THREAT ANALYSIS

The most critical required capabilities of armored fighting vehicles (AFVs) – those related to system survivability and lethality – are threat driven. For decades, the capabilities of U.S. Abrams MBTs, particularly with respect to protection and firepower, have been considered superior to those of any potential adversary. But that comparative, competitive advantage has eroded in recent years as a result of intensive Russian tank modernization efforts and continuing advances in the lethality of anti-armor weapons (Russian systems as well as those of other countries). Thus, the study team focused on the armor/anti-armor threat environment presented by Russian capabilities, but the team considered other peer and near-peer threats, e.g., China's similar and improving capabilities.

Critical threats to U.S. armored combat vehicles include the advancing capabilities of modernized Russian MBTs, as well as various types of highly effective anti-armor weapons, ranging from large-caliber kinetic energy (KE) penetrators, to longer-range ATGMS, artillery, rocket-propelled grenades, and anti-tank/anti-vehicular (AT/AV) mines. Non-kinetic threats such as electronic warfare and cyberattack exacerbate threats to U.S. AFVs.

As recent operations in Ukraine and Syria demonstrate, Russian armor/anti-armor capabilities present a significant challenge to the combat effectiveness and survivability of the most capable Abrams tanks in future ground combat operations. For example:

- Russian modernization efforts have effectively addressed Western strengths and weaknesses revealed through U.S. military operations over the last 10-15 years.

- The Russian Ground Force is now a far more professional and capable force than the Soviet Red Army.

- Russian ground forces continue to rely on their traditional, proven reconnaissance-fire (tactical) and reconnaissance-strike (operational) loops, but they've been modernized to provide more lethal and effective Anti-Access/Area Denial (A2/AD) capabilities intended to help prevent the close fight.

  – The modernized recon-fire and recon-strike loops integrate reconnaissance assets (unmanned aerial vehicles (UAV), signal intelligence (SIGINT), electronic warfare (EW), and radar systems); weapons systems (artillery, multiple rocket launchers, mortars, ATGMS, cruise missiles); and Command, Control, Communications, and Computers (C4) capabilities to attack and defeat adversary targets beyond line-of-sight (BLOS).

  – Integrated tactical and operational air defense systems can effectively engage airborne and extended-range missile threats.

  - Artillery and air defense missiles outrange and outnumber corresponding U.S. systems.

- Operations have deployed experimental robotic combat vehicles and BLOS operational fires under combat conditions to establish proof-of-concept for continuing development.

- Russian armor has played a major role and proven to be highly effective in executing operations in urban environments.

Long a leader in the development and production of MBTs, Russia's current force includes T-72, T-80U, and T-90 series tanks (Fig. 2.1). Modernization efforts over the last 10-15 years have improved the capabilities of these fielded systems in many areas, including mobility, protection, lethality, fire control, and situational awareness. The T-90A includes a soft-kill active protection system (APS).

T-72B3 MBT

T-90A MBT w/Shtora APS

Figure 2.1 Russian MBTs

An even more capable Russian tank, the T-14 Armata, is under development. It will feature significant advances with respect to both protection and firepower, including new explosive reactive armor (ERA), a combined soft- and hard-kill APS, an improved main gun firing more capable KE rounds and gun-launched ATGMs, and more effective signature management. Overall, Russian tank modernization efforts and new systems developments are significantly enhancing their capabilities compared to U.S. armored formations.

Figure 2.2 Armata T-14 MBT

As part of its anti-armor weapons arsenal, Russia is developing advanced KE munitions that will provide improved accuracy, effective range, and armor penetration. For now, ATGMs pose the greatest threat to U.S. armored platforms as they are highly effective and steadily improving. The weapons class includes gun-launched missiles (GLATGMs), tube-launched ATGMs fired from other supporting AFVs (e.g., variants of the BMP-3 infantry fighting vehicle), and man-portable systems. Fielded Russian GLATGMs, the Svir and Invar laser beam rider systems, have effective ranges of about 5 km, with extremely high probability of hit. New GLATGMS known to be under development include a longer-range missile (Sprinter) and a dive-attack system (Sokol), expected to enhance end-game lethality. The varied tube launched ATGMs fired from other Russian AFVs have significantly greater ranges while maintaining a high hit probability, and they exhibit greater armor penetration. Notable examples of these weapons include the Konkurs/Konkurs-M, Kornet/Kornet-EM, and Khrizantema missiles. Man-portable systems include Fagot/Fagot-M and Metis/Metis-M. ATGMs are also launched from both fixed-wing and rotary wing aircraft. An interesting and novel man-portable tube-launched system under development is the Flomaster system, which features a KE warhead rather than the typical unitary or tandem shaped-charge (TSC) warheads, but it’s unclear whether this system will ever be fielded.

The capabilities of many Russian ATGMs exceed those of the best fielded U.S. systems (TOW-2B Aero RF, Javelin, etc.), although in principle, most ATGM threats can be defeated by a highly capable (integrated soft/hard-kill) APS. The U.S. does not currently have such a system. The Israeli Trophy APS has recently been installed on a limited number of U.S. Abrams tanks, but it cannot provide the full capabilities of an integrated soft- and hard-kill system. Overall, the Russian ATGM systems are diverse and operationally flexible (Fig. 2.3). Armor penetration capability for such systems ranges from about 550mm to more than 1200mm of rolled homogeneous armor equivalent (RHAe) steel, with some TSC warheads exhibiting a high level of lethality behind ERA.

Khrizantema Launch from a BMP-3 Variant

Konkurs Mounted on Motorcycle

Mi-28N (HAVOC) Helicopter with Ataka

Tripod Launch of a Fagot-M

Figure 2.3 Russian Tube-Launched ATGM Systems

Russia's extensive artillery capabilities also present a significant threat to U.S. armored formations. Artillery fire has long been a critical combat support element for Russian ground forces. Their systems include 122-mm, 220-mm, and 300-mm multiple rocket launcher systems (MRLS) with effective ranges of as much as 90 km; towed and self-propelled howitzers with ranges of over 70 km (Fig. 2.4); longer range missiles under development; and high rate-of-fire mortar systems with maximum ranges of 7-20 km, depending on the type of rounds fired. These systems feature a wide variety of warheads, including high-explosive (HE), HE-fragmentation (HE-FRAG), thermobaric, shaped-charge cluster munitions, and sensor-fuzed submunitions. The combined effects of Russian artillery fires can severely degrade the combat effectiveness of targeted ground forces, as demonstrated in the Ukraine conflict.

122-mm Tornado-G MRLS

152-mm 2S19 Msta-S Self-Propelled Howitzer

Figure 2.4 Russian Artillery Systems

Tanks and other U.S. AFVs are also susceptible to Russian RPGs and AT/AV mines. RPGs are effective short-range weapons, typically shoulder-launched from concealed or covered positions, making them particularly effective in urban operations. The RPG-7, featuring several warhead variants, is Russia's most common system and is used by numerous countries around the world. The RPG-29, a longer-range 105-mm system, is currently the most capable fielded Russian system. The RPG-30 is a developmental system specifically designed to counter adversary AFVs having a hard-kill APS capability. The lethality of these weapons is continually improving, and future RPGs will likely have capabilities currently found only in ATGMs.

Anti-tank mines have long been an effective element of ground combat operations, and they continue to present a significant threat to the tactical mobility and survivability of U.S. armored combat and support vehicles. Russia has one of the largest and most varied AT/AV mine inventories in the world; its mine warfare capabilities far exceed those of U.S. systems. Most Russian mines are designed to attack the tracks, wheels, or underbelly of adversary AFVs, but some fielded off-route systems are specifically designed to attack the sides and top of passing targets. Russian mine warfare capabilities also include systems designed to attack low-flying helicopters.

In summary, Russia continues to improve its armor/anti-armor capabilities, while also bringing capable threats in other domains to the battlefield. The proliferation of Russian systems ensures these threats will be encountered around the world, in other than peer-to-peer conflicts. The continual upgrading of M1A2 capabilities cannot overcome the ever more challenging threat to its survivability and lethality posed by Russian (and other nations') advances; nor can it mitigate tactical and operational mobility limitations. This ongoing, stressing threat environment provides the most compelling motivation for development of a highly capable next-generation combat vehicle.

3. DIRECT FIRE GROUND COMBAT SYSTEMS

3.1 DEFINITIONS

To ensure clarity, the study team adopted three terms to describe the 5th generation, direct fire, ground combat system:

1. Direct fire ground combat vehicle – a generic term for a vehicle/system that combines the core capabilities of mobility, firepower, protection, and command and control which is focused on the direct fire, close combat tasks of the Army.

2. Tank – the current direct fire ground combat vehicle; M1A2 SEP v3/4.

3. 5GenCV – not necessarily a tank; the team was careful not to presuppose the form of the next generation direct fire ground combat vehicle.

3.2 THREAT IMPLICATIONS FOR THE CURRENT TANK FLEET

The previous section laid out many of the systems that threaten the viability of the current tank, as well as the overall threat to the Army based on both Russian and Chinese technology. In simplified terms, some combination of threat systems will come together to challenge U.S. ground forces' ability to maneuver on the battlefield (Fig. 3.2.1). They will be applied to the entire friendly combined arms team, not just against tanks, simultaneously (despite the sequential depiction below) to find, fix, track, attack and exploit friendly forces.

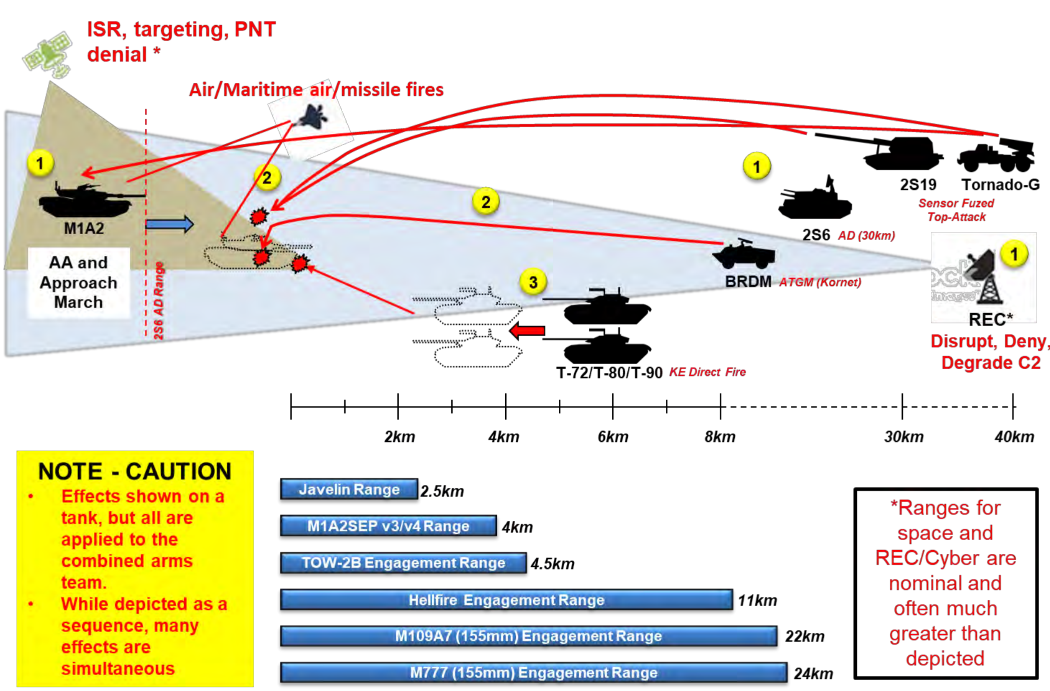

Figure 3.2.1 Simplified Threat Contact Continuum

U.S. tanks in an assembly area or on an approach march to the line of departure, which is where the direct fire fight/close fight begins, have no ability to directly affect adversary systems until they get to the close fight. They are targeted by adversary space, EW, and cyber systems, allowing adversary long-range precision fires (ground, air, and maritime) to attack while simultaneously degrading or jamming communications and satellite based PNT. The threat fires are often top-attack systems focusing on the most vulnerable and least protected part of the tank. Adversary air defense prevents or severely degrades friendly air support, and long-range adversary systems are outside the range of friendly counterfire.

Once tanks cross the line of departure, these systems continue to attack, now adding long-range ATGMs to the mix. As the attrited friendly force closes on the adversary defensive positions, adversary tanks begin to engage with KE rounds, compounding the challenge of protecting the U.S. tanks.

Assuming the threat systems achieve some level of success, the tanks are unable to communicate effectively with other tanks and the rest of the combined arms team due to jamming. Thus, the tanks and the rest of the combined arms team are unable to conduct a synchronized and coordinated response to the adversary.

A key point: the challenges posed by threat systems cannot be solved by the direct fire ground combat vehicle alone. It must operate within a combined arms team where complementary and reinforcing capabilities work synergistically to defeat an adversary combined arms team. The solution must include a direct fire ground combat vehicle. It is necessary, but not sufficient.

There are four broad categories of threats to the tank that, when combined with the M1A2's limitations, seriously impact and degrade its effectiveness (Fig. 3.2.2).

Figure 3.2.2 Challenging Threats to Abrams

1. The M1A2's weight seriously degrades both operational and tactical mobility. Its operational mobility is hampered because it is too heavy to be transported by rail cars or heavy equipment transporter (HET), and its tactical mobility is compromised by its inability to use many bridges. Furthermore, the increased ground pressure makes cross country mobility more difficult, especially in wet conditions. Given the various capabilities and their associated weight added to the system over the tank's lifecycle, there's little the Army can do to decease the M1A2's weight enough to address these challenges (Fig. 3.2.3).

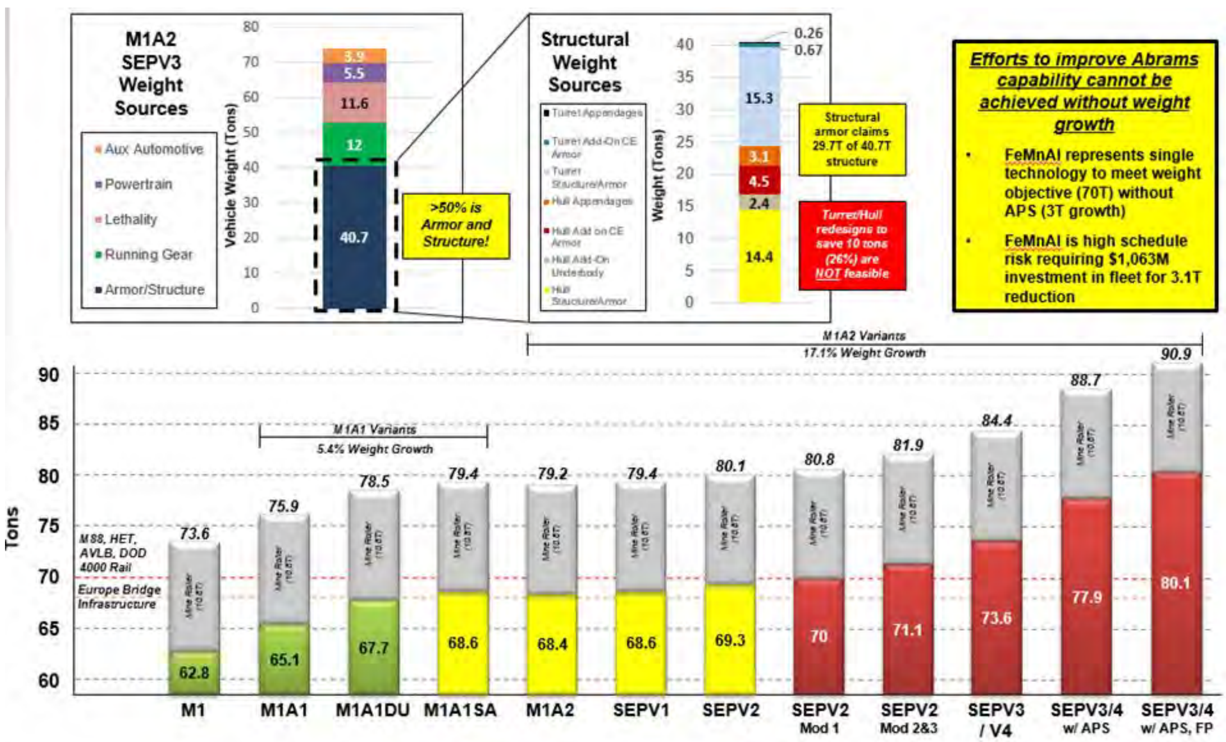

Figure 3.2.3 Abrams Weight Growth

2. Russian tanks with improved APS and ERA are beginning to degrade the effectiveness of current U.S. KE and chemical energy (CE, or shaped charge) rounds, threatening the Army's current overmatch in firepower.

3. Threat ATGMs and artillery with top-attack capabilities and sensor-fused systems pose a serious threat to U.S. passive armor. The proposed APS improvements can do little to counter threat top-attack munitions.

4. Adversary radio electronic combat (REC) and cyber capabilities will seriously compromise friendly command and control, degrading U.S. capabilities to fight as a combined arms team.

Current and proposed upgrades to the M1A2 may mitigate some of these limitations, but they cannot solve them. Ironically, many of the proposals for upgrades add weight to the system.

3.3 WHY THE ARMY NEEDS A DIRECT FIRE GROUND COMBAT SYSTEM

The Army's mission as part of the Joint force requires it to maintain direct fire ground combat systems (Fig. 3.3.1).

Tasks Directly Related to the Direct Fire Ground Combat System

(from DODD 5100.01, Army Doctrine, MDO Concept Paper)

- Conduct **combined arms operations** as part of a joint and/or multinational force.
- **Dominate the close fight** to isolate, defeat or destroy enemy forces
- **Defend friendly land**, populations and resources,
- **Occupy, control, exploit, and retain enemy land** and secure their populations/resources

To Do the Above, the Army Requires a Force that Must:

- **Cross contested ground** to eject an enemy, or
- **Defend ground** to prevent an attacking force ejecting the Army from it.

This requires a system that can move, survive, and kill any enemy system it encounters – *a direct fire ground combat vehicle* with the following core capabilities

- **Mobility:** The ability to move cross country as ***part of a combined arms team***, in most ground environments.
- **Firepower:** The ability to destroy all of the enemy's ground systems
  - A higher rate of fire of tank killing rounds than any other system
  - More stowed anti-tank kills than any other anti-tank system
  - The ability to fire accurately on the move
- **Protection:** The ability to survive better than any other vehicle against all current and projected enemy systems ***when operating within a combined arms team.***
- **Command and Control:** ability to fight as an integrated part of the combined arms team

Figure 3.3.1 Necessity for a Direct Fire GCV

As the land component of the Joint force, the Army is charged to "conduct combined arms combat operations…to defeat adversary ground forces and seize, occupy and defend land areas." To fulfill that mission, the Army has stated, as part of its long-standing doctrine, that success necessitates "the ability to prevail in close combat," which includes the direct fire fight. More recently, in response to potential adversary A2/AD operations and other emerging threats, the Army has developed the MDO concept, which states the Army "penetrates and dis-integrates adversary A2/AD systems and exploits freedom of maneuver…." Thus, the study team believes the Army's traditional requirement for a mobile, well protected ground combat vehicle with sufficient lethality to destroy comparable adversary systems will endure for the foreseeable future.

The study team's analysis of the Army's missions, doctrine, and concepts led to the identification four critical tasks related to the direct fire ground combat vehicle:

1. Operate as part of a combined arms team and Joint and/or multinational force

2. Dominate the close fight to isolate, defeat, or destroy adversary force

3. Defend friendly land, populations, and resources

4. Occupy adversary land and defend it from counterattacks

Direct and/or indirect fires alone cannot dislodge a determined adversary from territory it occupies. Friendly land forces must be able to cross ground defended by the adversary and, when necessary to hold that position, they must be able to defeat an adversary force crossing that ground. Crossing and defending contested ground requires a direct fire ground combat vehicle with an appropriate balance of critical capabilities: mobility, firepower, protection, and command and control.

Mobility and command and control capabilities are found in many other weapons platforms, including systems capable of killing tanks, such as aviation assets and artillery. The firepower and protection capabilities distinguish the direct fire ground combat vehicle from other tank killing systems in the force. In particular, the firepower capability provides a unique combination of stowing many more rounds capable of defeating adversary tanks and the ability to fire them rapidly while on the move during an assault.

Thus, the direct fire ground combat vehicle is essential to crossing contested ground against a defending adversary force. However, the study team determined the Army’s current system, the M1A2 SEP v3/4, has the following limitations:

- It weighs too much for effective operational and tactical mobility and any serious attempt to reduce the weight would essentially require a new vehicle design.

- Its limited growth potential means that while incremental improvements in firepower, protection and C2 can be made, they only mitigate some of the emerging threats, but do not solve any of them.

- It cannot take advantage of many emerging technologies that can address its shortcomings, nor can it take advantage of technologies that may arise in the near- to mid-term.

- As a result, the M1A2 will shortly be unable to maneuver on the battlefield, which puts at risk the ability of the force to maneuver and accomplish the Army’s assigned tasks.

A 5GenCV, designed from the ground up, can take advantage of 50 years of technology that has evolved since the M1 series originated. These technologies can be integrated from the start to leverage man-machine interfaces, trade-off passive armor based on more effective ERA and APS systems, include top-attack protection, and implement AI-aided processes, all of which have the capability to vastly improve firepower, protection and C2 while restoring tactical and operational mobility. Since growth potential has been a key factor in the development of the Abrams, it must be planned and included from the beginning to ensure the 5GenCV will be able to take advantage of emerging and as yet unforeseen technologies developed during the service life of the platform.

4. ANALYTIC ASSESSMENTS

The study team conducted a series of analyses to gain insight into technological advances in the Army laboratories and development centers by setting certain goals and then examining combinations of technologies into two conceptual variants of a future 5GenCV. An underlying assumption was that, given adequate funding, these technologies would be sufficiently mature in 2028 to permit entering EMD. Through this process, the study team identified which technologies would be highly leveraged on a future battlefield and which would have little impact.

The study team's analyses did not constitute a full-blown AoA, but the scope produced a proof of concept. The analyses also provided insights regarding the M1 capability by contrasting capabilities of 5GenCV concepts to both the U.S. M1 and advanced Russian tanks.

Both Measures of Performance (MOPs) and Effectiveness (MOEs) were identified for selected technologies. For example, MOPs for Detection, Recognition, and Identification (DRI) for U.S. 3rd generation (GEN 3) FLIR were computed under different visibility conditions and different combat postures. The DRI were also computed for Russian FLIRs under the same conditions. MOEs included loss exchange ratios, which were computed for the concept variants and different M1 configurations when confronting Russian advanced tanks in Army combat models.

Key agencies contributing to the analytic effort included:

- Ground Vehicle Systems Center (GVSC) – prepared concept variants with the help of the ARL, ARDEC, and AMRDEC

- Data and Analysis Center (DAC) – provided analyses of MOPs and MOEs of selected technologies incorporated into the concept variants with assistance of NVESD

- Center for Army Analysis (CAA) – produced a large-scale simulation of a specified scenario which included cases for analysis of the concept variants and two versions of the M1

- Engineer Research and Development Center (ERDC) – provided terrain analysis

The agencies used existing models and simulations, all of which have been verified and validated (V&V) by the Army, but the combat simulations have limited capabilities to capture MDO concepts, particularly those with non-kinetic effects.

4.1 TERRAIN ANALYSIS

A portion of the study effort was allocated to terrain analysis of northern Europe, to include ERDC's analysis of the cross-country mobility of the M1A2 under both dry and wet conditions (Fig. 4.1.1). During the wet season, cross-country mobility is significantly restricted. A similar analysis was performed for the study team's two conceptual variants, which had a ground pressure of 12-13 pounds-per-square-inch (psi) versus the M1A2 ground pressure of 22 psi.

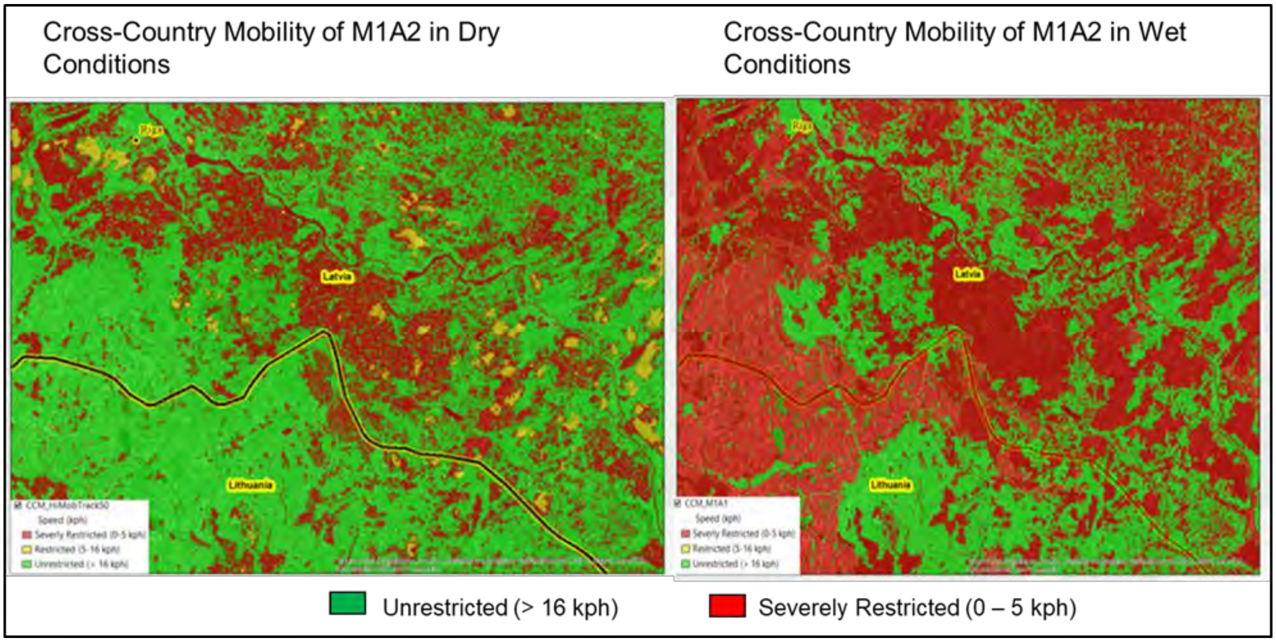

Figure 4.1.1 Cross-Country Mobility of the M1A2

From a tactical perspective, a defending force could mine trafficable routes, destroy bridges, and/or employ artillery to further complicate combat operations during the wet season.

ERDC also performed line-of-sight (LOS) analysis for the region. In over 20 selected positions, LOS was frequently in excess of 5 km. In the northern portion of the region, LOS was nominally restricted to less than 2 km.

Using data gathered from maps prepared by the former Soviet Union, ERDC also examined bridge classifications in the region and tree diameters for possible transition of wooded areas.

4.2 COMBAT SIMULATIONS OBSERVATIONS

For the analysis, GVSC prepared two concept variants for a 5GenCV. Study team members provided the following general guidance for consideration:

- Consider both a two- and three-man variant; crew in the hull with man-accessible turret

- Lethality:
  - Greater lethality than current 829A4 120 mm round
  - Extended range munition (gun fired or hyper velocity missile)
  - Target acquisition GEN-3 FLIR, pre-shot detection, hostile fire detection

- Survivability:
  - Improved, lighter weight armor (e.g., FeMnAl)
  - Active protection system
  - Top-attack protection, where feasible

- Mobility:
  - Latest innovations in propulsion (e.g., hybrid electric drive)
  - Improved track (e.g., band track)

- Size and weight goals:
  - Three-man concept variant at 55 tons
  - Two-man variant at 45 tons
  - Euro rail transportable
  - C-17 transportable

- Sustainability – A goal of at least 50% fuel savings over the M1A2

GVSC models met or exceeded each of the study team's parameters.

Both DAC and CAA performed analyses of the two concept variants, and the scope of the analysis was expanded to include two versions of the M1A2: SEPv3 and SEPv4.

DAC performed a series of analyses that included the following cases:

- Variations in terrain

- U.S. forces in offensive and defensive postures

- Different visibility conditions

- Alternative Russian force structure (Russian tanks and Russian tanks with infantry employing the Kornet anti-tank guided missile)

DAC staff used their model "Ground Wars" for force-on-force analysis and performance models such as NVESD NVTherm for FLIR analysis. They also represented different technologies which might contribute to a 5GenCV, including:

- Adaptive armor (included placement locations of vehicles)

- Thermal signature reduction (treated parametrically to represent effects of 'masking')

- Improved accuracy of KE rounds (current KE rounds are of limited effectiveness at longer ranges)

- Larger caliber gun (only limited improvements possible with current gun and overmatch is critical)

- Longer range ammunition (the M1 is currently outranged by Russian gun launched guided missiles)

In a similar manner, CAA used the Joint Integrated Contingency Model for their analysis. The time frame for the analysis was the late 2020s. The NGIC was unable to provide sufficient technical data on the Russian T-14 Armata tank to support quantitative analyses, so the examination was based on variants of the T-90 tank, which was considered to be the most capable and prevalent tank in the Russian force for that time frame. The results of CAA's analyses are available in the classified annex.

Together, these analyses indicated that regaining land dominance is possible. With loss exchange ratios from less than 1-to-1 with current systems, the lighter-weight concept vehicles outfitted with advanced technologies favorably improved loss exchange ratios by an order of magnitude.

4.3 ARMY ANALYTIC AND MODELING & SIMULATION (M&S) CAPABILITIES

During the analytic process, the study team observed the following:

Observation #1: Army analytic organizations have begun to address modernization options using existing tools. DAC, CAA, and GVSC are working closely together to evaluate design options and assess lethality and survivability. These organizations provided outstanding concepts and analyses to materially assist the study team. Insights gained will help provide recommendations regarding critical technologies for a 5GenCV and exemplars for future AoA.

Observation #2: Army combat models have extremely limited capabilities to address non-kinetic effects and capabilities needed in MDO. These capabilities include but are not limited to:

- Communications networks
- Unmanned systems integrated with combat forces
- Masking
- Directed energy systems

The DAC analyses were based on ground force capabilities and did not capture the full extent of MDO (e.g., artillery, Air Force and Army Aviation, Space assets, cyber, and EW). Nor did they reflect the potential contributions of organic robotic vehicles. Furthermore, certain technologies such as masking and directed energy have yet to be technically assessed in realistic environments and/or models that accurately portray their contributions.

Observation #3: Increases in lethality required the ability to address human factors issues relating to a reduced crew size. For example, larger caliber guns may require autoloaders, but current M&S does not adequately capture the impacts to human factors performance when crew size is reduced. There are opportunities to modify existing virtual trainers such as the Close Combat Tactical Trainer (CCTT) to 2- and/or 3-man crews. The modification would allow investigations on how best to configure crew compartments, optimize crew combat efficiencies, and determine performance impacts. Until such actions are taken, the physical and mental demands on the crew in a 5GenCV will not be well understood. How will AI assist the crew? What cognitive load (or possible overload) can be expected by introducing unmanned systems? Will a smaller number of crew members be able to perform the requisite duties (e.g., maintenance and security) in austere environments over protracted periods of time? To answer these questions, experiments need to be performed using adaptations of virtual trainers. For example, crew performance could be evaluated using OneSAF scenarios.

Observation #4: The Army should take advantage of advances in M&S being employed by commercial industry such as model-based systems engineering, physics-based models, and high-performance computing. Moving from concepts, such as the ones used in the study team’s analyses, to more technical designs is a major challenge. The Army needs to leverage advances in M&S to field a 5GenCV by 2040.

5. 5TH GENERATION COMBAT VEHICLE

5.1 THE BATTLEFIELD OF 2040

Based on analysis of current Russian and Chinese weapon systems and developments, the study team made a set of predictions regarding the battlefield in 2040 to aid in visualizing challenges that U.S. ground force formations may be required to deal with and overcome:

1. Long-range precision fires and high volumes of long-range fires will potentially dominate the battlefield. Russia and China currently enjoy numerical overmatch over U.S. forces, and that numerical overmatch will continue. In addition, the increased precision of both conventional and guided artillery munitions will challenge U.S. armored and unarmored systems with varied, effective, and lethal fires. The combined capabilities present potential adversary forces with the ability to saturate the battlefield with fires from positions of relative security, forcing U.S. formations to respond with a combination of dispersion, constant movement, and establishing cover for protection.

2. Adversary fires capabilities will be enhanced by networked sensors across the breadth and depth of the battlefield. These sensors will provide redundant identification and detection in the visual, non-visual (infrared and thermal), acoustic, and electronic spectrums. Increased capabilities and density of these sensors will shrink or remove sanctuary areas while providing higher resolution targeting capability.

3. Developments in narrow AI have the potential to streamline and accelerate the fires kill chain. An AI network could have the ability to categorize threats, select an available delivery system, select an appropriate munition, compute firing data, and send the firing data with the fire command to a delivery system within seconds. Adversary commanders will likely reduce constraints on the kill chain, potentially enabling fires systems to engage targets upon detection with little or no human oversight.

Combined, these three elements form a lethal and responsive fires complex that will challenge or negate U.S. maneuver on the battlefield. At its most effective, any U.S. system that can be seen or emits across any spectrum will be detected, automatically targeted, engaged with precise or high-volume fires, and destroyed. Anything that can be seen will be targeted, anything that can be targeted will be hit, and anything that can be hit will be destroyed. Without a solution to address this precision fires equation, the U.S. will lose the ability to conduct maneuver without suffering unacceptable losses and the Army will be left with only a fires solution to the battlefield. To maintain its requirement for mobile striking power and conducting maneuver, the Army requires a ground combat system that will be able to move and maneuver on the battlefield.

5.2 COMBAT VEHICLE GENERATIONAL EVOLUTION

The evolution of direct fire combat vehicles can be described in terms of generations, where new periods are marked by platform-improving performance features resulting from major advances in design, technology, and systems. Generational shifts occur when a technological innovation cannot be incorporated into an existing platform through upgrades and/or retrofits, so a new platform emerges. Historical trends demonstrate that new generation platforms outperform older generations.

In the evolution of direct fire combat vehicles, the capabilities were defined by the available technology. As technology advanced, generational shifts increased capability (Fig. 5.2.1).

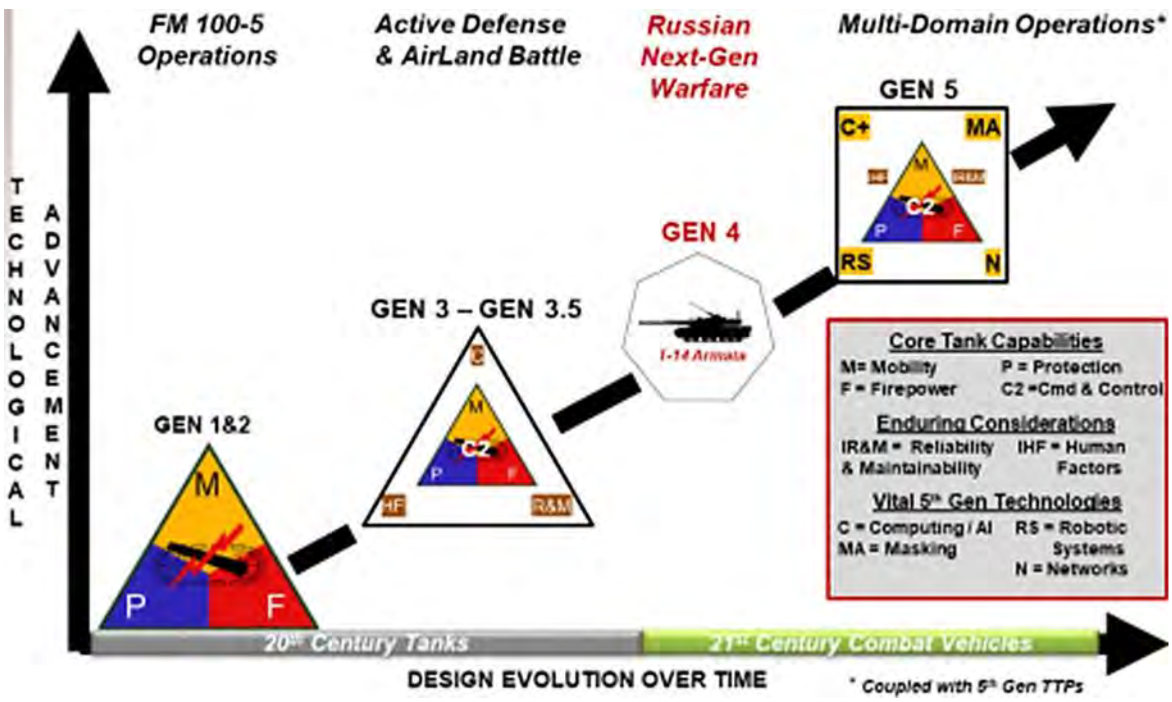

Figure 5.2.1 Direct Fire Combat Vehicle Evolution

The M48 Patton Tank typified the U.S. first generation, post-Korean War MBT. Its capabilities were narrowly defined in terms of mobility (M) provided by tracks for off-road movement, protection (P) from rolled homogeneous steel armor, and firepower (F) from a large caliber 105-mm cannon.

The M60 Patton Tank epitomized second generation tank capabilities, enhancing MPF with survivability on a nuclear/chemical contaminated battlefield, and a rudimentary fire control system that provided improved firing accuracy while stationary. The second generation was also delineated by nascent, night-fighting capabilities in the form of infrared (IR) spotlights.

The M1 Abrams tank marked the third generation, adding capabilities in:

- Human factors, where the crew compartments and functions were designed with ergonomics analysis to increase the effectiveness, survivability, and endurance of the crew.

- Computing power in the form of a digital fire control system that enabled the tank to compute accurate ballistic solutions out to 2400 meters and fire while on the move.

- Reliability and maintainability by designing mechanical components to increase the crew's ability to conduct maintenance and repairs in austere environments, reducing the manpower and man-hour demands on mechanics.

- Protection enhanced by the introduction of composite armors in combination with rolled homogeneous armor that defeated all kinetic and chemical energy penetrators then fielded by the Soviet Union.

- Firepower enhanced through digital fire control and the introduction of advanced night vision and thermal optics linked to the cannon's fire control.

- Mobility improved with the turbine engine and upgraded suspension system.

Each successive generation of tanks facilitated the execution of an operational framework or capstone concept, e.g., AirLand Battle, MDO, etc. The doctrine defined the role of the tank and informed its design.

Generations one and two were designed and fielded from 1944 through the 1970s under the framework of FM 100-5 Operations, which required tanks to support infantry and the rest of the combined arms team. Tanks were considered the centerpiece for combined arms warfare and required to mass, maneuver rapidly, break through defenses, strike deep into the adversary's rear, and win decisive battles. To compensate for the U.S.S.R.'s numerical superiority, U.S. commanders were to use firepower to overcome adversary numbers.

The third generation was designed to fight under the concepts of Active Defense and AirLand Battle. Active Defense required tanks to fight outnumbered against a superior U.S.S.R. forces and win an elastic battle of attrition. Covering forces would trade space for time while forces in the main battle area concentrated to defeat the Soviet main attack. AirLand Battle required tanks to lead the U.S. offensive while the Air Force and long-range fires destroyed oncoming Soviet echelons in depth. With its excellent mobility, long-range accuracy, penetration capability on the move, and nearly impregnable armor, the M1 was suited for both concepts.

In many ways, Soviet tank development paralleled U.S. developments: the T-55 was the U.S.S.R.'s first generation tank; the T-64 was the second generation, and the T-80 and T-90 were 3rd generation.

Both the U.S. and U.S.S.R. enhanced their third-generation platforms through upgrades and modernizations. The upgrade programs improved their respective tanks to the point that they became significantly more capable than the tanks as originally fielded. For example, the M1A2 improvements included a 120mm cannon replacing the M1 105mm, upgraded armor, and digital systems to integrate the tank as part of the combined arms team. While these improved platforms were more capable than their third-generation predecessors, a generational shift did not occur, and these platforms are more correctly referred to as generation 3.5.

Recently, Russia claims to have developed and fielded a fourth-generation tank, the T-14, because it uses the latest technologies and design to compete on the modern battlefield. The most significant departure from their third-generation tanks include:

- Robotics to produce an unmanned remote turret
- An armored capsule to increase crew survivability while reducing weight elsewhere
- The integration of active protection systems

The T-14, developed with a new design philosophy and technologies, is intended to gain overmatch against current U.S. third-plus generation systems and enable conventional military action in Russia's New Generation Warfare doctrine. By employing tanks in limited numbers as part of a Battalion Tactical Group (BTG), technological superiority is intended to cancel an adversary's numerical advantage, and Russia's transition from a massive conscript force to a smaller, more professional contract force requires greater levels of crew survivability.

Responding to the Russian 4th generation combat vehicle, the study team concluded that if the U.S. merely produces its own version of a 4th generation combat vehicle, it will prove costly and not produce the degree of overmatch desired for the 2040 battlefield. The situation is not unlike that faced by the U.S. during the Cold War, when Army Gen Donn Starry recognized the importance of employing technology to level the battlefield:

> It must be the role of technology to provide weapons systems which render ineffective costly investment by our foes—not simply to try to match something the other fellow has just fielded...With new weapons we should seek new dimensions of combat...Technology should seek to make battle outcome less, not more calculable. Instead of restoring some balance to the neat firepower score equation we should introduce new imponderables into the traditional calculus of battle.[4]

To render Russian developments ineffective and to introduce uncertainties into adversaries' calculus of battle, the U.S. can leverage technology to leap-ahead past the 4th generation to a 5th generation direct fire combat vehicle.

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[4] Remarks delivered to the American Defense Preparedness Association Conference on Combat Vehicles, Fort Knox, KY, 18 Sep 1986.

5.3 THE 5GENCV

A 5GenCV moves across the 2040 battlefield, destroys the adversary with direct fire and maneuver, and plays a central role in the execution of MDO. To better understand the 5GenCV, the study team divided capabilities and technologies into three categories:

1. **Core Tank Capabilities** are those capabilities that define a direct fire ground combat vehicle, of which the tank has been the primary manifestation, consisting of mobility (M), firepower (F), protection (P), and command and control (C2). They reflect the vehicle's ability to shoot, move, communicate, and survive on the battlefield. For the U.S., the only platform in which all four capabilities reside is the M1 Abrams MBT.

    - Mobility is the vehicle's ability to move off-road in all but the most restrictive terrain with high dash speed and endurance to match the rest of the combined arms formation. The vehicle is capable of being recovered with like vehicles or recovery assets, can utilize existing tactical bridges and civilian infrastructure, and can be operationally redeployed using rail or heavy equipment transporter trucks.

    - Firepower is the vehicle's ability to detect, identify, engage, and destroy any adversary ground system at long-range and on the move with high levels of accuracy while maintaining a large number of stowed kills and a high rate of fire.

    - Protection is the vehicle's ability to withstand strikes from adversary kinetic energy and chemical energy rounds on the front glacis, defeat ATGMs and other antitank systems with active protection systems and protect the crew from sensor-fuzed top-attack munitions.

    - Command and Control refers to the crew's ability to fight the individual vehicle within the direct fire fight, fight as part of the combined arms team in the direct fire fight, and fight while leveraging all other elements of the combined arms team to include indirect fires. The crew can function and continue fighting in contested environments and under conditions where the vehicle's capabilities are degraded due to adversary fire or system failure.

2. **Enduring Considerations** are not tied to any one specific technology or capability. Rather, they are present in vehicle design and serve to increase the effectiveness of the vehicle's core capabilities. These enduring considerations are human factors and reliability and maintainability.

    - Human Factors are the physical design decisions that enhance the crew's ability to fight through intuitive man-machine interfaces and the ergonomics that support crew comfort and endurance while simplifying and easing routine tasks. Examples of this are positioning of crewmembers, control panels, switches, and access panels within the vehicle or the simplicity and responsiveness of displays and controls.

- Reliability and Maintainability: reliability is defined as the mean time between mission hardware failure; maintainability speaks to the ability of the crew and support units to repair and maintain the vehicle in austere environments while limiting demands on all classes of supply.

3. **Vital 5th Generation Technologies** are the emerging technologies that, if properly matured and integrated, have the potential to produce leap-ahead capability. These include computing (with AI), masking, networking, and robotic systems.

   - Computing could employ AI and assured PNT to accelerate crew tasks, mission planning, and mission execution. Instead of designing a ground combat vehicle and then putting computers inside of it, the vehicle is designed around the onboard computing network.

   - Masking combines technologies that could reduce the vehicle's visual, thermal, infrared, acoustic, and EM signatures to reduce detectability. It also refers to systems that reduce an adversary's ability to accurately target the vehicle following detection.

   - Networks enable the vehicle to connect to and leverage the broader warfighting information network. This may include assured voice and digital communications, non-satellite dependent PNT, providing on-demand and relevant information from all information systems and Intelligence, Surveillance, and Reconnaissance (ISR) platforms to the crew, and leveraging the cyber domain in a contested environment.

   - Robotic Systems leverage external and connected systems and sensors and exercise C2 over supporting unmanned systems. The vehicle could have the future capacity to interface with and command robotic systems which have yet to be developed.

5.4 THE 5GENCV IN COMBAT

The study team postulated a scenario around how an attack may develop involving a 5GenCV (Fig. 5.4.1). For clarity, the scenario did not include other components of the combined arms team.

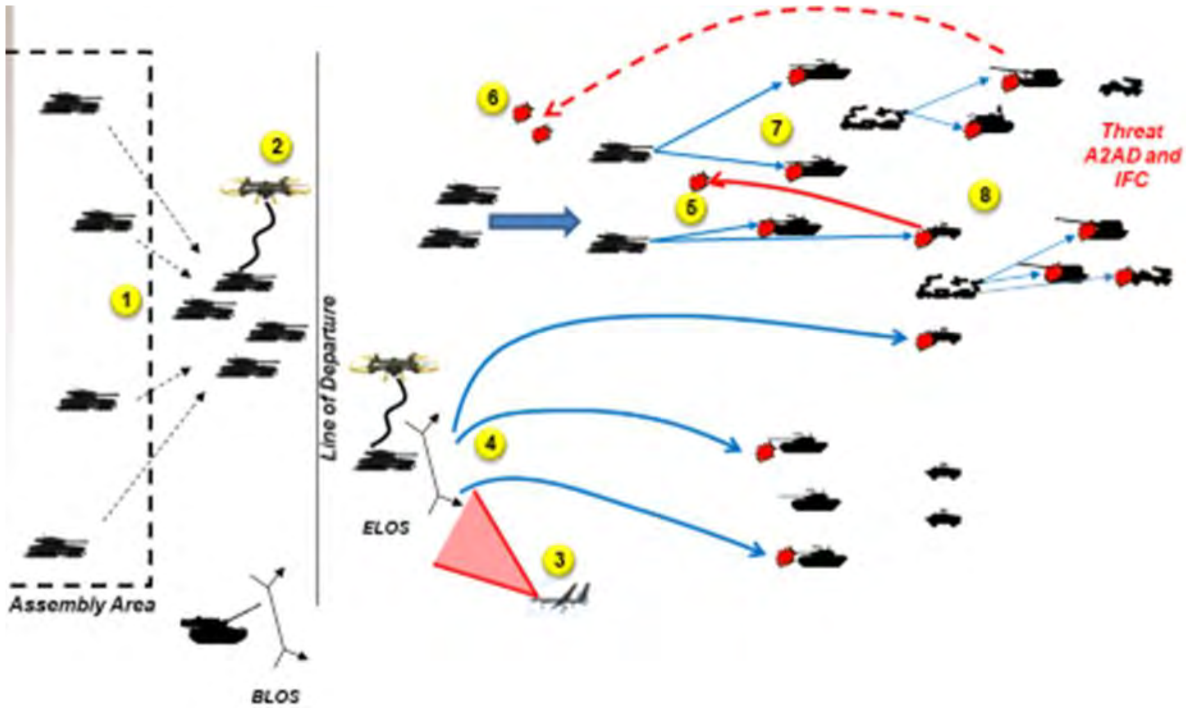

Figure 5.4.1 The 5GenCV in MDO

The U.S. formation starts off dispersed to reduce its visual, cyber, and EM signatures. Ground combat vehicles receive their operations and mission orders via an onboard C2 suite that provides them with relevant overlays, threat information, and operational graphics. The element's company commanders and platoon leaders use their C2 systems to rapidly produce and securely disseminate plans to leaders within their formations. Onboard PNT and AI systems immediately begin analyzing the terrain to recommend the most covered and concealed routes past the line of departure to their rally points. Upon the order to execute, drivers navigate using overlays on their heads-up displays and Integrated Visual Augmentation System (IVAS) goggles, rapidly moving to their rally points and assault positions without getting lost or disoriented.

Once the vehicles arrive at their final covered and concealed position, they're able to employ unmanned systems to look over the horizon and identify threats, fighting positions, and confirm routes without having to expose themselves to adversary observation and fires.

Assuming adversary forces have deployed arrays of sensors and UAVs as part of their defense, these assets actively hunt for the U.S. formation by scanning for visual signatures and EM emissions. In turn, the U.S. formation make use of directional antennas and dynamic signature management to reduce its EM signatures. The 5GenCV's reduced thermal signature and ability to disperse allows them to effectively hide from adversary airborne ISR platforms, navigate their way through the adversary sensor network, and reach their support by fire and assault positions.

The support by fire elements, aided by short-range UAVs, identify adversary defensive positions, and begin cooperative engagements by sending precision target coordinates to BLOS systems to their rear. As the U.S. artillery batteries begin their fires, the 5GenCVs in the support position employ their own extended line of sight systems to begin attritting the adversary with precision direct fires.

Attacking U.S. formations continue their forward maneuver. As the adversary detects the movement, they employ ATGMs, but adversary gunners struggle to get target locks due to the 5GenCVs' integrated electronic active protection suite, consisting of laser dazzlers, spoofers, and laser warning indicators. Adversary gunners cannot get accurate range readings with their laser range finders, their targeting beams fail to lock onto U.S. combat vehicles, and those ATGMs that are successfully launched are destroyed by the APS suite's hard kill systems. The ATGM barrage proves ineffective, and the U.S. maintains its rapid offensive tempo. The adversary's fires network initiates an artillery barrage to fix or destroy the U.S. formation, but the formation of 5GenCVs moves too quickly and maneuver within the adversary's protective indirect fires.

Within direct fire range of the adversary defense, the adversary tanks attempt to engage the oncoming U.S. formation with direct fires. The APS suite on the 5GenCVs prevents the adversary tanks from reading accurate ranges, and the laser warning indicators on the U.S. formation provide adequate warnings to enable evasive action and move to cover. The adversary tank gunners, unable to generate a ballistic firing solution against U.S. vehicles, are forced to estimate range and lead, causing most of their rounds to miss. The few accurate KE rounds that strike are defeated buy the 5GenCVs' frontal armor and ERA.

As the 5GenCVs successfully initiate the direct firefight, gunners and vehicle commanders use AI-assisted target tracking and engagement to produce a higher rate of more accurate and lethal fire than the adversary. The U.S. formation dominates the close fight, penetrates the adversary's main line of resistance, and exploits its success by destroying the adversary's A2/AD and integrated fires system, allowing the Joint Force Air Component to increase its sorties.

The M1A2 Abrams MBT cannot survive this rapid, lethal series of engagements because armored formations would be fixed and destroyed before the direct fire fight ever occurs.

A 5GenCV as postulated would penetrate the adversary's artillery and firepower shield and allow U.S. forces to retain their ability to conduct effective maneuver against a near peer adversary.

6. 5GENCV TECHNOLOGY PROGRAM

The Army has initiated several programs to modernize heavy armor, dating back to the 1960's. Most if not all the programs, from the MBT-70 of the 1960's to the FCS program of the early 2000's, have been expensive failures. The study team used the M1 program, the only successful heavy combat vehicle program in this period, to provide a model for a 5GenCV program. The study team explored some of the reasons for the previous failures to collect lessons learned, avoid the problems encountered in the past, and help assure a successful program going forward.

6.1 M1 REPLACEMENT PROGRAMS

The ASM Program was a U.S. Army combat vehicle procurement program from the mid-1980s to the 1990s and was focused on the Soviet threat. Interestingly, the program started as the M1 and Bradley were entering full rate production. In March 1985, the Army downsized the program from 24 systems to its six highest priority vehicles: four to be built on a heavy common chassis (weighing 55 to 62 tons) and two on a medium chassis (weighing up to 36 tons).

The four systems to be built on a common heavy chassis were the Block III MBT; the Combat Mobility Vehicle, an engineering vehicle for mine clearance and other engineering tasks; the Advanced Field Artillery System, a self-propelled howitzer; and the Future Infantry Fighting Vehicle. The chassis was to have certain common elements such as engines, transmissions, suspensions, modular armor, and tracks. Because tanks traditionally have had the engine in the rear, while self-propelled artillery and infantry fighting vehicles have had the engine in the front, the ASM common heavy chassis could have had two models. By the early 1990s, a reduced threat, reduced budgets, and the succeeding force draw-down all contributed to the diminishment of internal Army support for the ASM program.

The next effort for new combat vehicles was part of the FCS, the Manned Ground System, which followed several concept studies (Army After Next and Future Combat Vehicle/Strike Force). The FCS program was the largest and most ambitious planned acquisition program in the Army's history, intended to field not just a system, but an entire brigade. FCS consisted of a system of 18 systems developed from scratch and integrated by means of an advanced, wireless network, including nine manned ground vehicles (MGV), four unmanned aerial systems (UAS), three unmanned ground vehicles (UGVs), and two unattended munitions and sensors systems. The systems were interconnected in a ubiquitous, wireless network. The MGV made use of a common chassis (utilizing hybrid-electric drive, a two-man crew, indirect vision for driving and local situational awareness, and advanced technology sensors, computing, and communications). The initial objective was for the MGVs to be transported by C-130 Hercules, and they had weight constraints of less than 20 tons. Battlefield threats were to be identified and avoided through comprehensive situational awareness. Additional survivability components were added to account for undetectable threats (e.g., dismounted infantry with anti-tank munitions and improvised explosive devices) and the weight of the MGV systems steadily increased from 20 to 35 tons. The program was approved to enter EMD (Milestone B) in 2003, despite concerns about technological immaturity, schedule slips, and cost escalation. Over the next several years, vague and overly ambitious requirements, lack of mature technologies, and unforeseen risks prevented steady development progress. The entire FCS acquisition program was cancelled on June 23, 2009.

While the Army recognizes the need for a mix of combat systems (light, medium, and heavy) for countering the variety of adversary capabilities and operational environments, the lesson appeared to have been lost at times under FCS. A rapidly deployable combat system (i.e., C-130 transportable at ~20 tons) will always be required, but the system will not have enough capability to counter peer adversary MBT formations. A heavy armored combat capability will remain essential to counter adversary MBTs.

The next effort was the GCV program, which focused on the fighting vehicle (i.e., Bradley) requirement (vs. a family of platforms and systems). Where the FCS MGV was weight constrained, GCV took the opposite approach and did not have a transport weight requirement. Instead, designers focused on a nine-Soldier dismount squad and increased survivability. The Soldier size and number (crew + squad) were much greater than on the Bradley, a four-fold increase that produced significantly greater weight. The system growth requirement (approximately 20%) caused significant infrastructure (structure, powerpack, suspension, etc.) to be added. Additionally, the survivability (force protection) requirements were a major weight driver. The resulting system was ~70-80 tons. The system was terminated in 2014. Prior to that, the Future Fighting Vehicle (FFV) program was established as a follow-on to GCV as an S&T development effort, designed to help the Army explore its options for upgrading its existing armored vehicles. FFV considered a variety of weights, from 30-60 tons.

Contemporaneously, the Tank Automotive Research, Development and Engineering Center (TARDEC) initiated a new program focused on the new fighting vehicle and settled on ~45 tons as the focused gross vehicle weight. The program, Combat Vehicle Prototype, began in 2012, was funded at ~$1B, had sub-system demonstrations/tests completed in 2019, and was subsequently terminated. As the gross vehicle weight was determined early, it established the vehicle infrastructure. The focus was on relevant components using advanced technologies, including suspension (longer roadarms, new lightweight track), powertrain (new engine, transmission, generator, generator controller, heat-exchanger, batteries), and lethality (50mm cannon, integrated fire control).

Given the lack of success of these efforts, the study team modeled much of the proposed 5GenCV program upon the successful M1 Abrams predevelopment program.

6.2 HISTORY OF THE M1 PREDEVELOPMENT

The development of the precursors to the M1 Abrams, the MBT-70 (1963-1970) and XM 803 (1970-1971), promoted advancement in technologies for nuclear, biological, and chemical (NBC) protection; suspension and stabilization systems; and the turbine engine. The MBT Task Force, operating from January-August 1972 and chaired by MG William R. Desobry, Armor

Center Commander, laid out the MBT program and wrote critical performance specifications and essential documents. In 1973 the M1 program was established with MG Robert J. Baer as Program Manager (Fig. 6.2.1). In 1974, the program established a Tank Special Studies Group to validate requirements based on lessons learned from the 1973 Arab-Israeli War. The group was led by General Glenn K. Otis, Armor Training Center Commander. The operational lessons learned focused on the newly developed AirLand Battle Doctrine, and the technical activity, which included competitive full system prototypes, involved testbeds for the hull, turret and firepower, and mobility.

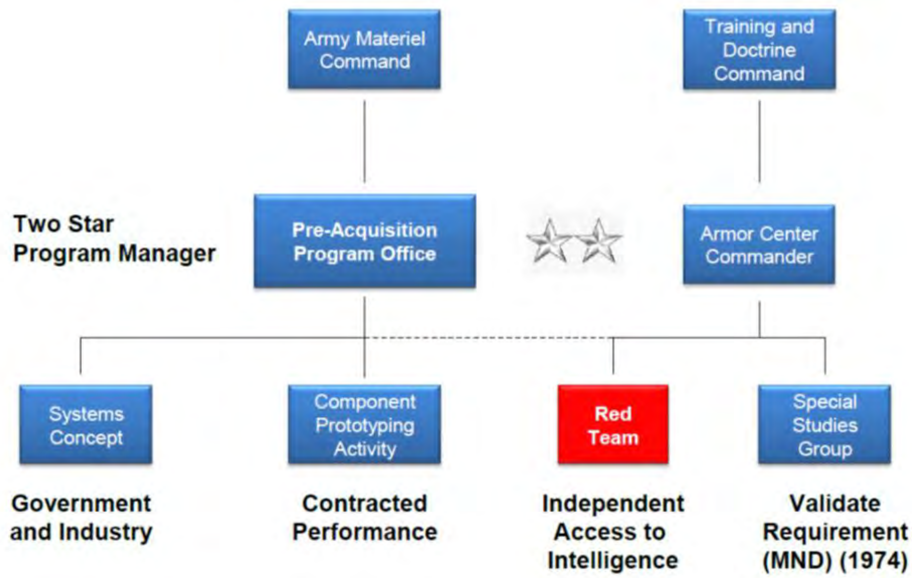

Figure 6.2.1 The Management Approach Used for the M1 Program

The M1 program was structured to ensure that 55 critical technology events planned to be incorporated into the M1 were mature before being incorporated into a system-level platform. Based on the success of the M1 program, the study team recommends that a similar approach should be adopted for development of a 5GenCV. From a platform level perspective, the most difficult aspect of development is the integration of systems engineering aspects. In developing a 5GenCV, all critical technologies should be sufficiently mature before they are incorporated into a system level platform. Key elements of the M1 approach were:

- Component maturation
- System prototyping
- Experimentation for both component and system prototyping
- Red Teaming employing national intelligence capabilities

6.3 M1-BASED APPROACH FOR THE 5GENCV TECHNICAL PROGRAM

The study team identified nine testbeds and associated critical technologies divided along the three categories of capabilities and technologies that define the 5GenCV:

1. Core Capabilities – (1) Mobility, (2) Firepower, (3) Protection, (4) C2 and Networks
2. Enduring Considerations – (5) Reliability and Maintainability, (6) Human Factors
3. Vital 5th Generation Technologies – (7) Masking, (8) Robotic Systems, (9) Computing

The study team then developed schedules for each of the testbeds and estimated associated costs, which totaled $2.27B (Fig. 6.3.1).

In addition, the study team developed the option of having competitive systems prototypes for an additional cost of $700M before Milestone B. These costs are in line with those of previous, similar programs. Examples include:

- GVSC (then TARDEC) accomplished similar program (Combat Vehicle Prototype) focused on Fighting Vehicle (OMFV) Mobility, Survivability and Lethality (~$1B; 6 years)
- MBT70, 1963-1970 (~$300M then => $2.1B now)
- XM1 1973-1976 (~$200M then => $1.2B now)
- GCV ($1B 2012; 2 contractors; 4 years; ATR, turret test stand)

Subject	Specifics	Cost	Duration	Comments
Core Capabilities				
Mobility	Hybrid-Electric	$450M	5 Years	Multiple Platforms
Firepower	Autoloader & Gun	$625M	5 Years	Turret Integration (Includes Initial Design)
	Advanced Munitions	$300M	5 Years	GLATGM, Hypersonics
Protection	APS; Adv. Armor; Underbelly	$320M	4 Years	Integrated, Layered Suite
C2 and Network	C2 and Network Capability	$180M	3 Years	Leverage Related Ongoing Activity
Enduring Considerations				
Reliability & Maintainability	Prognostics and Analytics	$50M	5 Years	Integration into C2 Systems Reliability Analysis
Human Factors	2&3 Man Crew Enablers	$50M	3 Years	Operational Architectures
Vital 5th Generation Technologies				
Computing	AI Applications	$85M	3 Years	Platform Integration
Masking	Vehicle Test	$60M	5 Years	Platform Integration
Robotics	Wingman, RSV	$150M	5 Years	Multiple Platforms Remote and Autonomous Ops
Testbed Subtotal		**$2,270M**	**7 years**	
Competitive Systems Prototyping		**$700M**	**4 years**	
Testbed and Prototype Program Totals		**$2,970M**	**7.5 years**	

Figure 6.3.1 Cost and Duration for Each Testbed

The study team provided a top-level assessment. The Army will need to conduct a more thorough investigation of the appropriate technology approaches, costs, and schedules. In particular, the application of the new technologies in robotics, AI based crew assists (navigation and target cueing), predictive maintenance, and others, have no precedence in the M1 program and must be considered to ensure a proper investigative approach.

The study team also provided a nominal budget schedule over the 7.5-year period of the technical program, including competitive prototyping in the overall effort before Milestone B (Fig. 6.3.2).[5] The nominal schedule leverages ongoing efforts in the areas of technology for the various testbeds. The length of each testbed was determined by the maturity of the technology and the fact that new funding is required in the current Program Objective Memorandum (POM) to begin the program. Shortening or lengthening the program depends on the decision to proceed and the availability of resources.

[5]The study team adopted the recommendation of the FY 2019 ASB Study, “Army Futures Command” that all future programs include competitive prototyping before Milestone B.

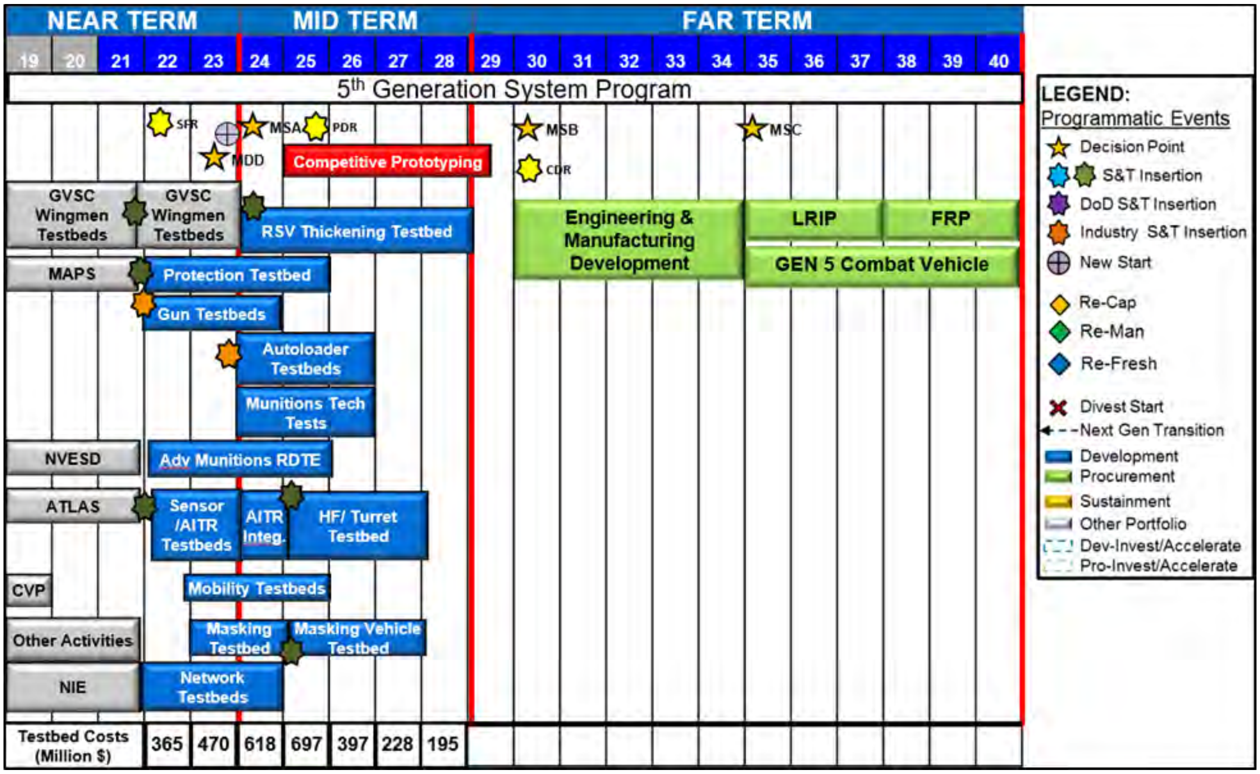

Figure 6.3.2 Schedule and Budget Over 7.5-Year Technical Program

6.4 THE M1 ABRAMS MODEL IMPLEMENTATION

The study team examined the M1 Program's management approach to extract key elements for use with development of a 5GenCV. It found much of the technology enabling the proposed testbeds is already being pursued by the Army R&D community, newly consolidated under AFC. Consistent with AFC's mission, the Army can develop a pre-acquisition activity similar to the M1's that defines and matures the technology and systems concepts, to include:

- Creation of a single-purpose activity dedicated to establishing readiness of the Army to pursue a next-generation combat vehicle
- The authority to procure from the industry the technology and prototypes necessary to prepare for Milestone B
- The budget authority to conduct such a program

In parallel with the pre-acquisition activity, AFC would need to specify requirements for the 5GenCV and conduct an AOA using technology and systems concepts. Continuous Red Teaming of the concept will provide real time AoA against known threats if the Red Team has access to relevant threat data and has the capability to assess vulnerabilities of the concepts being investigated.

6.5 PROTOTYPES AND TESTBEDS FOR THE 5GENCV

In developing a 5GenCV full system prototype, subsystems such as the chassis and turret will need their own testbeds and prototypes (Fig. 6.5.1). Key components of the prototypes include:

- System analysis starting prior to testbed activities to make testbeds relevant (need system functional review level of analysis and general gross vehicle weight)
- Competitive prototyping activity with multiple contractors
- A system preliminary design review
- Production of system prototypes
  - Chassis prototype
  - Turret prototype (test stand)
  - Combines for system-level prototype

Figure 6.5.1 Chassis, Turret, and System-level Prototypes

7. FINDINGS AND RECOMMENDATIONS

The study team developed seven findings in two classes, those dealing with determining the requirement for a 5GenCV (1 through 4) and those addressing the recommended development program (5 through 7). From those, the study team drew six recommendations to help determine available technology and to mature both the technology and systems concepts.

7.1 FINDINGS

The findings reflect two general topics that the study team investigated. The first was the threat, and for the purpose of using a near peer adversary, the study team focused on the Russian military. Specifically, the study team looked at Russian doctrine and materiel for waging war through the first half of the 21st century, as well as U.S. technology available to field a combat vehicle toward the end of the first half of the 21st century that would provide overmatch against the projected Russian capability. The study also investigated whether today's systems including the M1 Abrams would be superior to the Russian platforms during the end of this period. Both the threat and technology contribute to generating options for a next-generation combat vehicle. Because of the uncertainty involved in predicting both the Russian doctrine and capabilities and the directions that the new technology might take by the end of the first half of the 21st century, the study team refrained from making specific predictions on either the warfare characteristics or the design of a new generation of combat vehicle. Rather, it created a program that provided the maximum breadth of options for a next generation vehicle and tools for experimentation to investigate the options. This experimentation would assist in narrowing the option set to a vehicle design to be executed in the EMD phase of the program. The down selection of preferred options could be made several years into the recommended program.

1. Russian "New Generation Warfare" and emerging Chinese capabilities have contributed to a new U.S. operational concept, Multi-Domain Operations. The threat and MDO require a 5th Generation Combat Vehicle that is significantly more capable than current systems.

The Russians, and to a lesser degree the Chinese, have observed U.S. doctrinal and materiel developments through the Cold War and conflicts in in the Middle East. Both have reacted to U.S. advancements by innovating their own doctrinal and materiel improvements. In turn, the U.S. has improved operational concepts by expanding Airland Battle to MDO. Arguably, AirLand Battle focused all then-existing domains into one, the land domain. Its successes in the Middle East, coupled with the rapid development of digital technology, led to the development of MDO. The employment of all five domains will require a different combat vehicle capable of taking advantage of the improvements inherent in MDO, particularly the availability of battlefield information from multiple sources. The MDO concept will be matured as the combat vehicles are matured, as was the case with the M1 Abrams.

2. The Russians have demonstrated the following in their operations in Ukraine in both open and urban environments:

- **Tanks dominate close combat. More tanks were killed by other tanks than other anti-armor weapons**

- **Increased Anti-Tank weapon lethality**

- **Massed Precision and Area Fires**

- **Cyber and Electronic Warfare**

- **Employment of UAVs**

The Russians demonstrated in Ukraine, and to a lesser extent in Syria their operational concept for the first half of the 21st century. The study team employed the lessons learned from the Ukraine conflict in a manner similar to how TRADOC employed those of the 1973 Arab-Israeli War to help define the requirement for the M1. The Ukraine conflict employed three of the four phases of Russian Next Generation Warfare:[6]

1. Grey warfare–the use of information and cyber operations to influence the civilian population

2. The use of insurgents and “little green men”–local sympathizers and Russian soldiers out of uniform to prevent identification while achieving military objectives

3. Full-scale conventional warfare to gain objectives

The Russian uses of UAV’s networked to long-range fires was effective in the Donbas region of Ukraine, particularly when their long-range weapons were armed with thermobaric warheads, which proved highly effective against Ukraine formations. Both sides also used ATGMs with good effect. In the end, when the number of losses were totaled, the tank-on-tank battles accounted for the most losses of armor on the Ukraine battlefield.

3. Threat analyses (Ukraine lessons learned, T-14 development, Russian modernization, Scenario 7, etc.) assist in determining the essential requirements for a new system.

- **The threat helps to establish the need for armor as part of a combined arms force.**

- **Reducing weight and improving reliability will have the effect of reducing the sustainment tail and strategic lift requirements. Reduced weight also allows air movement of small numbers of 5th Gen Combat Vehicles for limited contingency operations.**

[6] The Russians did not employ Weapons of Mass Effect in either conflict.

- **M1A2 SEP v3/v4 tactical mobility is challenged in Eastern Europe**
- **Advanced ATGMs, Top-Attack, and Emerging KE are future protection problem.**
  - **Unmanned turret mitigates several issues (crew protection, silhouette, weight, mobility)**
  - **Integrated CE/KE/EFP hard & soft kill active protection systems improve protection**

The summary of all the threat information and analyses verified the need, for the foreseeable future, for a combat vehicle to serve as a critical element of the combined arms team. The vehicle should have enhanced mobility, adequate protection, and firepower overmatch. The threat analysis also determined that the future vehicle must be lighter and easier to sustain in order to be effective in Eastern Europe. The emerging pacing problems for next-generation combat vehicles are artillery and ATGM's with top-attack munitions. Future armor concepts will be required to counter these threats. While the Army analytic community is limited in its ability to address many of the technologies applicable to a 5GenCV, analysis conducted for this study indicated an opportunity to make significant improvements over the vehicles planned as part of the M1 product improvement program. In some scenarios, an order of magnitude improvement could be observed. Current analytical models do not address robotics, software-based crew assists (e.g., target cueing), and networked information systems. Therefore, significant additional improvements in margins over both the M1A2 and threat vehicles are anticipated.

4. The M1 is approaching the end of its product improvement cycle.

- **All product improvements add weight to an already too-heavy vehicle.**
- **There is inadequate space and power for computational capability to accommodate modern information systems.**

An important task of the study was to establish whether the requirement for an armored combat vehicle in the combined arms team could be met by ongoing improvements to the M1 Abrams. The study team believes that the M1A2 SEP v3 and SEPv4 are capable of restoring margin lost due to Russian improvements to their armor, including the T-90 and the T-14 Armata. The M1 program cannot match Russian innovation, and any improvements in the M1 to overcome advancements made by the Russians will add weight to an already too heavy vehicle. MDO will also require the addition of significant computational capability to address AI-based advancements and networked operations. The M1A2's space and power limitations will limit the application of these advancements.

5. As during the start of the M1 development program, the current Army tank development program is behind the Russian development program. The potential inability of the Russians to produce in quantity its prototypes offers the U.S. the opportunity to move beyond their

advancements. However, the Russians are upgrading existing vehicles with technology proven by their prototyping activities.

Advancements made by the Russian Design Bureaus have limited the superiority margins of the M1's principal capabilities. The T-14's autoloader, unmanned robotic turret, crew protection advances, and more efficient main armament surpass U.S. tank developments. A similar situation occurred with the armor competition between the U.S. and Soviet Union during the Cold War. During the 1960s and 1970s, improvements to the U.S. MBT, then the M60 Patton, were insufficient to allow the U.S. to surpass the Soviets. Development of a new MBT was required, and the M1 Abrams restored U.S. superiority for nearly 40 years. One major difference between the armor past and current armor competitions: today there's a question concerning the Russian ability to produce the T-14 in quantity, whereas there was no doubt that the Soviet Union had the resources to produce required quantities of their armor. Regardless, the Russians will attempt to apply as many of the relevant improvements as part of the T-14 program to their existing combat vehicle fleet, particularly the T-90.

6. The technology base to support the development of a 5th Generation Combat Vehicle is not sufficiently mature to begin EMD (Milestone B).

- **Critical Component and Systems technology have not reached TRL 6.**

- **Current analytics capability is insufficient to develop employment concepts and assess supporting hardware approaches.**

The study team believes that the requisite technology and doctrine is currently not ready for application to a Milestone B major system acquisition. Based on other studies conducted, the ASB advocates that the technology reach TRL 7.[7] Further, limited experimentation has been conducted with important technology to assess its contribution to a combat vehicle developed for MDO-based operations. The ASB also advocates the use of competitive prototyping before Milestone B to establish an adequate industrial base. Both techniques were employed in the M1 development. The data from the M1 and other major acquisition programs performed by all services strongly suggests that such activities reduce risk and reduce time and cost in the follow-on EMD program.

7. This study group believes that the precedent set with the development of the M1 offers the best approach for development of a 5th Generation Combat Vehicle.

- **Critical component development maturation and competitive system prototyping before commitment to system acquisition (Milestone B).**

- **Doctrine development conducted in parallel with hardware activity**

[7] Per recommendations from ASB FY 19 "Army Future Command."

- **Conducted in parallel with current systems product improvement**

As the findings indicate, the study strongly endorses the application of the program construct employed for the development of the successful M1A2 program. Minimizing the pre-acquisition program results in a longer and more expensive post-Milestone B program. The team believes the Army should initiate this program in parallel with the M1 SEP program until it is evident the 5th generation program will achieve success. The study advocates a combat vehicle that would provide overmatch against adversary vehicles for an entire generation, as did the M1. The combat vehicle is an important contributor to deterring conventional war, as was demonstrated against the Soviet Union during the Cold War. A significant improvement in armored vehicles is required to regain conventional warfare deterrence for the 21st century.

7.2 RECOMMENDATIONS

The study team's recommendations reflect a development program schedule which is deliberate rather than fast. A deliberate paced program is necessary to regain the significant overmatch necessary for conventional warfare deterrence. The length is determined by the status of the technology and the fact that new funding is required in the current POM to begin the program. Shortening or lengthening the program in the end depends on the decision to proceed and the availability of resources. Regardless, the study team advocates pursuing a pre-acquisition program which completes the technology and systems concepts before entering Milestone B.

1. A 5th Generation Combat Vehicle technical program should follow precedent set by M1 program (SECARMY, CSA, CG AFC).

- **6-8-year pre-acquisition program**
- **$2B to complete technical maturation; $3B to complete technical maturation and competitive systems prototyping**
- **Experimentation for both component and system prototyping**
- **Red Teaming employing national intelligence capabilities**
- **Program balances initial cost and time with reduced risk, time, and money savings post-Milestone B (EMD)**

The program recommended by the study team parallels that of the M1 program. A top-line investigation of the time and cost of the M1 program indicated that the costs and duration recommended here are reasonably consistent with those experienced in the past. However, such a top-level assessment should not substitute for a thorough investigation of the appropriate approaches, costs, and schedules for the technology. In particular, the application of the new technology—robotics, AI based crew assists such as computer-based navigation and target cueing, predictive maintenance, and others—have no precedence in the M1 program and must be detailed to ensure a proper approach. For example, while the study team advocates what it believes are the necessary software investigations, it took no formal position on a system of systems integration laboratory (SoSIL) to simulate the relevant software in a combined arms MDO environment. While the Army's analytical capability can evaluate the mechanical elements of a combat vehicle such as armor penetration, it is unable to evaluate software intensive, information-based systems which will dominate 21st century systems development. That capability is important and today a SoSIL is the best approach to such evaluations. A more thorough investigation of the recommended technical activity, including consideration of a SoSIL, should be undertaken by the Army.

2. Army Futures Command (AFC) should manage the pre-acquisition effort employing the approach used by the M1 pre-acquisition program (CG AFC, ASA(ALT)).

Much of the technology advocated by the study team is already being pursued by the Army R&D community in AFC, and it's consistent with AFCs mission to pursue a pre-acquisition activity that defines and matures both technology and systems concepts. The study team recommends AFC create a pre-acquisition activity that employs the management principles employed by the M1 program. They include creation of a single purpose activity dedicated to establishing the Army's readiness to pursue a next-generation combat vehicle, the authority to procure from industry the technology and prototypes necessary to prepare for Milestone B, and the budget authority to conduct such a program.

3. AFC should, in parallel with the pre-acquisition effort, determine the requirement for the 5th Generation Combat Vehicle informed by (among other considerations) the above technical effort. This team believes a stand-alone activity should be established for this effort. This effort should include an analysis of alternatives (AoA) (CG AFC).

In parallel with the pre-acquisition activity, AFC must establish the requirement for a 5GenCV. The study recommends that an investigation of the requirement for a next generation vehicle be undertaken along with an analysis of alternatives (AOA) involving the technology and systems concepts outlined in the previous recommendations. The study team further believes that a Red Team should provide continuous assessments of the alternatives against the adversary threat. The Red Team must have access to relevant threat data and possess the capability to assess vulnerabilities of the concepts being investigated.

4. Any program to establish the technology base for a 5th Generation Combat Vehicle should ensure a competitive industrial base (CG AFC, ASA(ALT)).

The industrial base necessary to supply both advanced combat vehicle systems and subsystems is limited. The study advocates development of a larger competitive industrial base before the start of Milestone B. The funding for the technology pursuits and system prototypes should be attractive to industry, however, Government must determine an industrial base strategy for procurement of a 5GenCV and execute it in the pre-acquisition phase. Industry will provide technology and systems concepts responsive to Army requirements, but a competition strategy must be created by the Government which provides the opportunity for the industrial base to participate both at the appropriate component and system levels.

5. The Army should, as it did in the pre-acquisition program for the M1, look outside the Army for technology that would further the capabilities of a 5th Generation Combat Vehicle. It should investigate technical areas (e.g. energetics, materials, modeling, and simulation) where increased investment would significantly improve the development and employment of a new vehicle. (CG AFC)

- **Allies (Israel, Great Britain, France, Germany, South Korea, Japan)**
- **Department of Energy**
- **Industry / Commercial Sector**
- **DARPA**

This study team examined technology being pursued by the Army only. Other organizations outside the Army could provide combat vehicle technology and concepts that would be of interest to the Army. During the M1 development, U.S. Allies provided technology relevant to the M1, including active armor (Israel), passive armor (Great Britain) and the main armament (Germany). The Department of Energy provided materials for armor and analytical capability to analyze armor interaction with both shaped charge and kinetic energy penetrators. DARPA demonstrated the first digital fire control system for a tank. Thus, the study team recommends that an investigation be undertaken of relevant technology today being pursued by other organizations outside of the Army.

6. DARPA should be engaged to help the Army explore high risk technology advancements and assist in assessing technical characteristics of the future battlefield. MOUs and programs between Army and DARPA are already in place. (DUSA, CTO AFC, ASA(ALT))

- **Information Science**
- **Robotics**
- **Smart Munitions including Hypersonics**
- **Artificial Intelligence**

DARPA can provide investigations relevant to a next-generation combat vehicle that would be very risky for the Army to pursue on its own. It also can provide projections to assist the Army in understanding technologies likely to shape the battlefield of 2040. Members of the Army R&D community work with DARPA and can assist in convincing DARPA to help with assessing and developing technology for a next-generation combat vehicle. DARPA is already investigating technology applicable to next-generation combat vehicles and MOU's between the Army and DARPA are already in place that could facilitate such a cooperative program.

7.3. SUMMARY

Because of the importance of the next-generation combat vehicle to conventional warfare deterrence, and should deterrence fail, to winning the land combat wars of the 21st century, the study team recommends a comprehensive and deliberate approach to the development of the 5GenCV. Product improvement of the M1 provides time to develop a next-generation combat vehicle that will provide overmatch for a generation, as did the M1.

APPENDICES

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CLASSIFIED ANNEX

The classified annex, published under separate cover, provides information and findings from the study team's analyses pertaining to the following topics:

1. M1 Abrams series
   - Overmatch in defined scenarios
   - Survivability

2. 5GenCV concepts
   - Concepts Analysis Agency (CAA) analyses
   - Loss exchange ratio

Access to the Independent Assessment of the Next Generation Anti-Armor Strategy classified annex will be made available to individuals with the appropriate security clearance and need to know. Requests for access should be submitted to the Executive Director, Army Science Board, 2530 Crystal Drive, Suite 7098, Arlington, VA 22202-3911.

APPENDIX A. TERMS OF REFERENCE

SECRETARY OF THE ARMY
WASHINGTON

04 JAN 2019

MEMORANDUM FOR

Deputy Under Secretary of the Army, 101 Army Pentagon, Room 3E650, Washington, DC 20310-0101
Chairman, Army Science Board, USAG Fort Hamilton, 113 Schum Avenue, Brooklyn, New York 11252

SUBJECT: Request for an Army Science Board Study titled "An Independent Assessment of the Next Generation Anti-Armor Strategy"

1. I request that the Army Science Board (ASB) conduct a study titled, "An Independent Assessment of the Next Generation Anti-Armor Strategy." The study will have three complementary objectives:

a. Examine emerging threats, operational concepts, and doctrine necessary to defeat massed armored formations considering the capabilities of the Army's next generation combat capabilities.

b. Assist the Army's senior leadership in developing an understanding of next generation combat vehicle architectures, technologies, and the tradeoffs between them that support the development of next generation anti-armor strategies.

c. Recommend appropriate investment strategies to field next generation armor combat capabilities.

2. To meet these objectives, the ASB study team's tasks will include, but will not be limited to, the following:

a. Assess relevant emerging threats, operational concepts, and doctrine.

b. Determine how organizations will fight with new technologies.

c. Suggest next generation combat vehicle and supporting system design parameters.

d. Investigate ways to increase lethality, improve survivability, and address strategic, operational, and tactical mobility while also reducing sustainability demands across all next generation combat capabilities.

e. Report on other factors and considerations as deemed appropriate.

3. The study team must consider the results of the ASB Fiscal Year 2017 Manned-Unmanned Teaming (MUM-T) study and articulate how the findings of that study will affect the design of the next generation combat capabilities and supporting systems. The study must also report on how Joint Force operational concepts must be developed and/or modified to leverage the MUM-T construct.

4. The Secretary of the Army is the sponsor of this study. The Commanding General, U.S. Army Futures Command will assist the study team with accessing information and relevant classified information up to Top Secret and including Sensitive Compartmented Information and Special Access Programs.

5. Provide a briefing with findings and recommendations on or before 30 September 2019 to the Chief of Staff, Army and me. The study will operate in accordance with the Federal Advisory Committee Act and the Department of Defense Directive 5105.4, "Department of Defense Federal Advisory Committee Management Program." It is not anticipated that this study will need to go into any particular matters regarding the interpretation of United States Code, nor will it cause any member of the study team to be placed in the position of acting as a procurement official that may constitute a conflict of interest.

Mark T. Esper

CF:
Chief of Staff, Army
Under Secretary of the Army
Vice Chief of Staff, Army
Assistant Secretary of the Army (Acquisition, Logistics, and Technology)
Chief Information Officer/G-6
Deputy Chief of Staff, G-2
Deputy Chief of Staff, G-3/5/7
Deputy Chief of Staff, G-4
Deputy Chief of Staff, G-8
Commander
    U.S. Army Training and Doctrine Command
    U.S. Army Futures Command

APPENDIX B. STUDY TEAM MEMBERS

James Tegnelia, PhD., Chair

Mark Glauser, PhD., Vice Chair

COL Clinton Ancker (USA Ret)

COL John Antal (USA Ret)

COL Christopher Cross, PhD. (USA Ret)

COL William Crowder (USA Ret)

Robert Douglas, PhD.

COL Herbert Gallagher (USA Ret) COL

William Hansen (USA Ret)

COL Rocky Kmiecik (USA Ret)

Hon. Richard B. "Dick" Ladd

COL Harry Lesser (USA Ret)

William Neal, PhD.

William Snowden, PhD.

Buck Tanner, PhD.

LTG Michael Williamson, PhD. (USA Ret)

MG Walter Wojdakowski (USA Ret)

Joseph V. Braddock, PhD., Consultant

MG William Hix (USA Ret), Consultant

Jeffrey Isaacson, PhD., ASB Red Team Advisor

COL Christopher Yuknis (USA Ret), Government Advisor

MAJ(P) Charles Bies, HQDA, Study Manager

Mark S. Swiatek, Tech Writer/Editor

APPENDIX C. LINES OF INQUIRY AND VISITATIONS

Ground Vehicle Support Center (GVSC) / 10 JAN 2019 / Austin, TX – ASB Team members met with Robert Sadowski, PhD. about GVSC developments and research in robotic and unmanned systems.

US Army Maneuver Center of Excellence (MCoE) / 8-9 FEB 2019 / Ft Benning, GA

- ASB Team members engaged with Mr. Robert Hay, Mr. Wakeland Kuamoo, Mr. Kent Evans to discuss various aspects of the M1 program, M1 performance, and M1 modernization initiatives and efforts.
- ASB Team members engaged with BG (Ret) Peter Jones, Mr. Jim Newill and SFC Ivan Vitanov to discuss threat capabilities and Russian Next Generation Warfare.
- ASB Team members engaged with Ms. Jennifer Williams, CPT Larry Baca, Mr. Tom Yanoschik, Mr. Stephen Miller, and Mr. Rhett Griner to discuss the Maneuver Battle Lab simulation and modeling efforts regarding Robotic Combat Vehicles.

Army Special Access Programs / 11 MAR 19 / The Pentagon, VA – ASB Team members engaged with Mr. Robert Cheatham and Mr. Aric Sherwood on relevant Special Access Programs.

National Training Center (NTC) / 13-14 MAR 19 / Ft Irwin, CA

- ASB Team members engaged with BG Broadwater, COL Lombardo, COL Michaud, and COL Woodward to discuss the NTC rotational model, NTC replication of threat capabilities, and armored formation performance against near-peer competitors.
- ASB Team members engaged with 1LT Hamilton and 1SG Ruiz to discuss threat ATGM capabilities and effects on US armored formation performance in simulated combat conditions.
- ASB Team members engaged with SFC Jason Henry, MSG Donald Gillem, and a rotational training tank platoon to discuss tank capabilities and capability deficiencies identified at the National Training Center.
- ASB Team members engaged with COL Michaud, LTC William Higgins, and Mr. Rodney Sheetz to discuss NTC Operations group capabilities for exercise control, data collection, and performance trends
- ASB Team members engaged with COL Woodward, CSM Michael Stunkard, LTC Thomas Frohnhoefer, CSM Ronald Corella, MAJ Patrick Merriss, MAJ Paul Tanghe, and MAJ Ian Macharrie to discuss 11th ACR (OPFOR) capabilities, threat force emulation, US tank capabilities, U.S. brigade combat team (BCT) capabilities, and threat cyber and EM activities during training rotations.
- ASB Team members met with LTC Russell Wagner, MAJ Michael Provencher, 1LT Hunter Nixon, and SFC Ian Workman at the 2/11 ACR Field Tactical Operations to discuss the role of vehicle technology on terrain and capabilities for successful combined arms maneuver.
- ASB Team members met with LTC Kurt Smith, MSG Gary Kurtzhals, MAJ Ethan Olberding, and MAJ Romas Zimlicki from the Dragon (Live Fire) Observer/Controller

Team to discuss trends in live fire capability, training issues identified at the NTC, and tank lethality.

Center for Army Analysis (CAA) and Army Geospatial Center/ 17 MAR 19 / Ft Belvoir, VA

- ASB Team Members engaged with Mr. Knudson, COL Burger, MAJ Timmins, and LTC Keillor to discuss Army M&S capabilities, data requirements for modeling the performance of US formations equipped with a future combat vehicle capability, and requested outputs for simulation and data modeling.
- ASB Team Members engaged with Mr. Michael Paquette, Mr. Dhiren Khona, Mr. James Hill, MAJ Jeff Murphy, Mr. Mike Mailloon, and Mr. Mike Campbell regarding Army terrain analysis capabilities, modeling vehicle performance over varying terrain types, and requested trafficability analysis for eastern European terrain in both wet and dry conditions.

Command, Control Communications, Computers, Combat Systems, Intelligence, and Reconnaissance (C5ISR) Center and Army Data and Analysis Center (DAC) / 1 APR 19 / Aberdeen Proving Grounds, MD

- ASB Team members engaged with Mr. Chuck Hoppe, Mr. Mike Monteleone, Ms. Mary Willis, Mr. Brownfield, Mr. Jim Mueller, Mr. Steve Goodall, Mr. Steve Lucas, Mr. Tom Sepka, Mr. John Franklin, Mr. Paul Olson, Mr. Brian Boscore, Mr. David Ossie, and Mr. Mike Lombardi to discuss C5ISR research, development, and modernization programs and threat electronic and network warfare capabilities.
- ASB Team members engaged with Jim Newill, PhD., Mr. John Carilineo, Mr. Randy Coates, Mr. Lou Farkas, Ms. Paula Smith, Mr. John Polezni, Ms. Denis Jordan, Ms. Meryl Doherty, Mr. Douglas Howe, and Mr. Tim Moye to discuss data modeling capabilities for the M1, data required to facilitate CAA analysis, and technologies that the study requires from AMSAA for modeling.

Defense Advanced Research Projects Agency (DARPA) / 4 APR 19 / Fairfax, VA

- ASB Team Members met with Mr. Robert Price, Mr. Main, Ms. Mason, Mr. Plason, Mr. Wierzbanowski, and Mr. Dunn to discuss DARPA projects and technology programs with applicability to future armored vehicle platforms.
- DARPA has several programs focused on optics, support to manned-unmanned teaming, and unmanned systems.

US Army Combined Arms Support Command (CASCOM) / 10 APR 19 / Ft Lee, VA – ASB Team members met with Mr. Douglas Absher, Mr. Alan Woodard, Mr. Scott Staples, Mr. Jeff Martin, and LTC Simon Heritage (Australian Army) to discuss Army sustainment modernization and programs to reduce formation sustainment requirements.

Headquarters, Department of the Army G4 / 19 APR 19 / The Pentagon, VA – ASB Team members met with Dr. Juan Vitali and Mr. John Fasching to discuss Army sustainment modernization priorities, vehicle electrification, and maintenance modernization.

National Ground Intelligence Center (NGIC) / 21 MAY 19 / Arlington, VA

- ASB Team members met with Mr. Clinton Aichs, Mr. Jim Anderson, and Mr. Phil Lemire from NGIC to discuss Russian Tank Design Bureaus, Russian Tank Modernization, and Russian tactical and operational force employment.
- Russian tank design is typically decentralized and leverages existing subsystems to develop “new” systems. Russians emphasize maneuver and overwhelming artillery fires.

Potomac Foundation / 12 JUN 19 / Arlington, VA

- ASB Team members met with Dr. Philip Karber and Dr. Joseph Braddock to discuss lessons learned from Russian Operations in Ukraine.
- Russians demonstrated extensive use of tanks in Ukraine, to include use in urban areas. Technology adaptation occurs on a 3-6-month cycle and the conflict is characterized by rapid acquisition cycles of low-cost and disposable capabilities.

DAC Phone Conference / 27 JUN 19 / The Pentagon, VA – ASB Team members conducted a classified phone conference with Mr. Randy Coates regarding DAC modeling outputs and simulation results.

APPENDIX D. ANALYTIC SUMMARY

This annex addresses the current M1 Abrams series' challenges deploying to and maneuvering on the battlefield. It also provides the postulation of two concept vehicles with a reduced crew size, located in the hull. A classified annex provides target acquisition and lethality performance data and data on the effectiveness for both the M1 series and the postulated concept vehicles.

Analysis of the M1 series resulted in the following observations:

- Getting to the battlefield is a major challenge. The current weight of the M1A2 SEPv3 with force protection kits exceeds 80 tons and cannot be transported by U.S. Army HET vehicles. Significant components must be removed for rail transport.

- Maneuver on the battlefield in certain areas of interest is also a significant challenge. Bridge classification in many areas will not support crossings and maneuver during wet seasons is problematical.

- Reduction in weight for the M1 series is costly, but if the M1A2 SEPv3 were reduced to 70 tons, transport on the HET would be possible and facilitate intra-theater transport.

- A 5GenCV will be needed to provide a deterrent force and overmatch against future adversaries.

The GVSC program provided two concept vehicles that incorporated technologies, which, given continued development, could be available for EMD around FY 2028. These technologies had been down selected over time for funding and pursued to the point where it is reasonable to conclude they would significantly enhance ground combat vehicle performance. Collectively, these technologies provide a step function increase in performance over the M1 series. And, because of the reduced weight, these concept vehicles can be more efficiently transported to and maneuver on the battlefield. Examples include:

- The third generation FLIR, which provides approximately twice the acquisition range performance of the second generation FLIR.

- A long-range munition(s), which permits engagements well beyond large caliber cannon range and is lethal to ranges beyond those of the Russian gun launched ATGMs.

- A larger cannon for increased megajoules on target.

- A reliable autoloader for increased rate of fire.

- Adaptive armor for increased survivability.

- Improved fuel economy through a hybrid electric drive engine.
- Band track for lower ground pressure and improved mobility.
- Incorporation of AI to maneuver and fight the systems more effectively.

D.1 INTRODUCTION AND OVERVIEW OF ANALYSES

The M1 series tanks rely on 50-year-old technology. Over time, the weight has increased to cope with increased lethality of potential adversaries. While the U.S. has focused on the war on terror, potential adversaries have continuously improved their armored capabilities to the point where it is questionable whether the M1 has overmatch. Russia now claims the Armata is a 4th generation tank with leap-ahead capabilities over the 3rd generation M1A2 SEPv3.

The ASB was tasked to determine whether the M1A2 SEPv3 or M1A2 SEPv4 can get to the battlefield and maneuver; whether the M1A2 SEPv3 or M1A2 SEPv4 could be expected to maintain superiority over adversary tanks for the next 30 years; and, if not, what next-generation combat vehicle is needed. The study team's analyses aimed to provide insight into these questions, as follows:

1. Analysis Objectives
   a. Quantify the viability of the M1 series to provide combat overmatch on battlefields of the future. Specifically, does the M1 retain overmatch vs. the most common Russian tank in the 2035 timeframe?
   b. Provide analysis of two competing concepts (i.e., measures of performance and measures of effectiveness) for a Next-generation combat vehicle (NGCV vis-à-vis the M1 series in a scenario of interest to the Army:
      - Will either of the NGCV concept vehicles achieve overmatch?
      - What technologies hold promise of achieving overmatch?

2. Assumptions
   a. NGCV will be available in 2035-2040 timeframe
      - All key technologies available and at TRL 7 by 2028
      - EMD for 3-5 years
      - FUE 2035-2040
   b. Region of interest remains Eastern Europe
   c. Most common Russian forces are T90's+

3. Critical Questions
   a. Does the U.S. need a tank?
   b. If so, does the Army need a new tank?

- Essential elements of analysis (EEAs)
- What options does GVSC envision?
- Does it have to be manned? (Not within scope of this phase of analysis.)

c. What characteristics/capabilities would a new tank need to achieve overmatch in that timeframe (2040)?

d. How would we leverage the plethora of new technologies to achieve overmatch into the 2040s? What are the critical technologies to pursue?

4. EEAs for the M1 Series

a. M1 EEA #1: Can the M1 get to the fight? A transportability analysis was performed.
   - Strategic Airlift
   - Intra- theater transportation
     - Rail
     - Heavy vehicle transport
   - Road march along main supply routes (MSR)

b. M1 EEA #2: What measures can be taken to reduce the weight below 70 tons to get to the fight?
   - Cost
   - Schedule
   - Technical risk

c. M1 EEA #3: Given it gets to the fight, what are the tactical mobility implications (in a scenario of interest)? Engineer Research and Development Center (ERDC) Terrain Analysis plus GVSC fight ability and logistics:
   - Trafficability analysis
   - Line-of-sight analysis
   - Bridge analysis
   - Obstacles to movement e.g., swamps and forested areas)
   - How does a weight reduction affect fight ability and logistics?

d. M1 EEA #4: Given the M1 series gets to the fight, does it still retain overmatch vs. the most common threat is a scenario(s) of interest?[8]

e. M1 EEA #5 Is the M1 series supportable during a period of prolonged operations:
   - Fuel consumption
   - Mean time between failures
   - Mean time to repair

5. EEAs for NGCV

If the M1 series is found lacking from the above analyses, what are possible concepts for a new tank? The study team and GVSC postulated two concepts as a potential replacement for the M1: a 3-Soldier crew, 50-ton class of tank; and a 2-Soldier crew, 40-ton class.

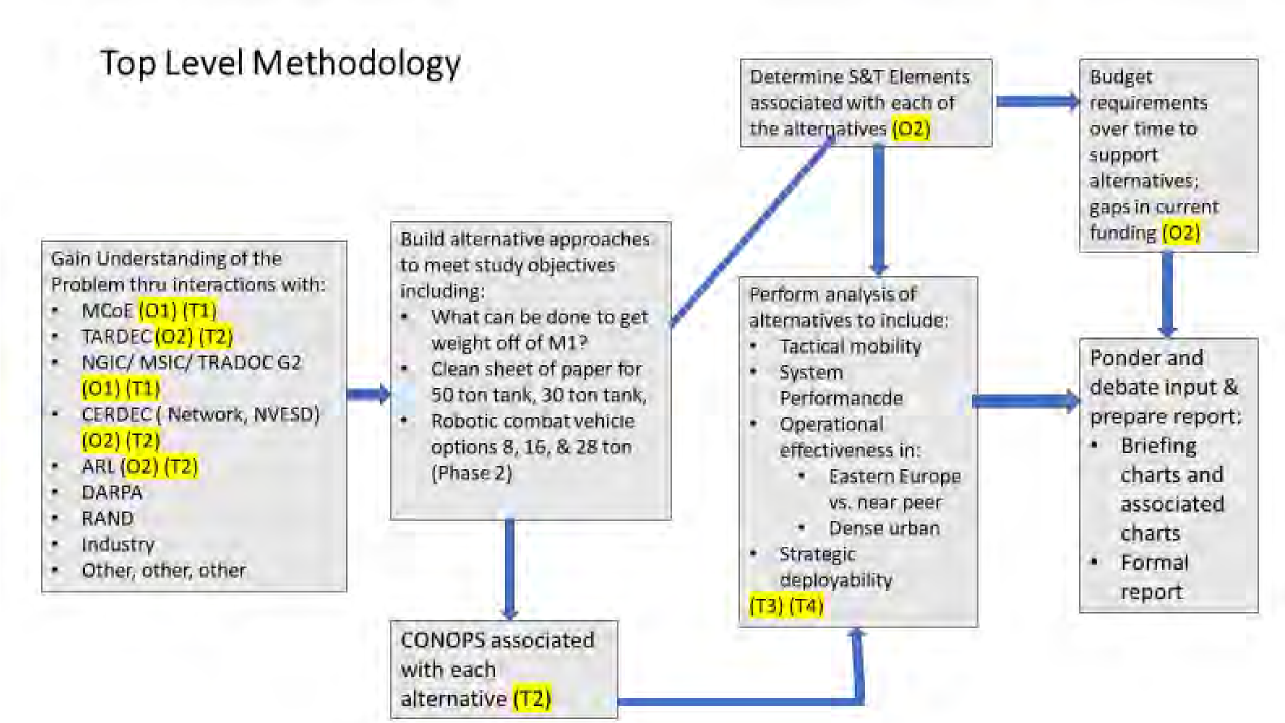
[8] Further discussed in classified annex.

a. NGCV EEA #1: Will these concepts enable strategic airlift within current aircraft parameters? Intra- theater transportability parameters?
b. NGCV EEA#2: What performance characteristics appear viable?
   - Target acquisition
   - Lethality vs. T-90 series
   - Survivability[9]
c. NGCV EEA#3: Are these NGCV concepts combat effective? Do they provide overmatch?
   - Data Analysis Center (DAC) Ground Wars analysis
   - Concepts Analysis Agency (CAA) COSAGE Analysis in Eastern European scenario[10]
d. NGCV EEA#4: Are there technologies that, if incorporated into the NGCV, would enable a Blue force to achieve a loss exchange ratio (LER) to be in the range of 3 – 5 under stressing battle conditions?[11]

6. Scope
   a. The scope of the study is limited to investigation and analyses performed by GVSC, DAC, CAA and ERDC working in conjunction with and in support of the study team. This analysis was focused on U.S. Army elements in the mid 2030's encountering the most likely Russian force in that timeframe in an Eastern European context.
   b. Unmanned force elements–both ground and air–were deferred to Phase 2 of the study.

7. Methodology
   The study team visited key agencies/stakeholders to gain an understanding of how future armored formations will organize and fight, the future threat, and emerging technologies potentially contributing to success on the battlefield. The team then explored what could be done to reduce the weight of the M1 and created two "clean-sheet-of-paper" designs: a two-Soldier crew concept weighing ~40 tons and a three-Soldier concept weighing ~50 tons. Due to time constraints, the introduction and analysis of unmanned systems was deferred until Phase 2 of the study. The study team worked with appropriate agencies for CONOPS and selection of potential high-payoff technologies and received analytical support from GVSC, DAC, CAA and ERDC (Fig. D.1.1).

[9] Ibid.
[10] Ibid.
[11] Ibid.



Highlights = TOR questions and tasks

Figure D.1.1 Methodology

8. Limitations
    a. Current force structure served as the basis for analysis, not the latest organization from the Maneuver Center of Excellence, which included robotic elements.
    b. The ASB didn't have sufficient funds to obtain support from TRAC, and therefore, the combined arms aspect of Battalion/Brigade offensive operations was not played, including *inter alia*, artillery fires, Apache support, or air defense in this level of maneuver warfare.
    c. The contribution of other domains in MDO (network, space, and cyber) were not a factor in force outcomes.
    d. The intelligence community was reluctant to make projections regarding how the Russian force would be equipped and what tactics they would follow during the timeframe for the ASB analysis.
    e. Urban operations were not treated.

D.2 DATA ANALYSIS ON M1A2 SEPV3[12]

The critical question of why the U.S. continues to require a ground combat vehicle as part of its combined arms maneuver team is addressed above in the main body of the report.

[12] The M1 EEA #4 regarding overmatch capability is detailed in the classified annex.

Based on its analysis of the data, the unanimous consensus of the study team was that the Army needed a new ground combat vehicle to provide leap-ahead capabilities and secure generational overmatch against near peer adversaries. Data supporting the determination was evident in each of the M1 EEA's.

D.2.1 M1 EEA #1: CAN THE M1 GET TO THE FIGHT?

The challenge with getting the M1 to the fight involved the need for multiple modes of transportation (Fig. D.2.1.1)

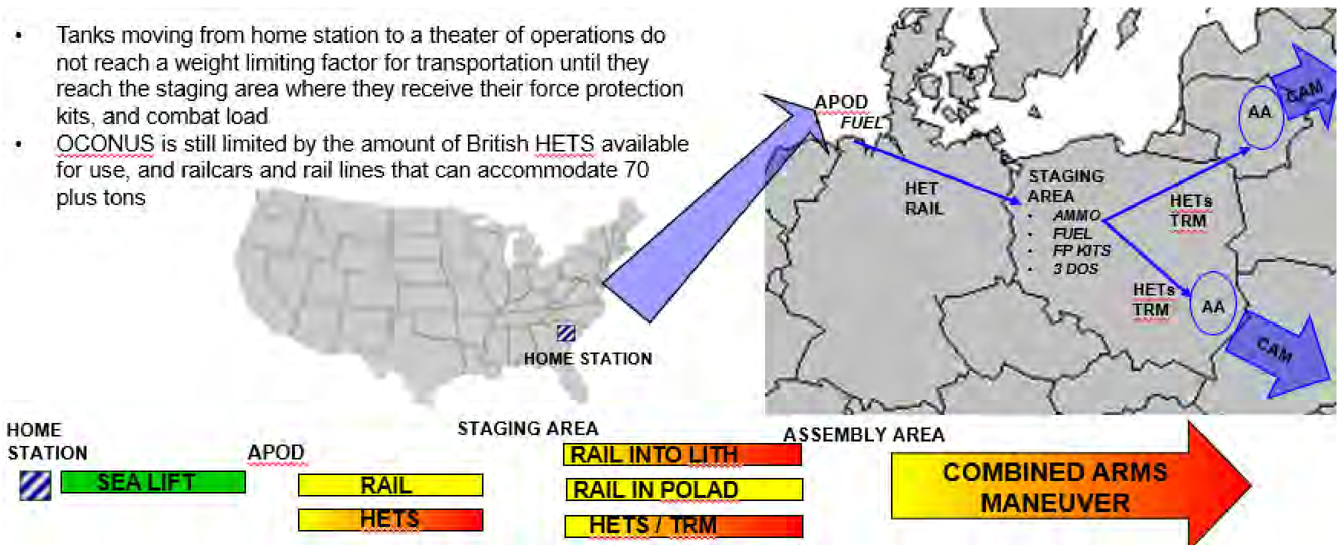


Figure D.2.1.1 Transporting the M1 Abrams

Data pertaining to the weights and dimensions of the M1A2 SEPv3 were obtained from a Transportability Statement by the Department of the Army Military Surface Deployment and Distribution Command Transportation Engineering Agency (Fig D.2.1.2). It concluded the "M1A2 SEPv3 CANNOT achieve transportability approval at this time."

The statement reviewed the capabilities and limitations encountered when transporting the M1A2 SEPv3. It indicated the vehicle at combat weight (73.59 tons) or with kits installed was beyond the capability of the HET and the Heavy Assault Bridge (HAB) (Fig. D.2.1.3). However, "a small number of the United Kingdom HETs are leased to move M1A2 SEPv2 tanks in NATO countries (Fig. D.2.1.4)."

The Transportability Statement also delineated how the sustainability requirements for the recoverability of the M1A2 SEPv3 were not met. When the platform was combat configured, it exceeded the tow limit of the current M88A2 Hercules, and testing demonstrated that two tow vehicles were required to recover an 80-ton MBT. Further, all combat configurations of the M1A2 SEPv3 exceeded the M88A2 70-ton capability.

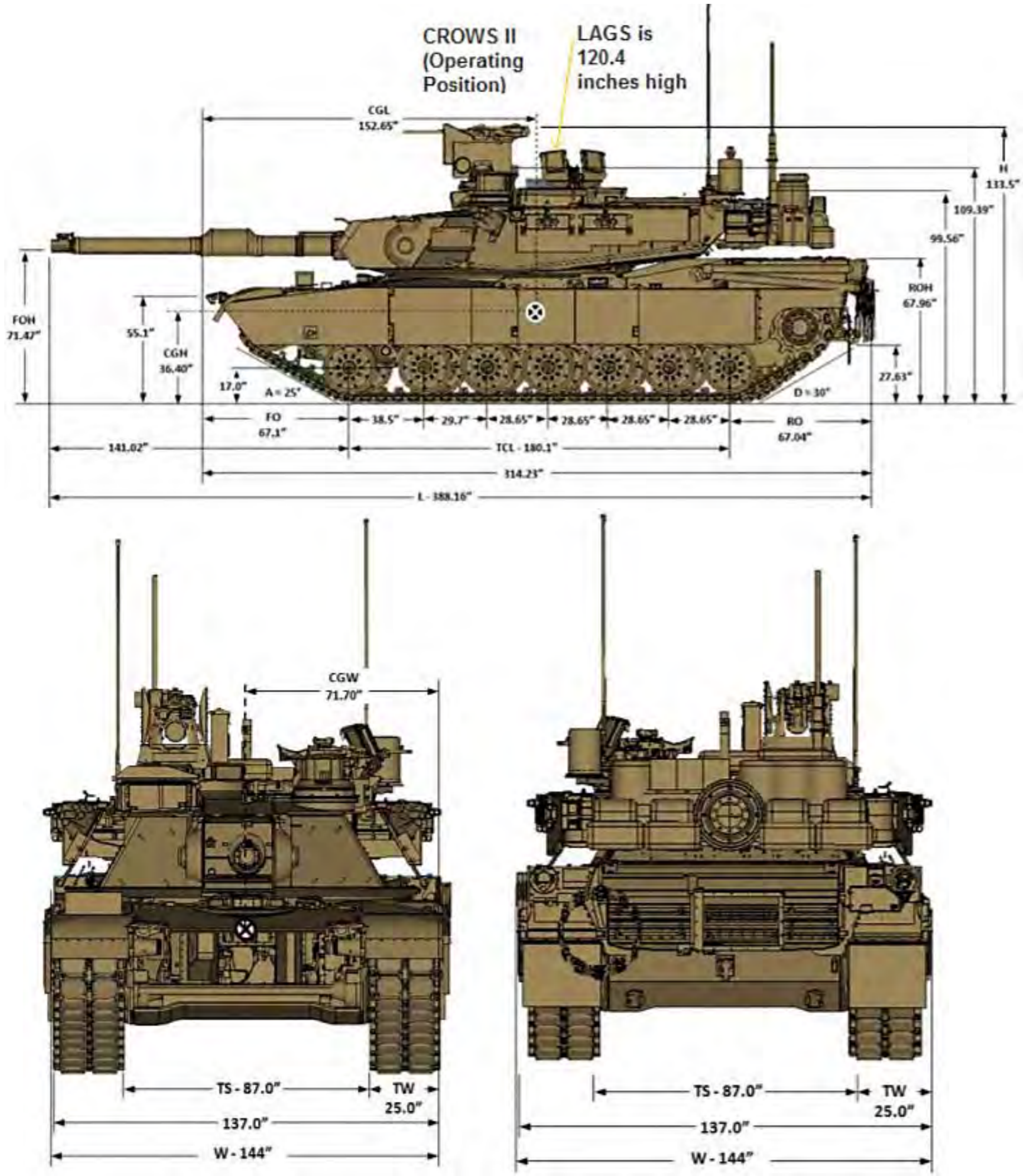


Figure D.2.1.2 Dimensions of the M1 Abrams

	Combat Configured with FP kits	Combat Configuration	Surface Transport (Reduced)	Air Transport
Length	388.2 inches	388.2 inches	371.2 inches	371.2 inches
Width	174.0 inches	144.0 inches	144.0 inches	137.0 inches
Operational Height	133.5 inches	133.5 inches	115.3 inches (CROWS II stowed & w/o LAGS) 120.04 inches (CROWS II stowed with LAGS)	133.5 inches
Gross Vehicle Weight (GVW)	157,000 pounds (78.50 tons)	147,180 pounds[1] (73.59 tons)	138,417 pounds[2] (69.21 tons)	132,619 pounds[3] (66.31 tons)
[1]Operational or Combat Configuration assumes 100% fuel and 100% ammunition and no FP kits				
[2]Surface Transport or Reduced Configuration assumes 10% fuel, no ammunition and no FP kits				
[3]Assumes 10% fuel, no ammunition and no FP kits with side skirts, BII, AAL, COEI, CTA-50, and ESML removed and palletized to get below C-17 and C-5 limits of 67.5 tons and 67.1 tons, respectively				

	Configuration	Weight
M1A2 SEPv3	Combat Load (100% fuel/ammo)	147,180 pounds (73.59 tons)
	Combat Load and Force Protection Kits	157,000 pounds (78.50 tons)
	Combat Load/Force Protection Kits/Mine Plow	164,560 pounds (82.28 tons)
	Combat Load/Force Protection Kits/Mine Roller	178,630 pounds (89.32 tons)
Force Protection Kits: ARAT I 1.28 tons, ARAT II 1.83 tons, Under Belly Armor 1.8 tons		
Mine Plow weight = 7,560 pounds		
Mine Roller weight = 21,630 pounds		

Figure D.2.1.3 Transportation Specifications of the M1 Abrams

Figure D.2.1.4 U.K. HET Hauling M88A2 Hercules

The M1A2 SEPv3 is capable of restricted rail transport in the U.S., NATO countries, and Korea, and passed a MIL-STD-810 rail impact test at a total weight of 71.86 tons (143,720 pounds). The SEPv3 must have CROWS II and LAGs stowed for NATO and Korea rail transport. Additionally, side grenade launchers need to be removed for Korea.

Items Removed for Rail Transport:
CROWS Weapon
Loader's Armored Gun Shield and weapon
Grenade Launchers
MOUS Antenna & Brackets
BFT Antenna & Brackets
Bustle Rack Extensions
Bustle Rack Items
Tank Skirts
Loader & Commander Sponson
Loader & Commander Sponson Items
Rear Hull Items

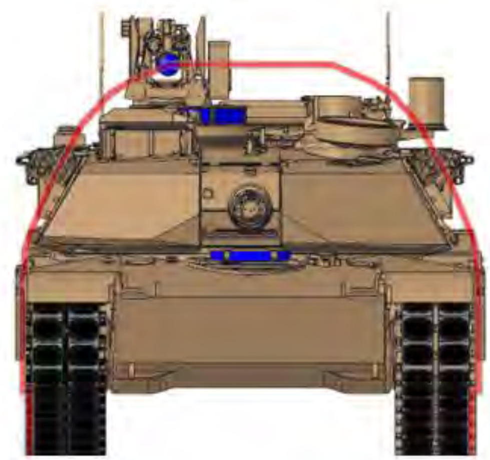


Figure D.2.1.5 M1A2 Rail Envelope
Source: DVECOM

To airlift M1A2 SEPv3 by C-17 Globemaster, the maximum load must be less than the current production weight. This can be accomplished by removing the side panels and requiring material handling equipment (MHE), reducing to 10% fuel, and unloading ammunition, all of which reduce the payload to 65 tons. The study team was also advised that the C-17's current ramp cannot sustain the M1A2 SEP v3 during boarding. Using the C-5 Galaxy, the maximum load is 68 tons, which would require unloading of the M1A2 SEPv3 components.

M1A2SEPv3 Transportability Gross Vehicle Weight = 146,920lbs. (73.46 Tons) NATO M Transport Weight = 137,725 (68.86 Tons)			
Category	Method (Range)	Max Payload @3,200nm (tons)	Max # of M1A2 SEPV3
Air	C-17 Non-ER (3,200nm)	65	0
	C-5M (3,200nm)	89	1

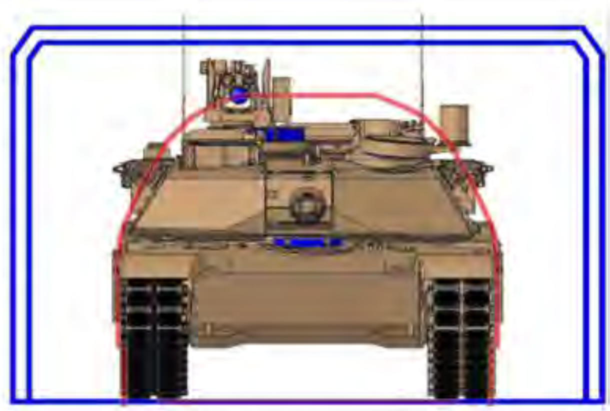


Figure D.2.1.6 M1A2 Air Envelope

Finally, the study team analyzed options for sealift. While not subject to the weight restrictions limiting airlift, available ports of debarkation still required intra-theater transport to staging areas, subjecting the transport to HET restrictions.

D.2.2 M1 EEA #2: WEIGHT REDUCTION MEASURES

The study team considered several options with two different weight reductions: a threshold goal of 4.500 pounds and an objective goal to reduce the weight to 70 tons. Three categories of weight reductions were specified: minimize schedule risk, minimize cost, and maximize total weight savings (Fig. D.2.2.1).

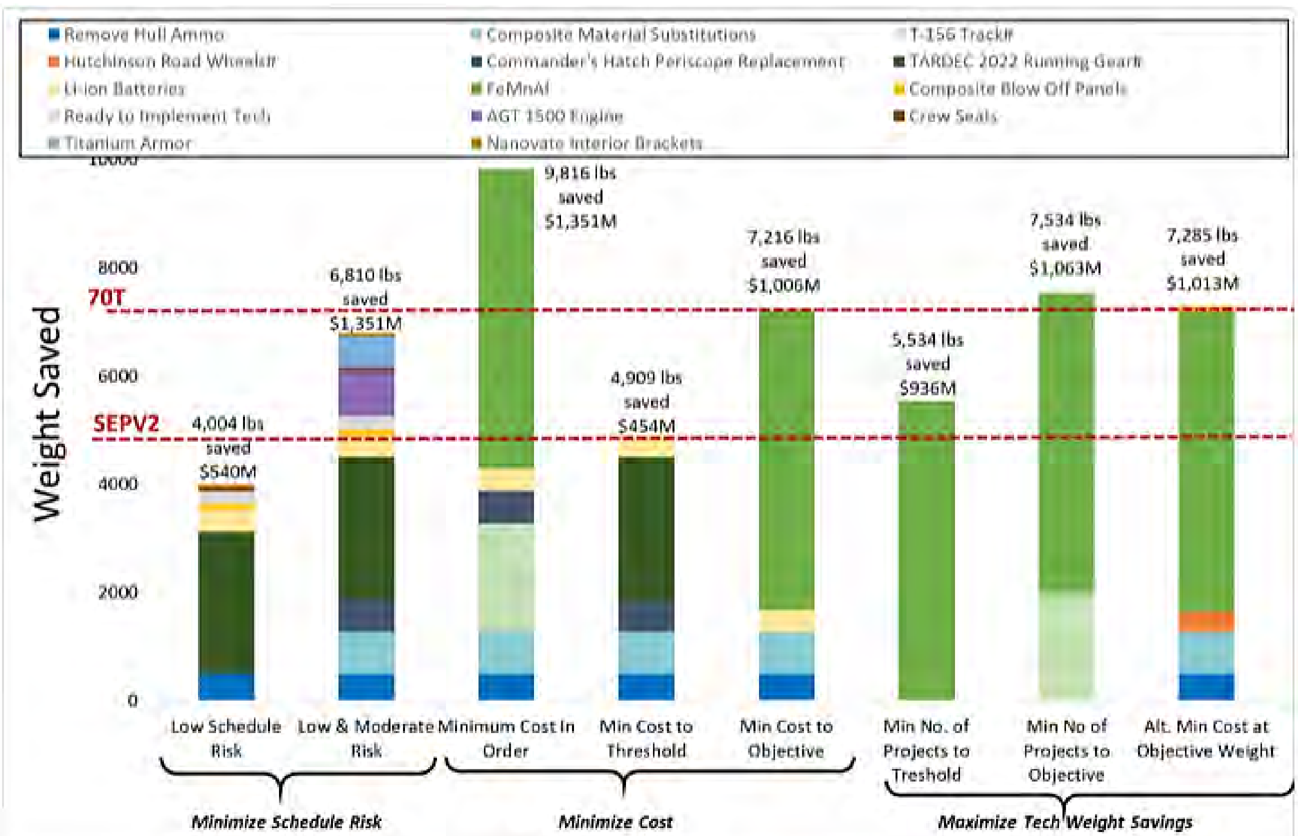


Figure D.2.2.1 Weight Saving Options: Actions and Technologies

The risk assessment revealed none of the various options provided sufficient weight reduction to permit C-17 transport (Fig. D.2.2.2). The advantage of getting to the 70-ton objective limit is that the M1A2 SEPv3 could be transported intra-theater by the HET vehicle. It should be noted that the force protection kits were not included in the M1A2 SEPv3 weights; they would have to be added in the staging area. This requires prior planning and pre-positioning of kits and MHE.

	COA	1. Low Risk	2. Low & Moderate Risk	3. Min $/lb. In Order	4. Min Cost to Threshold	5. Min Cost to Objective	6 & 7. Min No. Proj'ts to Threshold & Obj.	8. Alt. Min. Cost to Obj.
Threshold	List of Tech	Remove Hull Ammo, TARDEC 2022 Running Gear, Li-Ion batteries, Composite Blow Off Panels, Ready to Implement , Crew Seats, Nanovate Interior Brackets	Remove Hull Ammo, Composite Substitutions, Commander's Periscope Replacement, TARDEC 2022 Running Gear, AGT 1500 Engine	Remove Hull Ammo, Composite Material Substitution, T-156 Track, Commander's Periscope Replacement, Li-Ion Batteries, FeMnAl	Remove Hull Ammo, Composite Material Substitution, Commander's Hatch Periscope Replacement, TARDEC 2022 Running Gear, Li-Ion Batteries	FeMnAl	FeMnAl	FeMnAl
	Total Cost	$540M	$454M	$1,199M	$454M	$935M	$935M	$935M
	# of Projects	7	5	7	5	1	1	1
	Weight Saved * (lbs)	4,004 (NEITHER)	4,909 (THR)	9,816 (OBJ)	4,909 (THR)	5,534 (THR)	5,534 (THR)	5,534 (THR)
Objective	List of Add'l Tech		Ready to implement Tech, Li-Ion Batteries, Composite Blow Off Panels, Crew Seats, Ti Armor, Nanovate Brackets	N/A Technologies listed above already meet Objective		Remove Hull Ammo, Composite Material Substitutions , Li-Ion Batteries	T-156 Track	Remove Hull Ammo, Composite Material Substitution, Hutchinson Road Wheel
	Ttl. Cost ($M)		$1,334M			$1,006M	$1,063M	$1,013M
	Ttl. # of Projects		11 total			4 total	2 total	4 total
	Weight Saved		6,810 (THR)			7,216 (OBJ)	7,534 (OBJ)	7,285 (OBJ)
	Schedule Risk		Low - Med		Low - Med	Med - High	Med - High	Med - High

* Based on Weight Savings Targets of 4800 lbs (THR: Threshold) and 7200 lbs (OBJ: Objective)

Figure D.2.2.2 Projected Weight Savings, Technologies Incorporated, and Schedule Risk

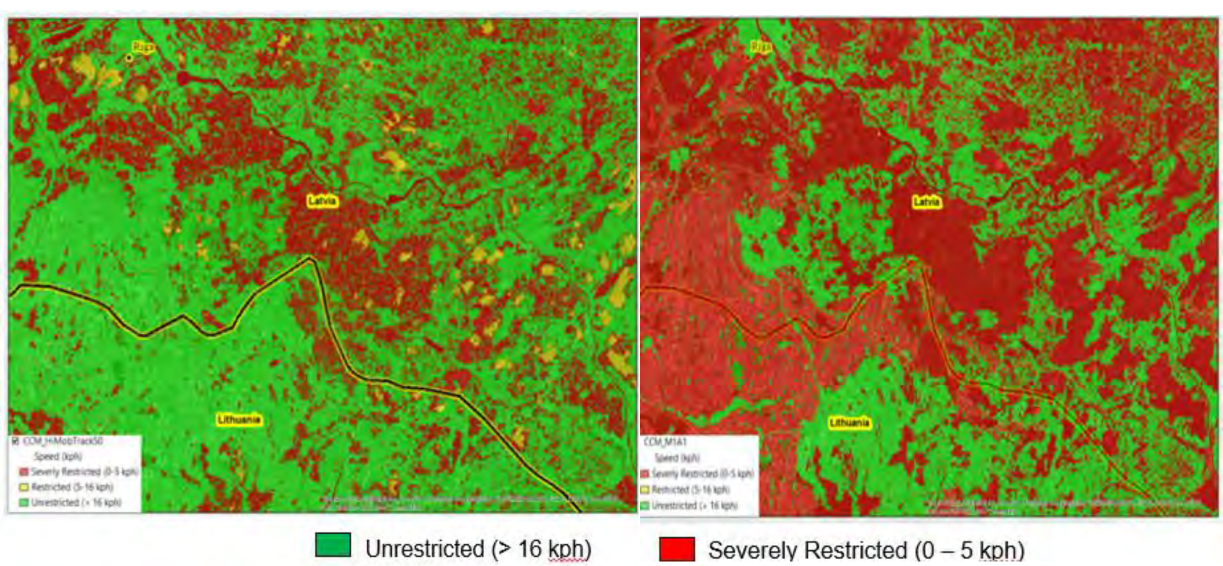
Several options were available to reduce the weight of the M1A2 SEPv3 to make it compatible with the U.S. HET. All options were costly, raising the question as to whether the funds are better spent on reducing the M1A2 SEPv3 weight or allocated to some other project, such as maturing technologies applicable to the next-generation combat vehicle.

D.2.3 M1 EEA #3: TACTICAL MOBILITY IMPLICATIONS

ERDC supported the study team with a terrain analysis of a selected region of North Eastern Europe covering portions of Latvia and Lithuania (Fig. D.2.3.1).

Figure D.2.3.1 Area Selected by ERDC for Terrain Analysis

ERDC also performed a cross-country mobility analysis of the M1A2 under both dry and wet conditions (Fig. D.2.3.2). During the wet season, cross-country mobility was significantly restricted (0-5 km/hour). During the dry season, the terrain in Lithuania permits relative ease of movement, whereas movement in Latvia largely restricted.



Wet Season **Dry Season**

Figure D.2.3.2 Seasonal Mobility Analysis

ERDC also performed a LOS analysis of approximately 25 points scattered throughout the selected region. LOS in the Latvia terrain was restricted, whereas in Lithuania, LOS out to a range of 5+ km was possible from multiple points. That range would permit Russian T-90 MS employment of their gun launched, ATGM (e.g., Refleks) out to its full range (Fig. D.2.3.3).[13]

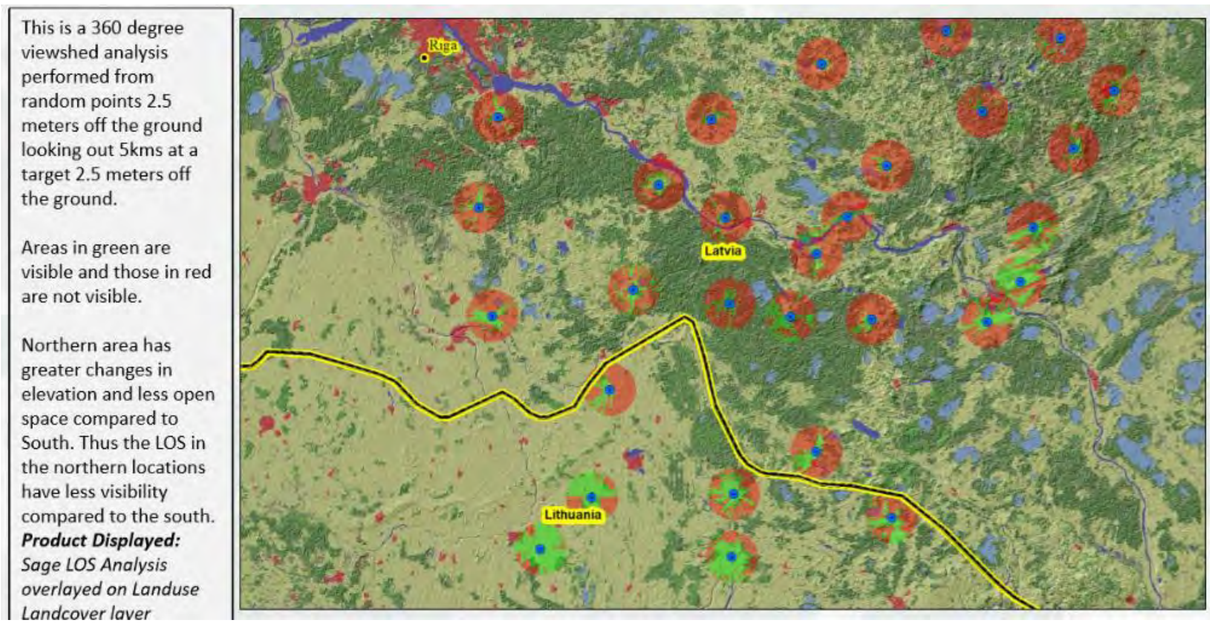


Figure D.2.3.3 Line-of-Sight Range for Points within Selected Region

An analysis of bridge load capacity was obtained from maps dating from when the region was part of the Soviet Union (Fig. D.2.3.4).[14] The vast majority of bridges in the region are rated at less than 30 tons. Even with a safety factor of 2.0, these small bridges could reasonably be expected to support an M1A2 SEPv3 in combat configuration bridge crossing. Most of the bridges in Latvia would not permit M1A2 SEPv3 crossings. The river/stream network in Lithuania is not as dense as that of Latvia, and bridge crossings would not be as significant.

ERDC also provided an analysis of obstacles to movement such as swamps and forested areas. the selected region with respect to what might restrict movement (Fig. D.2.3.5). Movement throughout Latvia was restricted where forests and swamps were prevalent. There were a few areas within Lithuania where terrain relief could be a factor.

[13] The aspect of engagement range has been analyzed by DAC and is covered in the classified portion of this report.

[14] These maps were obtained when the countries joined NATO and are now held by the Army Geospatial Center.

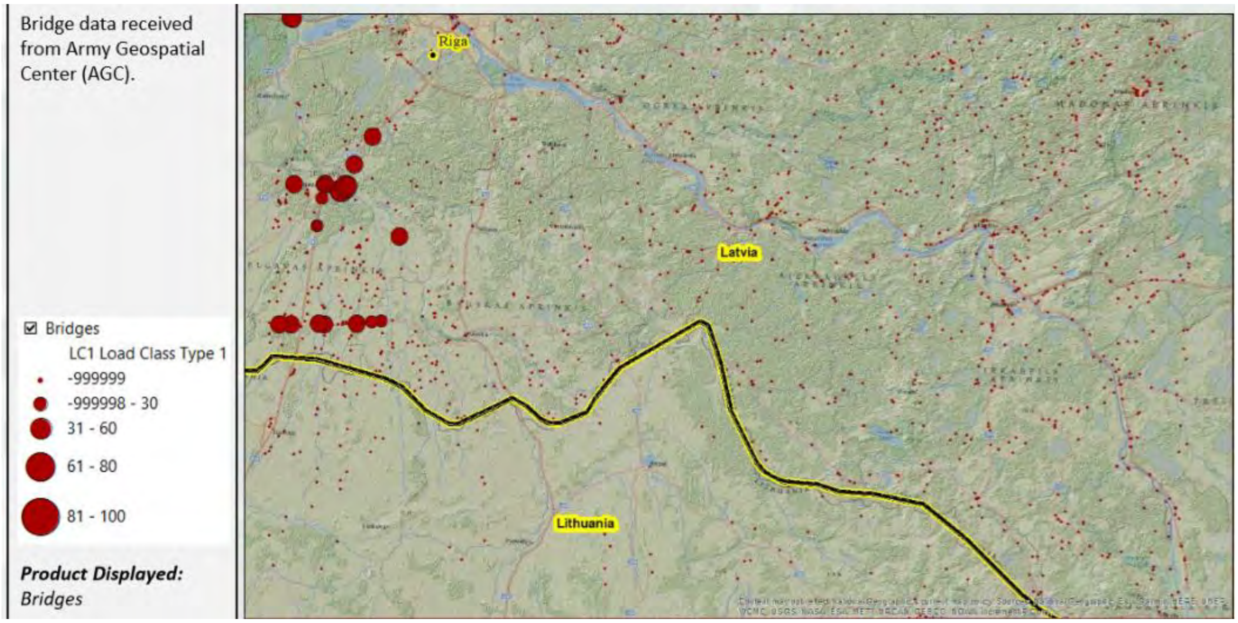


Figure D.2.3.4 Bridge Categories within Selected Region

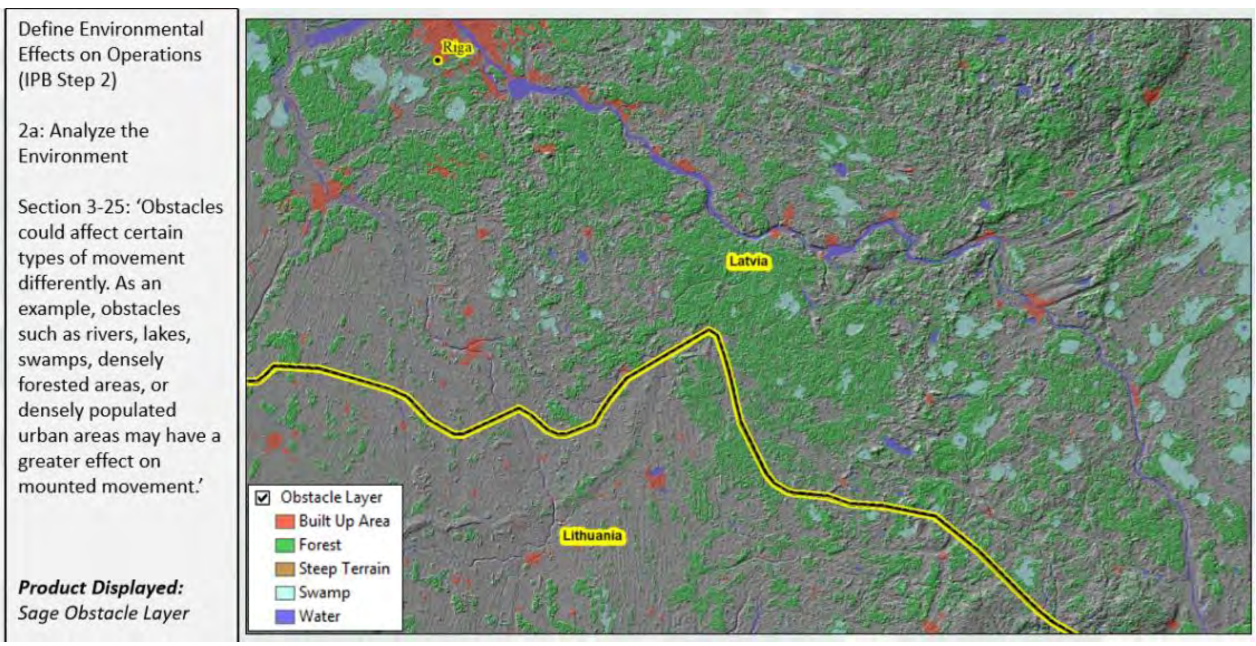


Figure D.2.3.5 Obstacles to Movement in Selected Region

As a result of these analyses, the study team concluded that the M1A2 SEPv3 in combat configuration could not reasonably be expected to conduct maneuver warfare in that portion of Latvia selected by ERDC. On the other hand, maneuver warfare would be possible in the portion of Lithuania, but only during the dry season. Thus, the overall tactical mobility implications of the M1A2 SEPv3 indicate severely restricted operations.

D.2.4 M1 EEA #5: SUPPORTABILITY DURING PROLONGED OPERATIONS

The study team analyzed the M1A2 SEPv3's fuel consumption, the mean time between failures, and the mean time to repair. Fuel consumption was extremely high, with typical re-filling operations leaving the formation vulnerable to adversary fires, which could halt an entire offensive operation. The mean time between failures was approximately 200 miles, posing potential problems for extended operations. Maintenance was further exacerbated due to limited supply parts on hand, complicating repair activities. Together, these factors made a road march along MSR impractical, further limiting intra-theater transport options.

D.2.5 CONCLUSIONS

The study team determined the most practical way to get the M1A2 SEPv3 to the fight on time would be to pre-deploy armor assets prior to outbreak of hostilities. Sealift was the most viable means of getting to theater, but intra-theater transport could not be counted on to support movement to the area of operations. Beyond the transport challenges, maneuver warfare was highly constrained in the selected area.

For these reasons, the study team concluded a replacement for the M1 series MBT was required to conduct offensive operations in support of the combined arms team.

D.3 DATA ANALYSIS ON NGCV

The study team conducted multiple interactions with GVSC personnel discuss tank technologies and the status of GVSC advanced projects. As the limitations of the M1A2 SEPv3 became apparent, the study team requested GVSC support in preparing two alternative concepts: a ~50 ton, 3-Soldier crew concept; and a ~40 ton, 2-Soldier crew concept. During the interactions, the following general guidance was agreed upon:

- The most expeditious way to meet the projected weight requirement was to reduce the crew size from 4 Soldiers to either 3 or 2 and to place the crew in the hull to reduce the turret size. At the time juncture of the visit, the Army Chief of Staff had introduced the idea of an optionally manned turret, which was considered as a constraint.
- Mobility ≥ M1 Abrams
- KE lethality ≥ M1 Abrams
- Modular tank KE and top attack ammunition were essential elements
- Integration of Modular Active Protection Systems (MAPS) with future growth
- Hybrid electric power train

- High voltage architecture (600 v DC)
- Modular force protection and C5ISR subsystems
- Crew reduction aided by mobility automation, AiTDR, common crew stations, etc.
- TRL 6 by 2028

Details on the two concept platforms are provided in the classified annex to this report.

APPENDIX E. THE CASE FOR 5TH GENERATION MOBILE STRIKING POWER

> **It must be the role of technology to provide weapons systems which render ineffective costly investment by our foes… by introducing new imponderables into the traditional calculus of battle.**
>
> *General Donn Starry.*

The proliferation of long-range smart munitions and miniaturized networked sensors has created a battlefield dominated by precision fires. The U.S. has worked to perfect long-range precision fires (LRPF) over the past fifty years, but now its potential enemies have caught up. An LRPF complex, augmented with a continually improving sensor web and controlled by AI, is recognized by our opponents as the battle-winning weapon system of future wars. Historically, whenever fires have dominated the battlefield, the battlefield area expands and becomes empty as Soldiers and systems stop moving and go to ground for protection. In future high-intensity conflicts against peer opponents, the density and effectiveness of precision fires could potentially deny both sides the ability to move across the battlefield and compel units and systems to seek cover and limit electronic emissions.

If, on the other hand, formations could move across a battlefield dominated by precision-fires, they would gain a tremendous advantage. Winning against a peer competitor will require rapid, decisive maneuver that generates a time advantage over the opponent. If the Army cannot maneuver across the land, it will greatly diminish U.S. forces' ability to apply fire and maneuver.

E.1 THE PRECISION-FIRES BATTLEFIELD

During the Cold War, the battlefield equation that all forces operated under was: "If you can be seen, you can be hit, if you can be hit, you can be killed." If trends in the development and convergence of LRPF, sensors, and AI augmented targeting continue, tomorrow's battlefield will be dominated by brilliant precision fires that are becoming more capable every day. In this case, the precision fires battlefield equation would be something like: "If you emit any signature anywhere on the EM spectrum (not just seen, but sensed), you can automatically be targeted (identified and located), hit, and killed." The speed of the kill-chain, currently measured in minutes, will soon be possible in seconds.

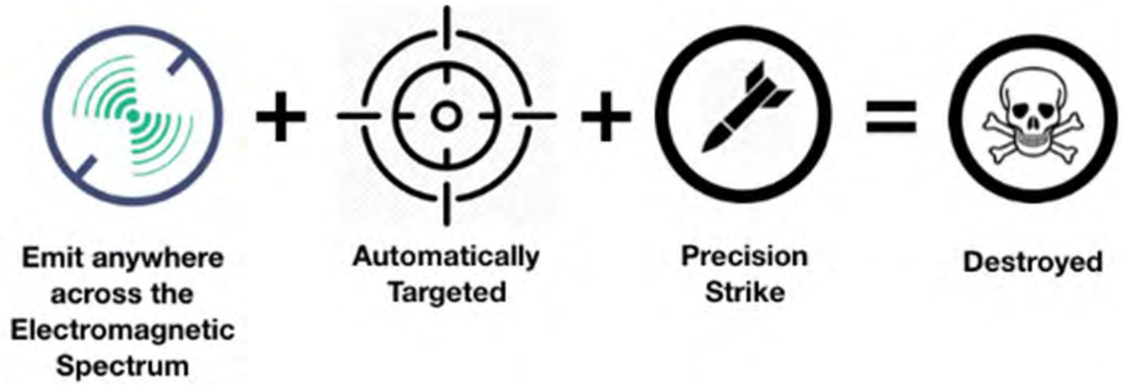


Figure E.1.1 The Precision Fires Equation

To execute MDO and restore maneuver to the battlefield, the precision-fires equation must be overturned. Executing MDO under the conditions described requires an offensive capability to move with speed across contested terrain, maneuver to the enemy's gaps with formidable mobile striking power, and place the enemy on the horns of a dilemma, forcing him either to run, surrender, or face destruction. This is the essence of striking power. In today's era, it may be defined as a central factor in executing MDO; as the ability to conduct sustained, direct fire attack and rapid maneuver across a battlespace dominated by a network of sensors and precision fires. Accomplishing it will require newly designed ground combat vehicles.

E.2 THE 5GENCV

To provide the mobile striking power needed to produce dominant maneuver in a hyper-lethal battlespace, the study team has endeavored to think outside the primary design factors of the tank: firepower (F), mobility (M), and protection (P).[15] In doing so, the study team conducted a survey of the historical development of the tank, determined where leap-ahead technologies marked a generational shift in design and capability, and extended the evolution of the next/5th generation based upon emerging technologies (Fig. E.2.1):

- **CORE TANK CONSIDERATIONS -** Firepower (F); Mobility (M); Protection (P); C2 (Command and Control)

- **ENDURING CONSIDERATIONS -** Reliability and Maintainability (R); Reliability and Maintainability (R&M); Deployability (D); Human Factors (HF)

- **EMERGING 5th GENERATION TECHNOLOGIES -** Computing and AI (C+) [embedded and external]; Masking (MA); Networking (N); and Robotic Systems (RS)

---

[15] These three parameters form a triangle, as represented by Richard E. Simpkin in his seminal book entitled "Tank Warfare," and were used to explain the relative priorities of any particular tank design. This triangle design philosophy was so powerful a concept that it was used as the model for the shoulder patch of US Army Armored Divisions.

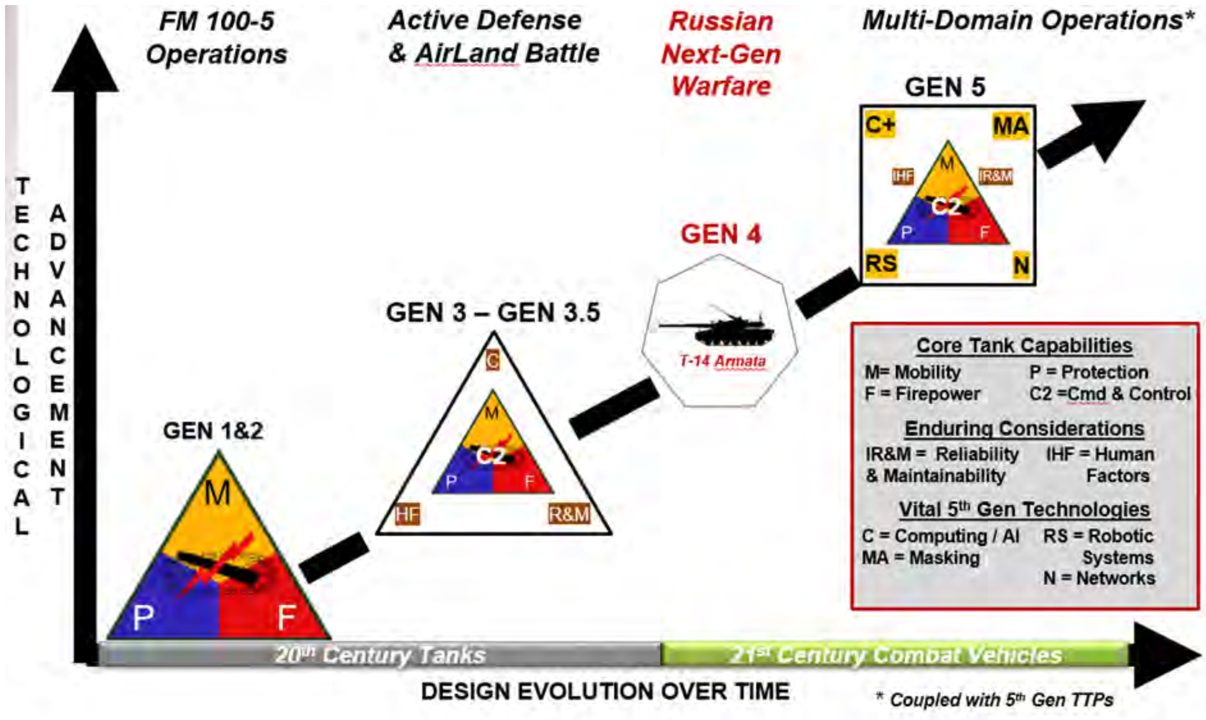


Figure E.2.1 Direct Fire Combat Vehicle Evolution

Focusing on today's platforms and capabilities, The U.S. M1 Abrams represents the third generation with its enhanced Reliability and Maintainability (better engine maintenance and rapid engine replacement design), Human Factors, and Computing (better electronic computer systems for targeting, maintenance, and improved situational awareness). The Russian T-14 Armata represents the fourth generation, with a three-man crew in an armor-protected compartment, operating a remote (and potentially automated) turret-gun-system. The Armata's leap ahead technology enables the fusion of accelerated target sensing, identification, and targeting at machine speed. The potential exists for a crew to maneuver the tank, use sensors to automatically search for targets, and enable the tank commander to direct/authorize an automated turret to engage targets. As the system improves and target identification and firing speeds are maximized, a robotic turret has the potential to revolutionize battlefield engagements.

Restoring U.S. overmatch in combat vehicle maneuver will require rethinking how to design, develop, and employ mobile striking power. A fifth-generation system will require masking and speed as definitive characteristics. The systems should also be maximized to operate in a heavily degraded environment, allowing formations to move across the LRPF battlefield under intense jamming. They must be un-targetable by most of the enemy's sensors to frustrate enemy decision-making. Leading the way, these 5GenCVs could generate the rapid freedom of maneuver that can achieve tactical objectives by defeating enemy forces in multiple domains.

The study team believes ground maneuver will continue to be a critical element in generating decisive actions on the battlefield. To overturn the precision fires equation, the 5GenCV must:

- Be difficult to detect across the entire EM spectrum
- Move rapidly enough that it can avoid becoming fixed by the enemy's fires
- Have sufficient embedded computing power to operate the latest C4ISR systems that enable a persistent stream of meaningful information, despite facing worst-case EW and cyber-attack scenarios
- Be designed with active and passive countermeasures to defeat enemy strikes and to project a false picture of the battlefield.

In short, it needs to be designed differently than the current fleet of armored vehicles.

APPENDIX F. PROPOSED TECHNOLOGY TESTBEDS

The study team identified nine testbeds and associated critical technologies divided along the three categories of capabilities and technologies that define the 5GenCV (Fig. F.1).

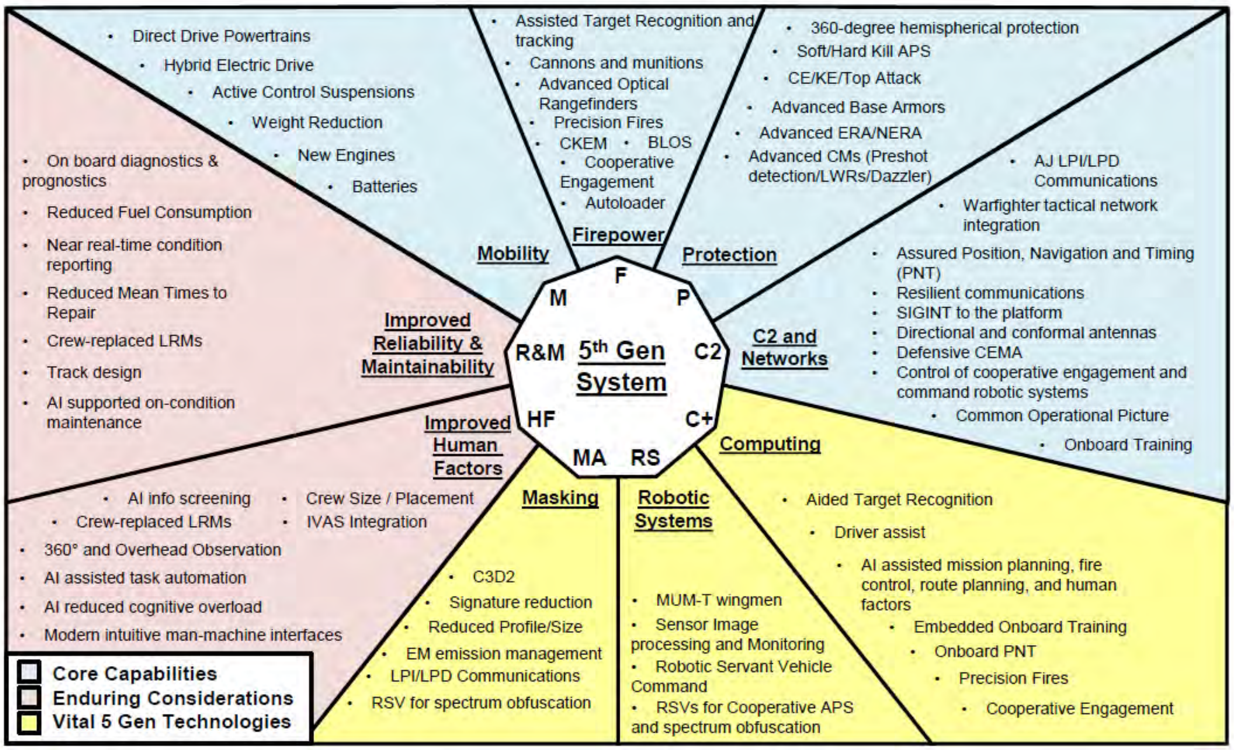


Figure F.1 Nine Testbeds and Associated Critical Technologies

F.1 MOBILITY

Mobility includes everything required to move the system, such as prime power (engine), transmission, cooling, battery, and suspension (track, final drives, roadwheels, etc.). Key design decisions that are required to be made early on include gross vehicle weight (GVW), mechanical vs. hybrid electric propulsion, track vs. wheels, quiet operation time, peak and steady-state power requirements, and amount of growth. After these key decisions are made, initial design is completed, and test assets can be started. An automotive test rig (ATR) is typically used to test out mobility. Prior to this, the major components all complete component testing. The engine is tested in an engine test cell.

Internal combustion engines remain the only viable power source for combat vehicles. Fuel cells are gaining in capability and already have applicability to tactical vehicles, generators, and systems that can utilize filling-station type reformer locations. Carrying hydrogen in combat vehicles is incredibly challenging due to the inherent vulnerability and corresponding armor required. On-board reforming requires too much volume. The NATO 400-hour test is conducted to prove maturity. A good rule-of-thumb is that 20 hp/T (horsepower/vehicle weight in stons) is required for racked combat vehicles.

Transmissions (whether mechanical or electrical) are also tested in separate cells prior to integration with the engine. An early test asset for the integrated powerpack (engine, transmission, heat exchanger, fans, generators, controllers, etc.) is called a HotBuck, which allows easy access to all components and is tested using dynameters in a lab. Control software and all hardware are developed, refined, and matured. The test asset (if configured with correct air flow) can also be used to provide first cooling test (full-load cooling test).

External suspension (where the torsion elements are contained outside the hull structure) is desirable for reduced internal volume. Torsion bars have typically been used but result in greater vehicle heights (~8" due to the structure of the underbelly blast deflections). Another type of external suspension provides active (or semi-active) control. Active suspension allows for higher cross-country speeds. External suspension becomes more complex when used in rough operating environments, so extensive testing is required. Active suspension provides greater flexibility (adjustable ride height) but requires a power source and plumbing.

Track improvements are becoming available (lighter weight, lower friction). Band track provides significant reductions in friction, reducing fuel consumption potentially by 50%. The weight capabilities for the band track are increasing, now up to 45-50T (on 6 road wheels). Continued improvements may make it applicable to a new GCV. Industry projects that a composite rubber track system capable of supporting a vehicle of 55T may be ready by 2023.

Ground pressure and ride height are critical parameters determining cross-country mobility. Lower ground pressure is desired; for example, current systems are ~13 psi and ~10 psi is desired.

The ATR will be tested in both lab and on track/measured courses, allowing the integration of crew-station (seats, inceptors, displays, etc.), structure, auxiliary items, vehicle electronics, and environmental control system.

A chassis prototype includes everything in the ATR plus all chassis components. This mobility testbed process is an accepted one for combat vehicle development and therefore the costs, components and tests that are conducted are well understood. The costs reflected in the study team's assessment are consistent with similar work recently conducted on the ground combat vehicle, which had a chassis weight similar to that expected for a 5GenCV. To make the testbeds relevant to the objective design, enough system-level design work needs to be completed, including the high-level system trades such as GVW, growth, number of crew and configuration, type of propulsion (mechanical or HED), general chassis size (width and length), etc.

Recognizing that balanced designs usually result in compromises, the study team identified the following mobility requirements:

- Speed on cross-country mobility: traverse specified course at an average speed of no less than 30 kph and at an averaged absorbed power of no more than 6 watts input into any occupant seat.

- Traverse NRMM hill terrain: traversing cross-country terrain IAW NATO Reference Mobility Model at V50 speeds (e.g., wet/dry at 20/25 mph and sand/dry at 18/25 mph).

- Vehicle cone index: traverse soft soil (mud) with a Vehicle Cone Index 1 (VCI-1) no greater than 25/15.

- Ground pressure: possess a nominal ground pressure of no more than ≤13 psi.

- Pivot steer: execute a turn on the vehicle's axis within 1.5 times vehicle length.

- Controlled 360-degree turn: execute a controlled 360-degree, left or right, turn and the entire vehicle stay within a 27 feet diameter.

- Climb slope with start/stop: climb and descend a 60% slope on dry hard surface while allowing the driver to maintain safe vehicular control in forward and reverse, braking, stopping, and starting without leakage.

- Traverse side slope, forward/reverse: laterally traversing a 40% dry hard surface side slope, in forward and reverse.

- Gap crossing, forward/reverse: cross a 2-meter trench in forward and reverse.

- Ford water: capable of fording in forward and reverse, at a depth of up to 36 inches without preparation.

- Climb obstacle, forward/reverse: capable of climbing, in forward and reverse, a vertical obstacle of up to 32 inches high.

- Braking effectiveness: when traveling on a dry level hard surface at 20 mph, stop within 35 feet from point of service brake application.

- Side drift: not exceed 3 feet of side drift over the 35-foot stopping distance.

- Pedal force: not require more than 220 lbs. of pedal force to operate the braking system.

- Brake fade: before and immediately after being subjected to 20 consecutive decelerations.

- Dead engine steer: provide the vehicle with braking control in the absence of engine power.

- Dash speed: accelerate from a standing start to 20/30 mph on level hard surface road within 9 seconds.

- Top speed: travel on a primary surface at sustained speeds of no less than 40/60 MPH forward, 15/25 MPH in reverse.

- Full load cooling: deliver a minimum continuous, steady-state operation at 0.7 tractive effort to weight ratio.

- Differential tractive effort: deliver a minimum tractive effort to weight ratio of 1.0.

- Single track tractive effort/weight ratio: deliver a minimum tractive effort to weight ratio of 0.9 at zero speed for 15 seconds on one side of the vehicle.

- Fuel consumption: traverse for 157 miles and stationary idle for 28 hours without refueling.

- Fuel type: use JP-8 as a main propulsion fuel.

- Startup to perform full essential functions (i.e., move, self-defend, shoot, and communicate) within 300/180 seconds after selection of Master Power-on.

- Immediate movement capability (to include internal crew communications and using passive optical means for driver viewing) within 30/15 seconds after selection of Master Power-on.

- Have sufficient mobility in degraded mode (e.g. short track, loss of roadwheel(s) or loss of transmission lower gear), to continue the operation.

- Conduct stationary operations in silent mode, operating key systems, (e.g., C2 suite, onboard sensors, integrated protective suite, weapon fire control, crew station and environmental control for electronics cooling and crew compartment(s)), for a period of 6/72 hours.

F.2 FIREPOWER

The proposed firepower testbed would supplement current development to accelerate the maturation of technology enabling a highly lethal, advanced direct fire solution for heavy combat vehicles. Adversaries' fielded and developmental platforms already have highly capable passive and reactive protection systems, and the incorporation of an APS will further enhance their survivability against U.S. anti-armor munitions. There is an urgent need for advances in the lethality in U.S. anti-armor weapons systems.

The U.S. is one of the few countries in the world that does not employ an autoloader in its tank. Autoloader technology is mature, but the development of this critical component subsystem must be expanded to achieve the high reliability and desired rate-of-fire. For example, a demonstration/validation prototype of state-of-the-art components would reduce technological and integration risk. Although a high-capability autoloader will add weight to the vehicle, in the aggregate it will reduce overall platform weight by reducing the required volume under armor.

Extended Line of Sight (ELOS) and BLOS are defined as engagement ranges from 3-5 km and beyond 5 km, respectively. ELOS engagements require enhanced optics, which may include a combination of next generation FLIR, reconfigurable image sensors, variable wavelength (short- and medium-wavelength) FLIR, and rounds that are fired with ballistic solutions but employ terminal guidance to greatly enhance hit probability. BLOS is not optimal for a direct fire ground combat system or tank-like vehicles for several reasons. Achieving desired lethal effects at range would likely require different, larger rounds, reducing the number of onboard stowed kills. Although technologically feasible for a combat vehicle to receive targeting data from other sources and have its rounds employ terminal guidance to hit targets painted with a coded laser, BLOS has negative tactical ramifications. For example, it can serve to unmask the forward line of troops and distract the vehicle's crew from the close fight, which is where a heavy combat vehicle makes its greatest contribution to the capabilities and overall effectiveness of the combined arms team.

Current direct fire systems rely on ballistic firing solutions generated by a fire control computer for accuracy. This ballistic firing solution is the result of calculations that include vehicle speed, target distance, target speed, turret cant, crosswind speed, barometric pressure, air temperature, ammunition temperature, and gun-tube droop. On-vehicle sensors provide accurate and reliable measurements for vehicle speed, turret cant, crosswind, pressure, droop, and temperature. Target distance and estimated target speed are dependent on accurate range estimation. On M1 tanks, range estimation is provided using a laser rangefinder. Shortcomings of the laser rangefinder, coupled with the physics of beam propagation and beam spread, are exploitable by adversary APS that can degrade the accuracy of ballistic solutions and reduce the effective range and the probability of first-round kills. Alternative rangefinders, such as image scaling, should be developed to produce more accurate ballistic solutions. The addition of terminally guided rounds would significantly enhance accuracy compared to that for currently fielded tank rounds and thus increase first-round kill probability.

Gun-launched ATGMs create several problems for direct fire cannons. Generally, ATGMs require an alternate loader or alternate launch means due to the size difference between conventional KE/CE rounds and ATGMs. ATGMs also require different storage methods than conventional rounds. Both considerations combine to reduce the number of KE/CE rounds that a combat vehicle can store on board, which axiomatically reduces the number of stowed kills available.

The study team identified four projects for firepower testbed:

1. Evaluate main gun options. The evaluation should include Rheinmetall's 130-mm cannon currently under development, a 157-mm straight chamber cannon, or other alternatives to be identified through an AoA. To generate the kinetic energy necessary to be effective, guns will need to be larger caliber to allow larger warheads to be fired at higher velocities.[16] A three-year program at an estimated cost of $150M is recommended.

2. Development/evaluation of a range of cannon-fired high-performance munitions. Technologies offering significant potential for enhancing the lethality of tank-fired munitions include KE, Multi-Purpose/Chemical Energy (MP/CE), Multi-Purpose Extended Range Munition, (MP-ERM, currently under development), ELOS technology, course-correction technology, and high-performance CE shape charge/Explosively Formed Penetrators (EFP) warheads. A three-year program at an estimated cost of $250M is recommended.

3. Autoloader design/development/evaluation. This should include turret integration. A three-year program at an estimated cost of $225M is recommended.

4. Evaluate advanced munitions options. Such munitions include a guided gun-launched rocket-assisted KE (RAKE) round capable of engaging enemy targets at greater ranges and achieving greater armor penetration; a tube-launched CKEM capable of achieving >20-30MJ on target, demonstrated by AMRDEC in the 1990s; and a GLATGM having both a long-range engagement capability and high hit probability. If development and evaluation efforts are successful, these munitions could provide significant new lethal capabilities for ground combat forces. Given anticipated advances in cannon technology and other high-performance munitions developments, however, these advanced munitions options may not be required for fielding. A four-year program, to be conducted in parallel with the noted other projects, is recommended; its estimated cost over that period is $300M.

F.3 PROTECTION

The proposed Protection testbed is designed to supplement current activities/funding and accelerate the schedule for developing a protection suite that could be used in a system level platform competition of a 5GenCV in the timeframe FY 25-29. The protection suite should include the integration of advanced developments in base armor along with ERA, non-explosive

[16] Kinetic energy defined by formula $KE = \frac{1}{2} mv^2$. By increasing mass (m) and velocity (v) of the warhead, the resultant kinetic energy growth can be nonlinear.

reactive armor (NERA), advanced underbelly protection, both hard and soft kill robust APS, and other advanced survivability countermeasures such as laser warning receivers (LWRs), Radar Warning Receivers (RWRs), and Optical Augmentation lasers that can address the full range of future KE, CE, and top-attack threats. Such a suite is designed to significantly enhance the survivability of a 5GenCV at reduced weight compared to the current M1A2

Base armor, along with ERA and NERA, needs to protect the vehicle and its crew from threats that cannot be defeated by the other countermeasures in the protection suite (e.g., APS). Advanced base armors including designs involving the selective use of ceramic materials, need to be developed and evaluated for their effective use against future threats. For a 5GenCV, threats that this armor needs to protect against are anticipated to be medium caliber KE projectiles fired in bursts, which are extremely difficult for other countermeasure systems to negate. In addition, advanced ERA/NERA concepts/designs need to be developed and evaluated for their ability to degrade the performance of threat KE and CE munitions including top-attack shaped-charge jets and EFPs. Such threats, along with artillery and other battlefield fragmenting munitions establish the armor protection levels for the vehicle. It is anticipated that this work will take 3 years to determine the correct armor “cocktail” and is estimated to cost $100M.

Regarding APS, for the past several decades the U..S has lagged behind other countries (e.g., Russia, Israel, and Germany) in developing hard- and soft-kill APS components and integrating them into systems that can protect armored vehicles against the full range of KE, CE, and top-attack threats. A focused, concerted effort that involves government labs, U.S. industry, and foreign partners needs to be initiated, with the goal of creating a 360-degree hemispherical protection bubble around the 5GenCV.

The initial 2-year APS effort needs to be focused on identifying, developing, characterizing, and demonstrating individual APS technologies and components (sensors, fire control, kinetic hard-kill and non-kinetic soft-kill effectors, etc.) that can be effective against different portions of the threat spectrum. The non-kinetic, soft-kill effort should involve the Rapid Capabilities and Critical Technologies Office (RCCTO) and the Indirect Fires Protection Capability (IFPC) program, which are developing advanced Directed Energy Weapons (DEW). Low/high-powered lasers and microwave weapons could defend combat vehicles against missiles, rockets, drones, and artillery. These efforts may directly contribute to the development of the 360-degree protection bubble for the 5GenCV. Threat spectrum variables include launch distances (<100m to 5+km), munition velocities (100 m/s to 1,500 m/s), guided (ATGMs) vs. unguided (KE) munitions, and aspects of attack (frontal vs. side vs. top-attack). The goal is to identify multiple components that can work against each portion of the threat spectrum so that together they address the entire spectrum. A suite of components is necessary to achieve a robust, 360-degree hemispherical bubble of protection. Components need to be compatible with the MAPS environment or demonstrate the ability to evolve into that environment. This effort is estimated to cost $100M.

In the 3rd year of the APS effort, the Army must determine the most promising components to select for incorporation into an APS suite that can address the full range of the threat spectrum. Soft-kill solutions should be emphasized for the CE and top-attack threats due to the infinite number of stowed kills they can provide against guided threats. Hard-kill APS solutions should be focused on the unguided threats as they are immune to the soft-kill systems. Adversary tank KE munitions should be the primary focus for the hard-kill solutions as they are the most stressing threat for hard-kill systems. In addition, hard-kill solutions to the KE threat will offer residual capabilities as back-up systems to the soft-kill systems that target the guided threats. Follow-on efforts should include the integration of the most promising technologies/ components using the MAPS environment and the characterization/demonstration of a hard/ soft kill APS suite to include static tracking and intercept. Such a demonstration system should be able to address the full range of KE, CE, and top-attack threats in a 360-degree hemispherical bubble. It is anticipated that this work will cost $50M.

The final, 4th year of the Protection testbed should include demonstration of an integrated protection suite that includes the armor and APS components, characterization of its capabilities against the full threat spectrum, its ability to upgraded and address any threat shortfalls, and its ability to be integrated into the system level platform competition for the 5GenCV.

F.4 HUMAN FACTORS

A significant improvement in the 5GenCV will be the addition of modern information capabilities, including networked operations to support MDO and AI-enabled target cueing to increase performance. In turn, the combination should produce reductions in weight and crew size, but it could also lead to crew work overload, cognitive loading, and reduced system performance. To produce positive trade-offs in human factors, the study team advocates creation of a simulation employing all the software associated with information upgrades to gauge crew workload and compare it to M1 crew size, workload, and performance.

Human factors related to C2 require man-machine interfaces and a component arrangement designed expressly to optimize the 5GenCV's mission by enhancing the crew's performance. It is imperative that the external network does not interfere in any way with this mission. Thus, the MOE for human factors (and C2) are:

- Can it help the crew act faster and more effectively than the enemy?
- Does it facilitate the synchronization of all combined arms?

The MOE must be accomplished in the following environments:

1. The crew must be able to fight the individual vehicle under all conditions, which requires:

- Verbal communication within the vehicle (can be wireless, must have wire backup) between/among all crew members for coordinating various functions. Functions include battle drills, navigation, positioning, maintenance/sustainment, movement, route guidance, protection, and all things Fire Control.

- Digital communication between/among all crew members for all the above, especially target ID, location, range, immediate safety action drills, etc.

- Open hatch capability for visual confirmation of orientation, route selection, safe obstacle mitigation, etc.

2. The crew must be able to fight the individual vehicle as part of a combined arms direct fire team under all conditions with direct fire only, which requires:

   - All the above from environment 1.

   - Communications via a network (verbal and digital) with fellow team members/other vehicles within range of the direct fire fight.

3. The crew must be able to fight while leveraging all other combined arms under all conditions with direct and indirect fire, which requires:

   - All the above from environments 1 and 2.

   - Communications via a network (verbal, digital, other) that enables the system (vehicle or team) to Kill enemy vehicles, Survive all enemy threats, Move to positions of advantage over the enemy, Recon/Observe/Report/Identify, Employ indirect fires, employ UAS's, and all other tactical tasks.

The study team estimates the program should last approximately three years and cost approximately $50M.

F.5 RELIABILITY AND MAINTAINABILITY

Consumption drives the size of a combat formation's logistics and sustainment footprint, and the consumption of four critical elements have the greatest impact on the footprint:

1. Fuel – dictated by platform weights, schemes of maneuver, and duration of the operation.

2. Ammunition – driven by the scheme of maneuver and intensity of the operation.

3. Water – determined by the number of Soldiers in the formation and duration of the operation.

4. Maintenance – a function of the duration of the operation and how well the platform is designed to minimize maintenance operations.

As the duration of the operation increases, the demand for sustainment increases.

The study team identified the following critical elements that need to be optimized in the design process:

- Mean time between failure (MTBF), or how long a component will last.

- Mean time to repair (MTTR), or how long it takes to repair/replace components.

- The ability to anticipate the need for consumables, parts, and maintenance; the ability to communicate that information (demand for service) in real time; and the formation commander's confidence in the accuracy of the demands for service and the reliability of service delivery.

The Army has been collecting data off current platforms but has not converted that data into design characteristics for future platforms. As a result, the analysis of root cause of failures is not being used to inform design teams on the components that drive failure or take the most time in repair. Current data collection efforts are focused on post operation, not real time. Therefore, the Army needs to develop an analytical approach focused on informing the design teams of platforms, components, and sub-systems.

The current data collection should be treated as a repository of learning material to develop the analytical tools, including AI support, enabling the Army to shift the design process into an anticipatory sustainment mode, along the lines of predictive maintenance. This concept would drive the need for line replaceable units (LRUs) with minimal time to replace. Further, all components need to be analyzed for those most in need of explicit wear by adding failure sensors, and those that can be imputed by virtual sensors.

Designs of components should be subject to rigorous failure mode analysis techniques to support detection and anticipation as well as post failure engineering to build in higher reliability in replacement components.

The testbed approach will require a shift from a transactional sustainment system/enterprise resource planning (ERP) to an AI-enabled sustainment system that captures the full range of sustainment-related information form the operational unit. The techniques and tools used in commercial operations of aviation have proven applicable and could be modeled as a starting point. To do so, platforms need the ability to process raw data into actionable information.

The shift in process and responsiveness needs to be analyzed for its impact across the sustainment footprint and concepts required to support the combat formations. The testbed should become one of the gates that all new designs must pass through with the forcing function being to maximize MTTF and minimize MTTR.

F.6 COMPUTING AND AI

The 5GenCV should take advantage of advanced computing capabilities to enable enhanced platform and Soldier performance. The study team advocates computer hardware will provide better performance without necessitating greater size, weight, power, and cost (SWAP-C), and AI will support better decision making, greater platform autonomy, and simplified human factors. The proposed Computing and AI Testbed will prove out these assumptions and conduct the experimentation and testing for new information systems in the 5GenCV.

Commercial-off-the-shelf (COTS)-based processors are used to execute software for C2 in current platforms such as the M1A2 Abrams and Stryker. Hardware for computers is obtained through the program of record for Mounted Family of Computer Systems (MFoSC). The 5GenCV should provide computer upgrades increasing performance for more demanding C2 and other non-real-time applications, e.g., embedded training and rehearsal. It should also employ additional real-time computers to enable autonomy, power management, lethality and protection capabilities, ATR, and vehicle electronics. More capable bus interfaces, e.g., vehicle integration for C4ISR/EW (VICTORY), should be employed to exchange data between processors for the various systems. The design for the vehicles must accommodate continuing hardware upgrades and their SWAP-C.

Emerging AI techniques to enhance computing capabilities on the 5GenCV include:

- Investigating the Kill Web concept by the NGCV CFT (Fig. F.6.1)
- Examining support to the “5th Gen Equation” put forth earlier in this document
- Leveraging autonomous driving capabilities that are being matured for consumer vehicles
- Developing and making decisions on courses of action (COAs) for mission planning
- Supporting navigation with route planning
- Assessing target acquisition with improved probabilities, classifications, and false alarm rates to increase in lethality and survivability (pre-shot detection, electronic signature management, LADAR/FLIR ATR, and hostile fire detection)

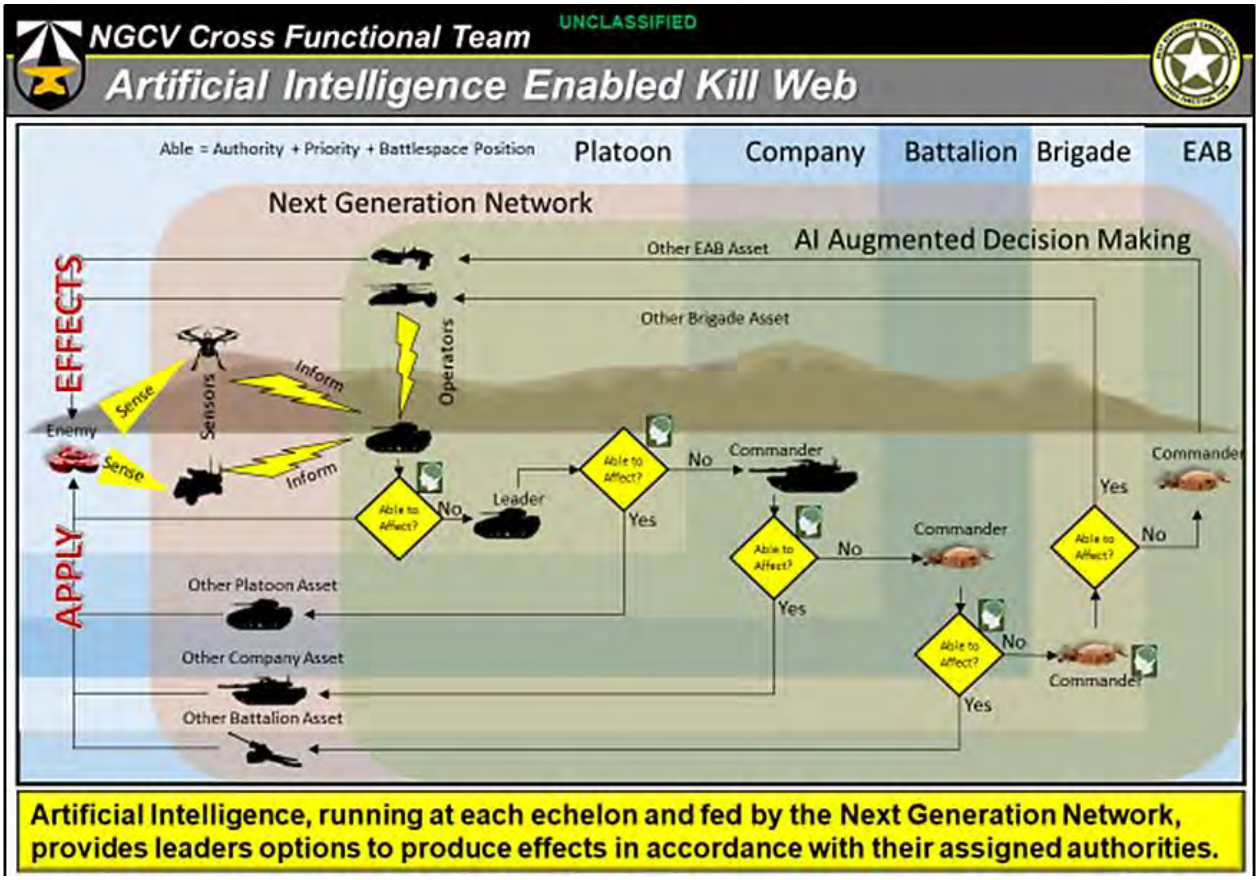


Figure F.6.1 NGCV CFT AI Enabled Kill Web

Computing and M&S will be conducted to support the design of architectures needed for the NRT and RT environments. Performance and SWAP-C needs for computers should also be assessed. A prototype of the hardware architecture design will be built and tested using the Army's Common Operation Environment (COE). S&T results will be leveraged from mobile, high performance computing activities.

For AI, operational concepts and software/data architectures will be detailed for the functions identified above. Prototypes for the applications will be prepared using S&T, COTS and other service developments running on top of the COE and the computing prototype. Experimentation and testing of the prototype will inform the development of capability descriptions.

The study team estimates testbed activities would last 3 years at a cost of $85M.

F.7 MASKING

Masking is proposed here as a suite of capabilities and design techniques to reduce the enemy's probability of detection, identification, location, and acquisition of the 5GenCV. Masking capabilities contribute to the overall survivability and protection of the vehicle, and they include practices traditionally falling under both camouflage, concealment, cover, deception, and deceit (C3D2), and signature management.

The testbed program should assess the military value of available and emerging masking capabilities that can contribute to survivability and protection of the 5GenCV. The testbed would also evaluate and advance the maturity of candidate systems, technologies, and design techniques. Various systems, technologies and design techniques are employed for masking. Signature types include visual, acoustic, near IR, IR, thermal retro-reflective, radar, particulate and radiated emissions, magnetic, and seismic.

The proliferation of networked ground and UAV-based sensors has driven the requirement to reduce the adversaries' target acquisition ranges. Techniques to reduce signatures were tried in the 1980's and 1990's but were costly. New techniques can reduce cost and possibly result in effects as dramatic as stealth design in aircraft. Early planning and developments for the FCS and GCV programs addressed signature management and these results should be leveraged for the 5GenCV.

Capabilities to be addressed in the testbed include:

- Profile design (e.g., lower radar cross-section)
- Active high-tech cognitive electronic warfare systems
- Passive low-tech systems to enable the vehicle to become unlocatable through a combination of stealth (i.e., all actions to reduce the EM signature through materials and design) and other technologies
- Camouflage (active and passive), concealment, decoys, and portrayal of false actions (e.g., physical decoys and dynamic holographic decoys and holographic environments)
- Color-changing materials
- Environmental manipulations (e.g., blend into the existing acoustic and visual background)
- Electronic masking (i.e., the controlled radiation of EM energy on friendly frequencies in a manner to protect the emissions of friendly communications and electronic systems against enemy electronic warfare support measures/signals intelligence without significantly degrading the operation of friendly systems)
- Use of electronic countermeasures (ECMs) and digital radio frequency memory (DRFM) to hide beneath the blanket of enemy or friendly jamming

- Employment of low probability of detection (LPD) and low probability of interception (LPI) waveforms for communications
- Obfuscating the radio frequency (RF) spectrum to counter enemy EW capability

Several of these technologies cannot be integrated into existing platforms and must be included at the beginning of the design process. This in turn requires a clean sheet approach to design that includes masking as a specific input.

To initiate the testbed, the study team believes the Army (i.e., GVSC with C5ISR Center) start with a simple parade float to test technology potential. When successful, outfit a combat vehicle to test with military sensors in tactical environments. Coordinate with the Robotics Testbed to include RSVs for decoys, etc.

The parade float is estimated to cost $10M and take 2 years to develop. Combat vehicle testing would cost $50M and take 3 years to develop and complete. Competitive prototyping and RSV integration could be undertaken at additional costs.

F.8 ROBOTIC SYSTEMS

The study team recommends a manned/unmanned teaming (MUM-T) robotic testbed focused on developing robotic servant vehicles (RSVs) to thicken formations as wingmen for human-operated combat vehicles. The performance objective should be for robot systems to operate semi-autonomously (commanded by humans) without having a human operator controlling the robot via joystick (controlled by humans), and the addition of these platforms must make the formation measurable more effective.

The use of robotics promises the potential to increase human survivability. The approach of human command versus control regarding the employment of ground RSVs is a critical capability the testbed must address. Controlling robots places cognitive demands on human operators and requires constant and uninterruptable communications links, both of which create vulnerabilities when combined with the combat OE. Commanding robots frees human operators from the constant cognitive and data transmission requirements. The convergence of AI with robotics and autonomous systems will be critical to enable the RSVs to take the commands of the humans and perform their respective tasks.

The testbed should leverage relevant GVSC/NGCV planned testbeds for robotic wingmen under the command of humans, starting with a small number of RSVs executing battle/movement drills (e.g., column to line, line to column) and expanding as experimentation progresses. The testbed should assess the feasibility of thickening the formations with a diverse portfolio of RSVs under the command of humans (i.e., not just one type or platform).

Added costs to planned GVSC wingmen testbeds (Phase 2, 2021, Phase 3, 2023) would be approximately $50M. Adding more diverse RSVs (thickening the formation) is estimated to cost

$100M and take 5 years to develop and test. Two competitive prototypes are assumed for cost purposes.

F.9 NETWORKS

New information systems are needed to enable enhanced C2 functions as well as new platform capabilities. The systems will be integrated into the current Integrated Tactical Network (ITN). New systems are also needed to mitigate ITN gaps for MDO. Although each individual system to be added will be tested by the responsible PEO, the Army has learned that experimentation and testing of the end-to-end system should be done to investigate potential integration problems, check for performance, and assess technology maturity. The proposed testbed will conduct the experimentation and testing for new systems to be integrated into ITN for the 5GenCV.

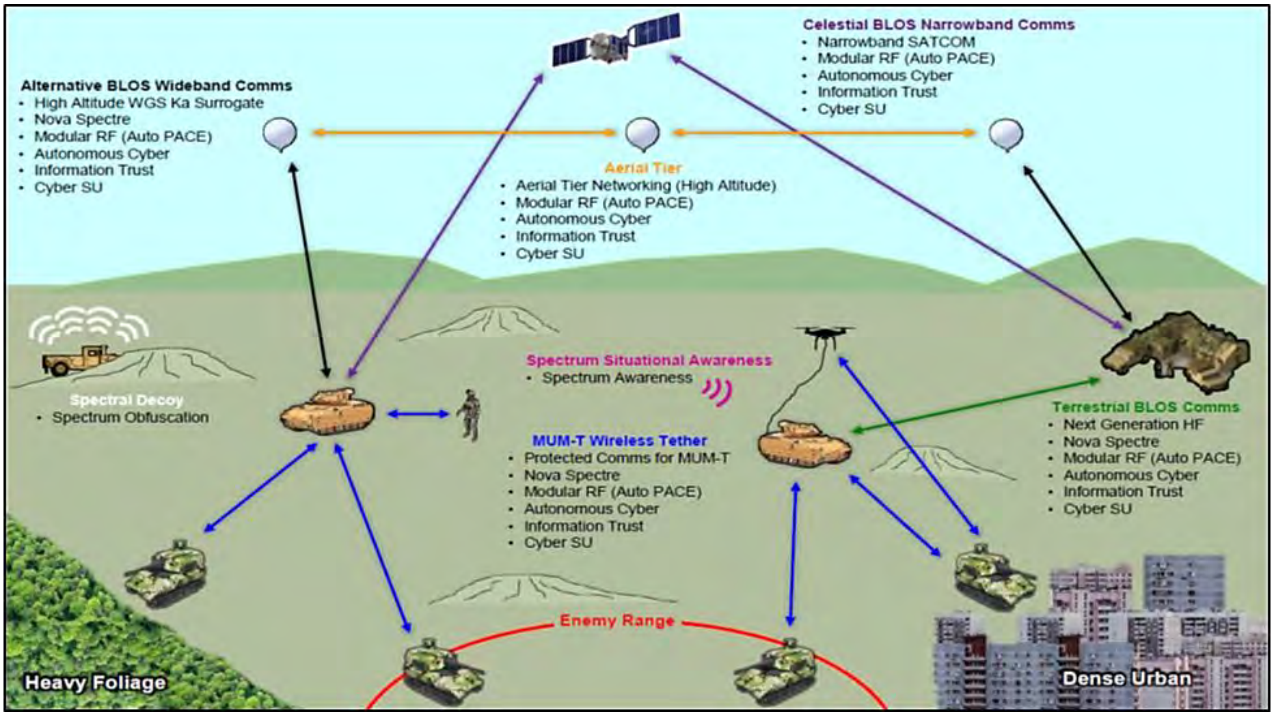
The ITN comprises computers, radios, sensors, and other information systems to support C2 for today's BCTs by enabling warfighters to exercise authority and direction over forces in the accomplishment of missions. The 5GenCV will use improvements to the network to support enhanced C2 capabilities in the following environments/conditions:

- Fighting the individual vehicle – to include all conditions, direct fire, requires verbal and digital communication within the vehicle (can be wireless, must have wire backup) between/among all crew members for coordinating various functions. The functions include battle drills, navigation, positioning, maintenance/sustainment, movement, route guidance, protection, fire control, target ID (location and range), immediate safety action drills, etc. Also requires open hatch capability for visual confirmation of orientation, route selection, safe obstacle mitigation, etc.

- Fighting the individual vehicle as part of a combined arms direct fire team – to include all conditions, direct fire only, requiring all of the above as well as communications via a network (verbal and digital) with fellow team members/other vehicles within range of the direct fire fight.

- Fighting while leveraging other elements of the combined arms team – again including all conditions, direct and indirect fire, requiring all of the above as well as communications via a network (verbal, digital) that enables the system (vehicle or team) to kill enemy vehicles, survive all enemy threats, move to positions of advantage over the enemy, conduct recon/ observe/report/identify, employ indirect fires, employ UAS's, etc.

AFC will need to establish requirements to field the new technologies that support and leverage the operational architecture for an augmented network. Products to meet the requirements may come from S&T projects, COTS items, and Joint and other Service efforts.



Source: C5ISR Center

Figure F.9.1 Enabling Network for 5GenCV

The operational capabilities needed to support the 5GenCV that require an enabling network include:

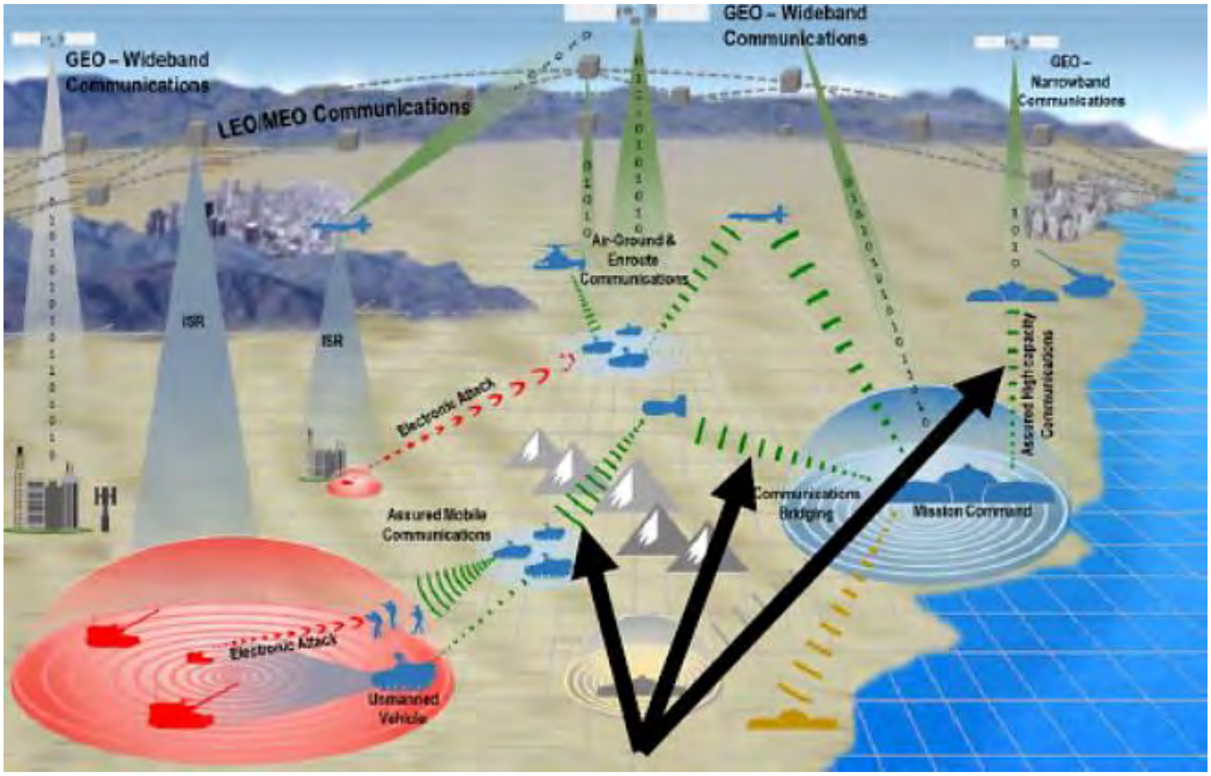
- Precision fires with detection of enemy emissions and targets using sensors, automatic recognition of targets using software applications, and dissemination of messages using communications

- C2 of robotic/unmanned systems, manned/unmanned teaming (MUM-T), and optionally manned operations using communications and software applications

- Cooperative engagement using communications and software applications

- Active protection using sensors and software applications

To operate in the face of increased EW threats in a contested environment, the network must also mitigate gaps in vulnerabilities with more resilient systems (Fig. F.9.2). Assured PNT and anti-jam, low probability of intercept and low probability of detection (AJ/LPI/LPD) communications are primary capabilities.



Source: C5ISR Center

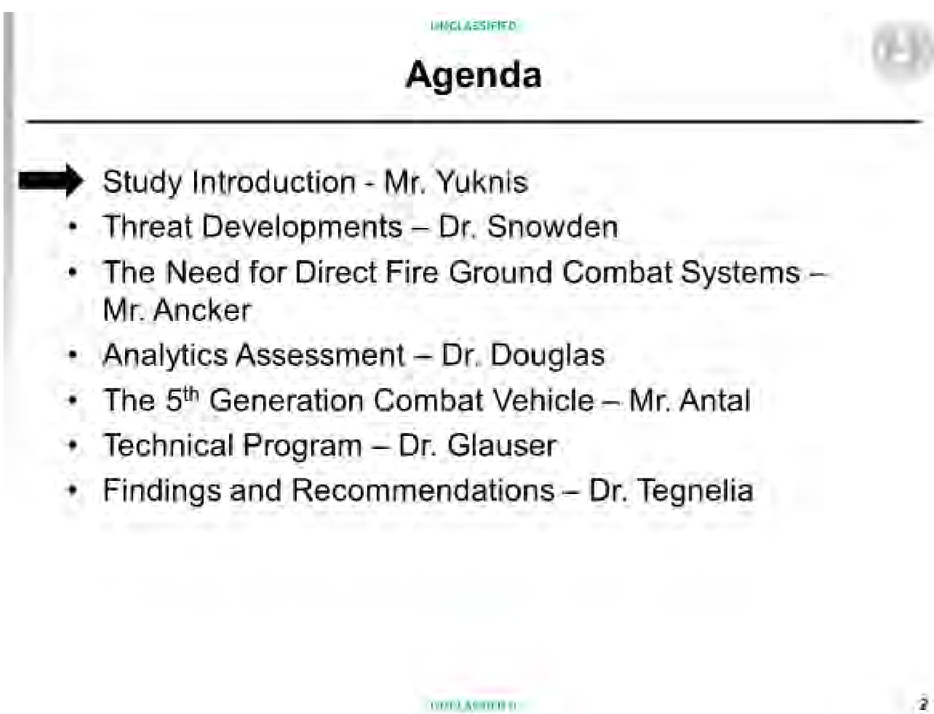
Figure F.9.2 Network Resilience to Mitigate EW Threats

The next generation network must build on ITN to ensure interoperability with current platforms (e.g., M1A2 and Stryker) and command posts. It must also accommodate affordability (i.e., it will be too expensive to start from scratch) and be designed to accommodate continuing computer hardware updates and emerging information system technologies.

The study team believes multiple stakeholders in the network community should be involved in this testbed. The ASA(ALT) Chief Systems Engineer can provide overall leadership as it has done in the Network Integration Environment (NIE). The C5ISR Center and DARPA can champion S&T in Joint and other Service developments. Army PEOs (C3T and IEW&S) can provide the baseline architecture. From previous similar events, the Army has learned that it is important to conduct end-to-end assessments of performance, vulnerabilities, and technology maturity in an operational environment when multiple new systems are integrated into the current network. A continuing series of tests and experiments should be conducted with the aim of designing an architecture that adds new technologies to ITN. Instrumentation and procedures that were developed for NIE events conducted since 2011 should be leveraged, as well as future Joint Warfighter Assessment (JWA) exercises and other ongoing efforts. Results of the testbed can be used to inform the evolution of the network. Annual testbed activities are estimated to cost $60M per year.

APPENDIX G. ASB APPROVED BRIEFING WITH FINDINGS AND RECOMMENDATIONS

The following briefing was presented to ASB members in plenary session on 18 July 2019. The study team's findings and recommendations were adopted unanimously by the ASB membership.



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Terms of Reference

TOR Tasks

a. Examine emerging threats, operational concepts, and doctrine necessary to defeat massed armored formations considering the capabilities of the Army's next generation combat capabilities.
b. Assist the Army's senior leadership in developing an understanding of next generation combat vehicle architectures, technologies and tradeoffs between them that support the development of next generation anti-armor strategies.
c. Recommend appropriate investment strategies to field next generation armor combat capabilities.

2019 Focus

- 1st Priority: Understanding Critical & Emerging Technologies
- 2nd Priority: Understanding Relationships Between Threats, Concepts, Doctrine & Associated Trade-off
- 3rd Priority: Armor Investment Strategy
- Context of: 2023 Decision Point for MDD & 2040 IOC

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Team Membership

Consultants

COL (Ret) Clint Ancker – Doctrine
COL (Ret) John Antal - Concepts
COL (Ret) Bill Hansen – Programatics
MG (Ret) William Hix - Programatics
COL (Ret) Rocky Kmiecik – M1 Program
LTC (Ret) Dick Ladd – Sustainment
COL (Ret) Harry Lesser - Intelligence
LTG (Ret) Michael Williamson – Programatics
MG (Ret) Walter Wojdakowski – Doctrine

ASB Membership

Dr. Christopher Cross – Technology
COL (Ret) William Crowder - Sustainment
Dr. Robert Douglas – Analytics
COL (Ret) Herb Gallagher – Protection
Dr. Mark Glauser – Mechanical Engineering
Dr. William Neal – Networks
Dr. William Snowden – Protection/Lethality
Dr. Buck Tanner – Vehicle Development
Dr James Tegnelia - Study Chair

Christopher Yuknis
Senior Government Advisor

MAJ(P) Chuck Bies, AR
Military Advisor/Study Manager

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Body of Research

Study Visits

- 8 days with Ground Vehicle Systems Center (GVSC, formerly TARDEC)
- C5ISR Center
- Aviation & Missiles Center
- Armaments Center
- Army Research Laboratory (ARL)
- Data & Analysis Center (formerly AMSAA)
- National Ground Intelligence Center (NGIC)
- Missile & Space Intelligence Center (MSIC)
- Center for Army Analysis (CAA)
- Potomac Foundation
- 4 visits to the Maneuver Center of Excellence and the Armor School
- DARPA
- Engineer Research & Development Center/Army Geospatial Center
- Space and Missile Defense Command
- National Training Center
- CASCOM at Ft Lee
- NGCV CFT
- PEO, Ground Combat Systems

Previous Studies & Emerging Concepts

- 1998 Tank Modernization
- 2000 Full Spectrum Protection of 2025 Era Ground Combat Vehicles
- 2016 Future Armor Anti-Armor Competition
- 2016 Disruptive Innovative Concepts for the Future Army
- 2016/17 MUM-T and RAS Studies
- 2016/17 Multi-Domain Battle
- 2018 TRADOC Pam 525-3-1 US Army in MDO in 2028

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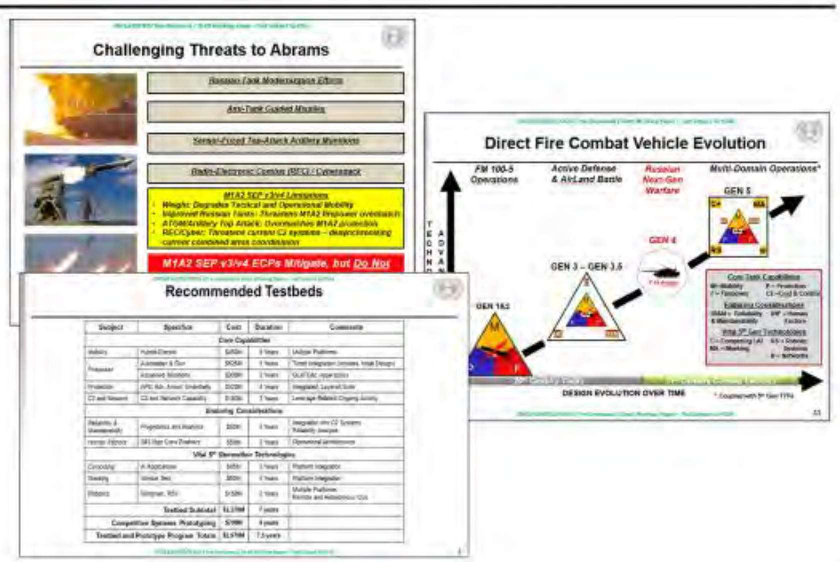
Critical Points



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Agenda

- Study Introduction - Mr. Yuknis
- ➡ Threat Developments – Dr. Snowden
- The Need for Direct Fire Ground Combat Systems – Mr. Ancker
- Analytics Assessment – Dr. Douglas
- The 5th Generation Combat Vehicle – Mr. Antal
- Technical Program – Dr. Glauser
- Findings and Recommendations – Dr. Tegnelia

Threat: Russia Capabilities

Critical threats to U.S. AFVs, including Abrams MBTs

- Advancing capabilities of modernized and developmental Russian MBTs
- KE munitions: new, more capable rounds under development
- Anti-Tank Guided Missiles (ATGMs): vehicle-launched, by dismounted infantry, and from aircraft
- Artillery: Multiple Rocket Launchers (MRLs), self-propelled howitzers, mortars
- Rocket-Propelled Grenades (RPGs)
- Anti-Tank/Anti-Vehicle (AT/AV) Mines
- Radio-electronic Combat (REC) / Cyberattack

Russian armor/anti-armor capabilities present a significant threat to U.S. Abrams combat effectiveness and survivability in possible future ground combat operations

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What Have We Learned from Russian Operations in Ukraine/Syria?

- Russian modernization efforts addressed Western strengths/weaknesses. All phases of Russian "New Generation Warfare" were employed except the WME phase. The interrelationship of "Kinetic" and "non-Kinetic" phases was in evidence.
- Russian Contract Force is now a far more professional and capable force than the Soviet Red Army we understood
- Russian Ground Force continue to rely on its traditional, proven reconnaissance-fire (tactical) and reconnaissance-strike (operational) loops, but they have been modernized to provide more lethal Anti-Access/Area Denial capabilities to avoid the close fight
  - Modernized recon-fire (tactical) and recon-strike (operational) loops integrate reconnaissance (UAVs, SIGINT, EW, radars), engagement (mortars, artillery, MRLs, ATGMs, cruise missiles, AF), and automated C4 systems to attack/defeat targets beyond line of sight
  - Integrated tactical and operational air defense systems
  - Russian artillery, MRLs, ATGMs, and air defense missiles outrange and outnumber U.S. systems
- Armor played a major role in the execution of urban operations.
- Operations included use of robotic combat vehicles and BLOS operational fires under combat conditions to establish proof of concept and support continuing development

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Threat: Russian Capabilities

Russian Main Battle Tanks

- Russia has long been a leader in the development and production of MBTs, including T-72, T-80U, and T-90 series tanks
- Modernization efforts are improving capabilities of fielded systems: mobility, protection, lethality, fire control, situational awareness
- Armata T-14 MBT under development: new ERA, improved top-attack protection, soft/hard-kill APS, improved main gun, extended range KE munitions, new Gun Launched ATGMs, improved target acquisition and signature management capabilities
- Russian modernization efforts and new systems developments are significantly enhancing their comparative capabilities against U.S. armored formations

T-72B3 MBT

T-90A MBT w/Shtora APS

Armata T-14 MBT

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Threat: Russian Capabilities

Tank-Fired KE Munitions

- Penetration capabilities of current and most-common Russian rounds inferior to U.S. KE munitions (M829A3/M829A4), but advanced KE munitions are under development; greater penetration and effective range

ATGMs

- **GLATGMs:** Current systems (Svir, Invar: LBRs) have effective ranges of ~5 km, high P_{hit}; new system (Sprinter) under development may extend effective range; dive-attack system also under development (Sokol)
- **Tube-Launched ATGMs** fired from other AFVs: many types, high P_{hit}, greater range, greater armor penetration capability
  - Examples: Konkurs/Konkurs-M, Kornet/Kornet-EM, Khrizantema
  - HERMES long-range, multi-purpose development system
- **Man-portable systems:** Fagot/Fagot-M, Metis/Metis-M, Flomaster
- Capabilities of threat ATGMs exceed capabilities of fielded U.S. systems (TOW 2B Aero RF, Javelin), but threats can be defeated by a highly capable (soft/hard-kill) APS

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Threat: Russian Capabilities

Representative Russian ATGMs

Khrizantema Launch from BMP-3 Variant

Russian Mi-28N (HAVOC) Helicopter Armed with Ataka ATGMS

Konkurs ATGM System Mounted on a Motorcycle

Kornet Missile System w/TIS

Tripod Launch of a Fagot-M Missile

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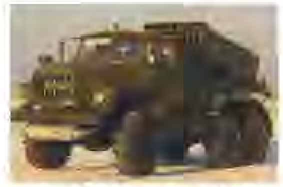
Threat: Russian Capabilities

Russian Artillery Systems

- Artillery fire has long been a critical combat support element for Russian ground forces
- Multiple Rocket Launchers: 122-mm BM-21 Grad, Tornado-G, 220-mm (Uragan), 300-mm (Smerch) systems; max ranges 40-90 km
- Self-Propelled Howitzers: 122-mm (2S1-Gvozdika), 152-mm 2S19 Msta-S), 152-mm 2S35 Koalitsiya (next-gen) systems; max ranges 15-70+ km
- Mortars: high-rate of fire 82-mm, 120-mm, and 240-mm systems, max ranges 7-20 km depending on specific rounds fired



Russian 122-mm Tornado-G Multiple Rocket Launcher

Wide variety of artillery munitions/warheads

- HE, HE-FRAG, enhanced blast, thermobaric, DPICM, SC, sensor-fuzed submunitions, mine-laying, flechette, smoke, illumination, incendiary types
- Combined effects can severely degrade the combat effectiveness of all targeted ground forces, including AFV units; Russia/Ukraine conflict

Russian 152-mm 2S19 Msta-S Self-Propelled Howitzer

Threat: Russian Capabilities

RPGs

- Effective short-range anti-tank weapons, typically launched from concealed or covered positions
- RPG-7: most common, with many warhead variants
- RPG-29: 105-mm system, most capable , longer range
- Potentially highly effective in urban environments
- Difficult to counter with APS
- RPG-30: Developmental system designed to defeat enemy AFVs with hard-kill APS capability
- Future RPGs likely will have capabilities currently found only in ATGMS

Russian RPG-29

Anti-Tank Mines

- Effective element of ground combat operations, attack tracks, wheels, and underbelly of AFVs
- Russia has one of the largest and most-varied AT/AV mine inventories in the world: blast effect, full-width attack, off-route types
- Present significant threat to tactical mobility and survivability of U.S. AFVs
- Russian mine warfare capabilities much greater than U.S. capabilities

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Bottom Line

- Russia continues to make advances to an already capable threat in the Ground Domain and evaluate these threats in operational environments.
- Russia also brings capable threats in the other domains.
- Proliferation of Russian technology ensures that these threats will be encountered beyond the boundaries of peer-to-peer conflict.

ATGM attack on an Iraqi M1A1 Abrams Tank

- Continual upgrading of M1A2 capabilities cannot overcome the threat to its survivability and lethality (i.e., *combat effectiveness*) posed by these Russian advances, nor can it mitigate tactical and operational mobility limitations.

Overall, the ever more stressing threat environment presents the most compelling driver for development of a 5th Generation Combat Vehicle.

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Definitions

- **Direct Fire Ground Combat Vehicle**: Generic term for a vehicle characterized by core capabilities of -
  - *Mobility*
  - *Firepower*
  - *Protection*
  - *Command and Control*

- **Tank**: The **current** direct fire ground combat vehicle, specifically for this presentation the M1A2 SepV3/4 Abrams

- **5th Generation Combat Vehicle: Future** direct fire ground combat vehicle

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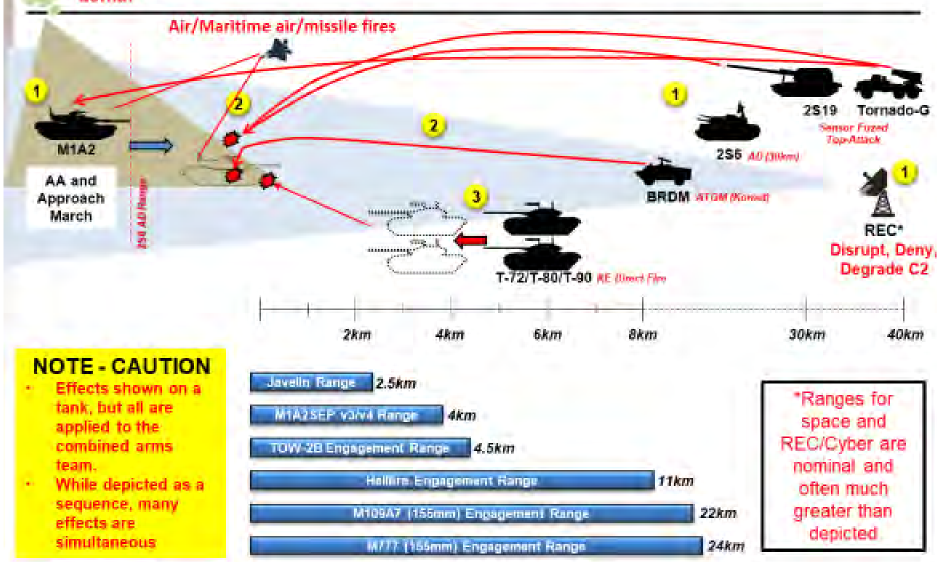
Simplified Threat Contact Continuum



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Challenging Threats to Abrams

Russian Tank Modernization Efforts

Anti-Tank Guided Missiles

Sensor-Fuzed Top-Attack Artillery Munitions

Radio-Electronic Combat (REC) / Cyberattack

M1A2 SEP v3/v4 Limitations

- *Weight: Degrades Tactical and Operational Mobility*
- *Improved Russian Tanks: Threatens M1A2 firepower overmatch*
- *ATGM/Artillery Top Attack: Overmatches M1A2 protection*
- *REC/Cyber: Threatens current C2 systems – desynchronizing current combined arms coordination*

M1A2 SEP v3/v4 Mitigate, but Do Not Solve, these Problems and Increase Weight, further degrading mobility

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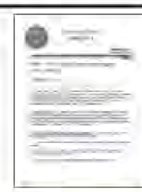
What Has the Army Been Tasked to Do and How it does it Do it?

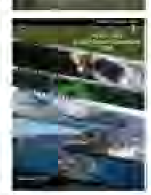
- "Conduct prompt and sustained **combined arms combat operations**…in order **to defeat enemy ground forces, and seize, occupy, and defend land areas."** *DODD 5100.01 Functions of the Department of Defense and Its Major Components*

- The outcome of battles and engagements depends on the ability of Army forces to prevail in close combat -- **that part of warfare carried out on the land in a direct-fire fight, supported by direct and indirect fires and other assets.** *Army Doctrine Reference Publication 3-0, Operations*

- **Multi-Domain Operations** poses solutions to…the problem of **layered standoff**. The **central idea** is the **rapid and continuous integration of all domains of warfare** to deter… If deterrence fails, the Army as part of the Joint Force, **penetrates** and **dis-integrates** enemy A2AD systems, **exploits freedom of maneuver** to defeat enemy systems, formations and objectives… *TP 525-3-1, The Army In Multi-Domain Operations*

- **Close Area/Deep Maneuver Area**: Friendly areas in the competitor's 'near abroad', the **focus of their strategic aims** which U.S. forces and allies must **protect, defend, and liberate**, when necessary. **Ground forces operate here.** *TP 525-3-1, The Army In Multi-Domain Operations*





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Why a Direct Fire Ground Combat Vehicle

Tasks Directly Related to the Direct Fire Ground Combat System
(from DODD 5100.01, Army Doctrine, MDO Concept Paper)

- Conduct **combined arms operations** as part of a joint and/or multinational force.
- **Dominate the close fight** to isolate, defeat or destroy enemy forces
- **Defend friendly land**, populations and resources,
- **Occupy, control, exploit, and retain enemy land** and secure their populations/resources

To Do the Above, the Army Requires a Force that Must:

- **Cross contested ground** to eject an enemy, or
- **Defend ground** to prevent an attacking force ejecting the Army from it.

This requires a system that can move, survive, and kill any enemy system it encounters – *a direct fire ground combat vehicle* with the following core capabilities

- **Mobility**: The ability to move cross country as ***part of a combined arms team***, in most ground environments.
- **Firepower**: The ability to destroy all of the enemy's ground systems
  - A higher rate of fire of tank killing rounds than any other system
  - More stowed anti-tank kills than any other anti-tank system.
  - The ability to fire accurately on the move
- **Protection**: The ability to survive better than any other vehicle against all current and projected enemy systems ***when operating within a combined arms team.***
- **Command and Control**: ability to fight as an integrated part of the combined arms team

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Ability to Prevail in the Close Fight and Maneuver as *Part of a Combined Arms* Team in MDO

- M1A2 SEP v3/v4
  - Weighs too much for operational mobility. Future improvements will only add weight
  - Little or no growth potential for improved mobility, firepower, protection, or C2 to address current and forecasted threat capabilities
  - *Can't grow into the future fight taking advantage of emerging technologies.*
  - **Result: Unable to prevail in close combat to ensure maneuver critical to MDO**

- 5th Generation Combat Vehicle
  - Clean sheet design can take advantage of 50 years of technology since the original M1 design.
  - Can integrate all systems for decreased weight and vastly improve mobility, firepower, protection and C2.
  - *Growth potential for technologies and capabilities that may not be mature now, but which will reach operational maturity during its service life – some that we may not even be able to envision now.*
  - **Result: Ensures capability for maneuver of the combined arms team, prevail in close combat to dis-integrate enemy A2AD systems, and occupy or defend terrain in MDO.**

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Analytical Insights

Purpose

- To demonstrate exemplars of analyses the Army needs to do to support development of the 5th Generation Combat Vehicle
- To provide initial analytical insights regarding:
  - Capability of the M1 to contribute in a specified scenario setting
  - Contrasting capabilities of 5th Generation Combat Vehicle variants with respect to the M1 and Russian tanks in same scenario setting

Scope

- Not a full blown Analysis of Alternatives – rather a proof of concept
- Measures of performance and effectiveness of selected technologies
- Analyses performed by Engineer Research and Development Center, Ground Vehicle Systems Center, Data and Analysis Center, and Center for Army Analysis in coordination with NGAAS Study team
- Used existing models and simulations, which have limited capabilities to capture Multi-Domain Operations concepts, particularly those which have non-kinetic effects
- Analytical results are generalized so briefing is unclassified – data is available for actual classified results

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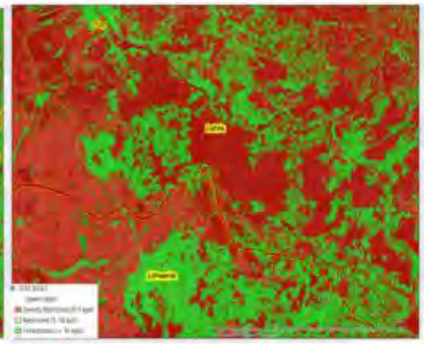
ERDC Terrain Analysis

Cross-Country Mobility of M1A2 in Dry Conditions

Cross-Country Mobility of M1A2 in Wet Conditions



Unrestricted (> 16 kph) | Severely Restricted (0 – 5 kph)

Restricted cross-country mobility in wet conditions provides increased opportunities for indirect fire engagements against M1A2 equipped force

Combat Simulations Observations

- GVSC and DAC Ground Wars and CAA Joint Integrated Contingency Model are Army validated combat simulations
  - Both simulations used vignettes based on Scenario 7 in the late 2020s time frame
- Blue systems included M1A2 SEP v3 and V4 and GVSC-developed 3-man and 2-man concept vehicles with advanced technologies
  - Adaptive armor
  - Thermal signature reduction
  - Improved accuracy of KE rounds
  - Larger caliber gun
  - Longer range munition
- Key Observation
  - **Regaining land dominance is possible** - Order of magnitude improvement in loss exchange ratios from less than 1-to-1 with current systems with introduction of advanced technologies in GVSC lighter-weight concept vehicles

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Observations about Army Analytic and M&S Capabilities

- Army analytic organizations have begun to address modernization options using existing tools
  - DAC and GVSC working closely together are evaluating design options and assessing lethality and survivability
- Army combat models have very limited capabilities to address non-kinetic effects and capabilities needed in Multi-Domain Operations
  - Communications networks
  - Unmanned systems integrated with combat forces
  - Masking
  - Directed energy systems
  - Others
- Increases in lethality require the ability to address human factors issues relating to reduced crew size
  - Larger caliber guns to increase lethality require autoloaders
  - Opportunity exists to modify the Close Combat Tactical Trainer (CCTT) to a 3-man and/ or 2-man crew to investigate how best to configure the crew compartment (i.e., hull) to optimize crew combat efficiencies
- Army should take advantage of advances in modeling and simulation
  - Model-based systems engineering
  - Physics-based models
  - High performance computing

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Starry's Challenge

"It must be the role of technology to provide weapons systems which **render ineffective costly investment by our foes** -- not simply to try to match something the other fellow has just fielded...With new weapons we should seek new dimensions of combat...Technology should seek to make battle outcome less, not more calculable. Instead of restoring some balance to the neat firepower score equation **we should introduce *new imponderables*** into the traditional calculus of battle."

General Donn Starry (USA Retired),
in Remarks delivered to the ADPA Conference on Combat Vehicles, Fort Knox, KY, 18 SEP 1986.

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The Future Battlefield

"Untutored courage is useless in the face of educated bullets."
Gen. G.S. Patton, Jr.

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The 2040 Battlefield

1. Long Range **Precision & High Volume Fires** will dominate.
2. **Sensor networks** will detect, identify, and report every movement, electronic emission, and significant variations in the thermal and acoustic spectrum. The precision strike system will be automated by AI.
3. If the battlefield is dominated by automated precision fires, enabled by ubiquitous sensors, integrated by an **automatic AI driven kill-chain**, then maneuver across the battlefield will become nearly impossible.
4. This is the deadly battlefield equation of the future.

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The Precision Fires Equation

In 2040, we project that the trends in the development of **long-range precision fires** linked to ubiquitous sensor capabilities will deny us the ability to conduct **ground maneuver on the battlefield.**

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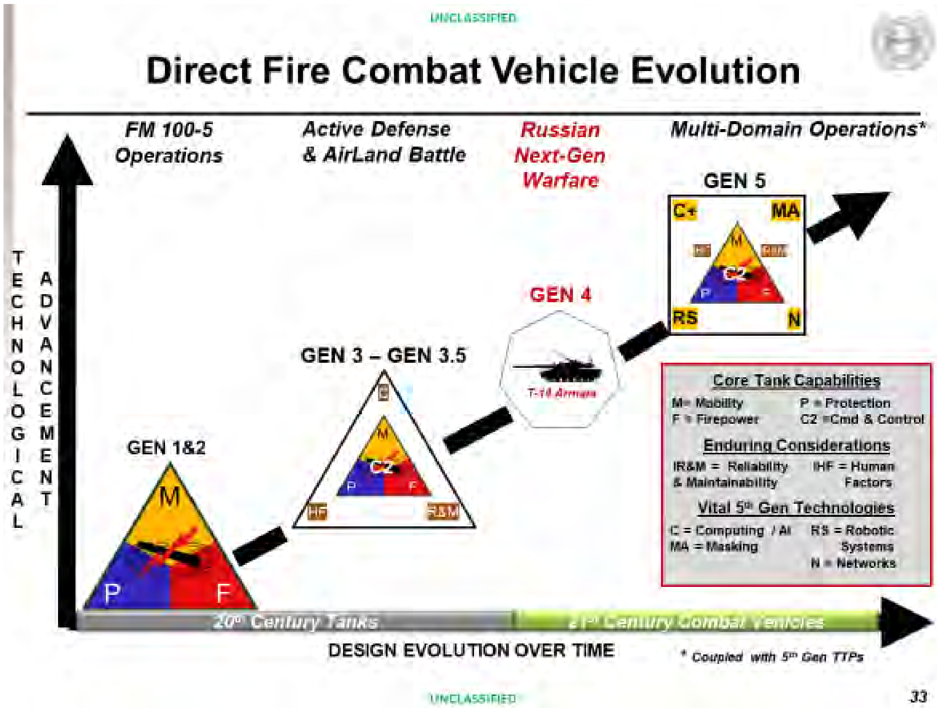

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Core – Enduring – Vital Considerations

Core Tank Capabilities
M= Mobility
F = Firepower
P = Protection
C2 =Cmd & Control

Enduring Considerations
IR&M = Reliability & Maintainability
IHF = Human Factors

Vital 5th Gen Technologies
C = Computing / AI
MA = Masking
RS = Robotic Systems
N = Networks

1. Core Tank Capabilities – M, F, P, C2

2. Enduring Considerations – IR&M, IHF

3. Vital 5th Gen Technologies
   C = Computing
   MA = Masking
   RS = Robotic Systems
   N = Networking

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5th Generation Combat Vehicle Definition

The **5th Generation Combat Vehicle** is a ground combat system with increased mobility, protection, firepower, command and control, and cognitive-enhancement. This vehicle generates **mobile striking power**, moves across the 2040 battlefield, destroys the enemy with **direct fire and maneuver,** and plays a **central role in the execution of MDO.**

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The 5th Gen Equation

A clean-sheet design that provides the ability to break the precision fires equation helps to meet "Starry's Challenge."

1. Core Tank Capabilities – M, F, P, C2
2. Enduring Considerations – IR&M, IHF
3. Vital 5th Gen Technologies – C, MA, RS, N

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History of the M1 Predevelopment

The Model that this Study is Following

- MBT-70 (1963 – 1970); XM 803 (1970-1971)
  - Developed technologies for NBC, Suspension, Stabilization Systems, turbine engine
- Main Battle Tank Task Force – January – August 1972
  - MG Desobry, Armor Center Commander (Chairman)
  - Lay out MBT Program, write Critical Performance Specifications, write essential documents
- 1973 – M1 Program Established with MG Baer as Program Manager
- 1974 – Program establishes Tank Special Studies Group
  - Validate Requirements based on Lessons Learned from the 1973 Arab-Israeli War
  - General Otis (Armor Training Center Commander) under GENs Starry and DePuy
  - Both Technical and Operational Lessons
- AirLand Battle Doctrine
- Technical activity
  - Testbeds
    - Hull
    - Turret & Firepower
    - Mobility
  - Competitive Full System Prototypes
    - Built MBT-70 and XM-803 prototypes but they did not include results from testbeds

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History of the M1 Predevelopment
The Model that this Study is Following (Cont)

- We have adopted the M1 Predevelopment Model since the ASB team believes such an approach can lead to success.
- The M1 program ensured that all of the 55 critical technology events incorporated into the M1 would work and were mature before incorporated into a system-level platform
- The ASB recommends this approach since from a platform level perspective the most difficult aspect of platform development is the integration of systems engineering aspects.
- The ASB team believes the leadership should insist that all critical technologies are **sufficiently mature** before they are incorporated into a system level platform.
- Key Elements of the approach:
  - Component Maturation
  - System prototyping
  - Experimentation for both component and system prototyping
  - Red Teaming employing national intelligence capabilities

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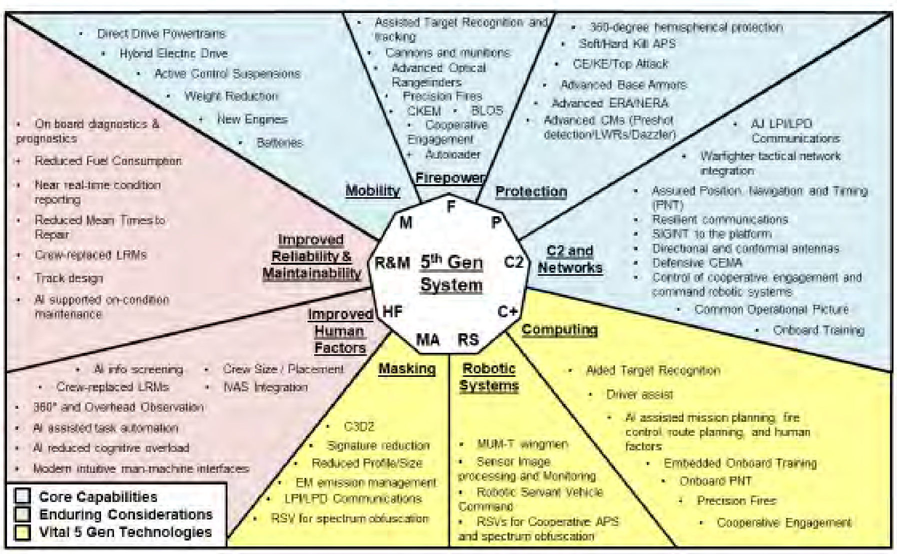
Critical Technologies



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Recommended Testbeds

Subject	Specifics	Cost	Duration	Comments
		Core Capabilities		
Mobility	Hybrid-Electric	$450M	5 Years	Multiple Platforms
Firepower	Autoloader & Gun	$625M	5 Years	Turret Integration (Includes Initial Design)
	Advanced Munitions	$300M	5 Years	GLATGM, Hypersonics
Protection	APS; Adv. Armor; Underbelly	$320M	4 Years	Integrated, Layered Suite
C2 and Network	C2 and Network Capability	$180M	3 Years	Leverage Related Ongoing Activity
		Enduring Considerations		
Reliability & Maintainability	Prognostics and Analytics	$50M	5 Years	Integration into C2 Systems Reliability Analysis
Human Factors	2&3 Man Crew Enablers	$50M	3 Years	Operational Architectures
		Vital 5th Generation Technologies		
Computing	AI Applications	$85M	3 Years	Platform Integration
Masking	Vehicle Test	$60M	5 Years	Platform Integration
Robotics	Wingman; RSV	$150M	5 Years	Multiple Platforms Remote and Autonomous Ops
	Testbed Subtotal	**$2,270M**	**7 years**	
	Competitive Systems Prototyping	**$700M**	**4 years**	
	Testbed and Prototype Program Totals	**$2,970M**	**7.5 years**	

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Funding Calibration

- TestBeds:
  - GVSC (then TARDEC) accomplished similar program (Combat Vehicle Prototype) focused on Fighting Vehicle (OMFV) Mobility, Survivability and Lethality: ~$1B; 6 years
  - MBT70, 1963-1970 (~$300M then => **$2.1B now**)
- Competitive Prototyping:
  - XM1 1973-1976 (~$200M then => $1.2B now)
  - GCV ($1B 2012; 2 contractors; 4 years; ATR, Turret test stand
- Less RDT&E Funding in 2019 relative to 1975

1975 Defense Budget:	$86.509 B	($411.871 B in 2019 Dollars)
Army Budget	$23.718 B	($112.445 B in 2019 Dollars)
Army RDT&E	**$9.389 B**	**($44.701 B in 2019 Dollars)**
Requested 2019 Defense Budget (Base):	$597.1 B	
2019 Army Budget	$181.995 B	
2019 Army RDT&E	**$10.484 B**	

$2-3B for a technology maturation program has historical precedent in the M1 program

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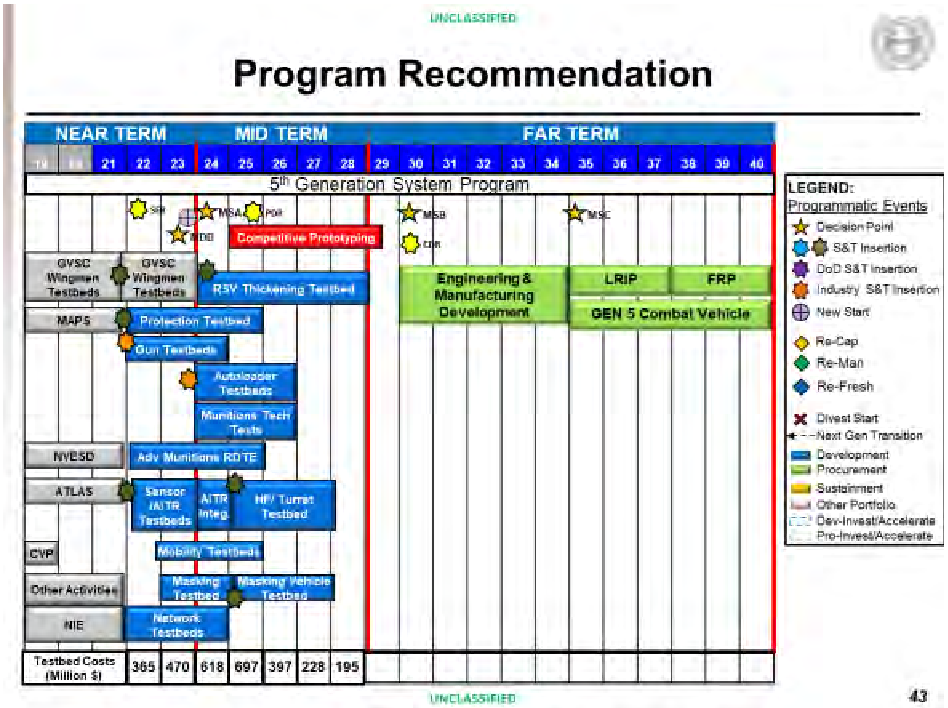

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5th Gen CV System Prototype

- System analysis started prior to TestBed activities to make testbeds relevant (need ~SFR level of analysis; general GVW)
- Competitive prototype activity requires multiple contractors
- Accomplishes initial system PDR level of design
- Produces System(-) prototype
  - Chassis prototype
  - Turret prototype (test stand)
  - Combines for system-level prototype

Images are conceptual and not representative


Hull


Turret


System

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Historically Successful Management Approach (1970s)

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Proposed Mobility Testbed

Program Description:
Automotive test rig (ATR), includes chassis structure, suspension, propulsion, vetronics, auxiliary subsystems (and elements of crew station) with ballast representing turret weight.

Discussion
Mobility testbeds are essential to program success. Test initially in labs; then mobile ATR.

- Powerpack development and integration requires dedicated test asset for development of control software, integration proof/learning, demonstration of performance.
- Hybrid Electric Drive offers greater ability to optimize performance across various requirements (with reduced fuel consumption) so is likely approach.
- Suspension (semi-active/active) allows increased cross-country speed. External suspension required for lower profile.

Project Description and Cost
Similar to the GCV ATR (24 month/$50+M effort in 2012).

- Cost in addition to the TD program which developed the design (36 month/$450M in 2010 to PDR).
- Engine/transmission, track, suspension (external) are all long-lead components (greater than 12 months)

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Proposed Firepower Testbed

Program Description

A technology development and evaluation testbed focused on selected key armament system technologies critical to achieving future MBT lethal capabilities against stressing threat systems

Discussion

Fielded and developmental threat systems have highly capable passive and reactive protection systems, and the incorporation of an APS will further enhance their survivability against U.S. anti-armor munitions There is an urgent need for advances the lethality in U.S. anti-armor weapons systems.

Project Descriptions and Estimated Costs

- Evaluation of main gun options: 130-mm (Rheinmetall), 157-mm straight chamber cannon or other alternatives to be identified through an AOA
  - 3 years, $150M
- Development/evaluation of cannon-fired high-performance munitions technologies: KE, MP/CE (MP-ERM), ELOS technology, course-correction technology, high-performance CE (SC/EFP) warheads
  - 3 years, $250M
- Autoloader design/development/evaluation (including turret integration)
  - 3 years, $225M
- Advanced munitions options: Guided, gun-launched rocket-assisted KE (RAKE) munition for greater armor penetration capability and greater effective range; tube-launched CKEM for >20-30MJ on target (previously demonstrated); GLATGM for longer range engagements;
  - (4 years, $300M)

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Proposed Protection Testbed

Program Description

A technology development & evaluation testbed focused on selected protection system technologies having significant potential to enhance the survivability of combat vehicles at reduced weight compared to the M1A2.

Discussion

A 5th Gen Combat Vehicle must be capable of greater protection against a range of advanced anti-armor threats at lower system weight. Key technologies for this leap-ahead objective include soft/hard-kill APS against CE/KE/top-attack EFP threats, advanced base armor, and ERA/NERA armor designs.

Project Description and Cost

- Armor/APS Protection Suite (4 years; $300M)
  - Development/Evaluation of advanced base armors effective against medium-caliber KE munitions and large-caliber KE fragments, including designs involving selective use of ceramic materials (3 years, $50M)
  - Development/Evaluation of advanced ERA/NERA concepts/designs able to degrade the performance of threat KE and CE munitions, including top-attack SC jets and EFPs (3 years, $50M)
  - Development/Demonstration of a robust soft/hard kill APS able to provide effective 360° hemispherical protection against advanced ATGMs, KE and top-attack EFP threats (3 years, $150M)
  - Follow-Up system-level demonstration of a robust integrated survivability-suite that includes the technologies cited above (1 year, $50M)
- Development/Evaluation of advanced underbelly protection concepts (2 years, $20M)

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Proposed C2/Network Testbed

Program Description - Assess information system technologies that enable identified core and enduring capabilities and mitigate MDO gaps

Discussion

C2 enabled by the network in these environments must:

- Fight the individual vehicle – direct fire
- Fight the individual vehicle or part of combined arms team – direct fire only
- Fight vehicle while leveraging all other combined arms – direct and indirect fire

Network must also enable platform capabilities:

- Command of robotic/unmanned systems, MUM-T and optionally manned operations
- Precision fires
- Cooperative engagement

Network must be able to operate in A2D2 and other contested environments, i.e., be resilient

Project Description and Cost

- Government Performers: Chief Systems Engineer, C5ISR Center, PEO C3T, PEO IEW&S
- Approach:
  - End-to-end assessments of performance, vulnerabilities and maturity in an operational environment when integrated into the current network (i.e., Integrated Tactical Network)
  - Leverage the instrumentation and procedures that were developed for Network Integration Evaluation (NIE) events
  - Piggy back on future Joint Warfighter Assessment (JWA) exercises and other ongoing efforts
- Schedule and Cost: Conduct annual testbed activities; Additional $60M per year

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Proposed Reliability & Maintainability Testbed

Project Objectives

Evolve and mature FCS "on board", system monitoring technologies, to drive/deliver advanced prognostics capabilities to support high levels of NGCVs mechanical and electronics systems/components readiness, effectiveness and efficiency.

Discussion

The M1A2C introduces LRMs. If augmented with AI-enabled conditioning monitors, advanced prognostics could reliably enable a push-based sustaining maintenance system

- "Push" (vs "Pull" or demand based) sustainment systems are increasingly common in late model POVs (privately owned vehicles) connected over the internet to central databases
- An AI-supported prognostic capability may increase NGCV readiness at the LRM and system levels with a smaller deployed support tail by improved predictive maintenance

Project Description and Cost

- Government Performer: CASCOM with GVSC
- Approach:
  - Develop AI-enhanced support system
  - Designate test-units; apply AI-enhanced support system to half of unit as test group, remaining half as control group
  - Identify issues with implementation, impact on unit maintenance, and operational readiness rates
- Cost and Schedule:
  - $50M over 5 years to develop and test

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Proposed Human Factors Testbed

Program Description

The addition of networked operations and Target cueing to the workload of a tank crew raises questions concerning cognitive loading, particularly with the desire to reduce crew size. A simulator employing all software being developed can be evaluated concerning crew workload and compared to M1 crew size, workload and performance.

Discussion

A significant improvement in 5th generation armor is the addition of modern information capabilities.

- Networked operations represent the gateway to Multi-Domain Operations.
- Artificial Intelligence enabling target cueing also shows promise of performance increases.
- Weight reduction requires crew size reduction. This combination could lead to crew work overload and reduced system performance. Creation of a simulation testbed would allow the interaction of added capabilities with crew and tank performance.

The primary purpose of this vehicle is to kill enemy tanks and other systems with direct fire while closing with and destroying the enemy. To accomplish this requires an internal C2 system designed expressly to optimize this mission. **It is imperative that the external network does not interfere in any way with this mission.**

Project Description and Cost

- Performers: TARDEC and NVEOL
- Description: Employ simulation technology to evaluate crew performance with the addition of software additions. The ability to compare operations with three and for man crews will be allowed.
- Schedule and Cost. Such a program can be begun with first developments of software. The program should last approximately three years and cost approximately $50M

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Proposed Computing / Artificial Intelligence (AI) Testbed

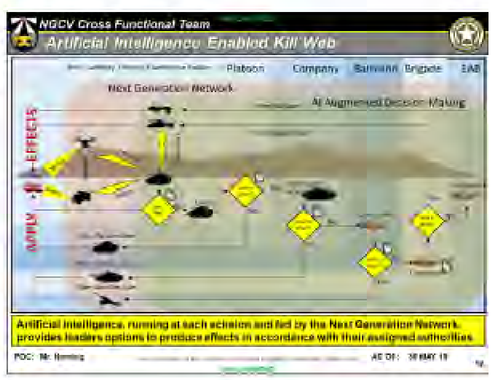
Program Description – Conduct a technology development and evaluation testbed focused on selected C2 and platform functions that can benefit from the application of AI techniques

Discussion – there has been wide interest in applying AI techniques to the following functions;

- Kill Web
- Autonomous driving
- Mission planning
- Route planning
- Automated target recognition

Project Description and Cost

- Government Performers:
- Approach: Products for:
  - Software applications
  - Architectures (operational, system and technical)
  - Big data
- Schedule and Cost: 3 years; $85M



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Proposed Robotics Testbed

Program Description

Perform a manned-unmanned team (MUM-T) robotic testbed focused on having robotic servant vehicles (RSV's) thicken formations as wingmen for human-operated combat vehicles. Must be able to measure formation effectiveness with robotic wingmen. **Command vs control is a key theme.**

Discussion

The use of robotics shows the potential to increase human survivability while thickening the friendly battlefield force.

- The goal for ground RSV operations should not be for humans to control robots, but for humans to command robots. The approach of command versus control regarding the employment of ground RSVs is a critical question the testbed must address.
- The convergence of artificial intelligence with robotics and autonomous systems will be critical to enable the RCVs to take the commands of the humans and perform their respective tasks.

Project Description and Cost

- Government Performer: GVSC
- Approach: Leverage relevant GVSC/NGCV planned testbeds for robotic wingmen under the **command** of humans as envisioned in the Gen 5 tank concept.
  - Start with a small number of RSVs executing battle/movement drills (e.g., column to line, line to column) and expand as experimentation progresses
  - Assess feasibility of thickening the formations with a diverse portfolio of RSVs under the command of humans.
  - Consistent with crawl, walk, run approach from NGCV/GVSC
- Cost and Schedule:
  - Added costs to planned GVSC wingmen testbeds (Phase 2, 2021, Phase 3, 2023), $50M
  - Adding more diverse RSVs (thickening the formation) cost $100M and take 5 years to develop and test. Two competitive prototypes are assumed for cost purposes

Proposed Masking Testbed

Project Objectives

Perform a testbed program to assess the military value of modern approaches to masking. **Masking employs next-generation concealment technology including:** profile design (lower radar cross section), active high-tech cognitive electronic warfare systems, and low-tech passive systems to become **unlocatable** through a combination of:

Stealth, camouflage decoys, simulation (create something from nothing), deception, environmental manipulations, electronic masking, and the use of electronic countermeasures (ECM) and digital radio frequency memory (DRFM) to hide beneath the blanket of enemy or friendly jamming.

Discussion

With the proliferation of networked ground and UAV based sensors, the desire to reduce the acquisition ranges of enemy sensors becomes an important capability.

- Techniques to reduce signatures were tried in the 1980's and 90's but were costly.
- New techniques which can reduce cost coupled with a proliferated threat make exploring these techniques important and can result in effects as dramatic as stealth is to aircraft.

Project Description and Cost

- Government Performer: TARDEC with NVEOL
- Approach:
  - Start with a simple "parade float" to test technology potential; if successful outfit a combat vehicle to test with military sensors in tactical environments. Coordinate with Robotics Testbed to include RSVs for decoys etc.
  - Approaches from multiple contractors.
- Cost and Schedule:
  - Parade Float would cost $10M and take 2 years to develop. Combat vehicle test would cost $50M and take 3 years to develop and test. Competitive prototyping and RSV integration could be undertaken at additional cost

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Agenda

- Study Introduction - Mr. Yuknis
- Threat Developments – Dr. Snowden
- The Need for Direct Fire Ground Combat Systems – Mr. Ancker
- Analytics Assessment – Dr. Douglas
- The 5th Generation Combat Vehicle – Mr. Antal
- Technical Program – Dr. Glauser
- ➡ Findings and Recommendations – Dr. Tegnelia

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Interim First Year Findings (1 of 3)

- Russian "New Generation Warfare" and emerging Chinese capabilities have contributed to a new US operational concept, Multi-Domain Operations. The threat and MDO require a 5th Generation Combat Vehicle that is significantly more capable than current systems.
- The Russians have demonstrated the following in their operations in Ukraine in both open and urban environments:
  - Tanks dominate close combat. More tanks were killed by other tanks than other anti-armor weapons.
  - Increased Anti-Tank weapon lethality
  - Massed Precision and Area Fires
  - Cyber and Electronic Warfare
  - Employment of UAVs

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Interim First Year Findings (2 of 3)

- Threat analysis (Ukraine lessons learned, T-14 development, Russian modernization, Scenario 7, etc.) assist in determining the essential requirements for a new system.
  - The threat helps to establish the need for armor as part of a combined arms force.
  - Reducing Weight and Improving Reliability restores tactical and operational mobility and will have the effect of reducing the sustainment tail and lift requirements. Reduced weight also allows air movement of small numbers of 5th Gen Combat Vehicles for limited contingency operations.
  - M1A2 SEP v3/v4 tactical mobility is challenged in Eastern Europe
  - Advanced ATGMs, Top Attack, and Emerging KE are future protection problem
    - Unmanned turret mitigates several issues (crew protection, silhouette, weight, mobility)
    - Integrated CE/KE/EFP hard & soft kill active protection systems improve protection
- The M1 is approaching the end of its product improvement cycle.
  - All product improvements add weight to an already too-heavy vehicle.
  - Inadequate space and power for computational capability to accommodate modern information systems.

Interim First Year Findings (3 of 3)

- As during the start of the M1 development program, the current Army tank development program is behind the Russian development program. The potential inability of the Russians to produce in quantity its prototypes offers the US the opportunity to move beyond their advancements. However, the Russians are upgrading existing vehicles with technology proven by their prototyping activities.
- The technology base to support the development of a 5th Generation Combat Vehicle is not sufficiently mature to begin EMD (Milestone B).
  - Critical Component and Systems technology is has not reached TRL 6.
  - Current analytics capability is insufficient to develop employment concepts and assess supporting hardware approaches
- This study group believes that the precedent set with the development of the M1 offers the best approach for development of a 5th Generation Combat Vehicle.
  - Critical component development maturation and competitive system prototyping before commitment to system acquisition (Milestone B).
  - Doctrine development conducted in parallel with hardware activity
  - Conducted in parallel with current systems product improvement

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Interim First Year Recommendations (1 of 3)

- A 5th Generation Combat Vehicle technical program should follow precedent set by M1 program. (SECArmy, CSA, CG AFC)
  - 6-8 year pre-acquisition program
  - $2B to complete technical maturation; $3B to complete technical maturation and competitive systems prototyping.
  - Experimentation for both component and system prototyping
  - Red Teaming employing national intelligence capabilities
  - Program balances initial cost and time with reduced risk, time and money savings post-Milestone B (EMD).
- Army Futures Command (AFC) should manage the pre-acquisition effort employing the management principles used by the M1 pre-acquisition program. (CG AFC, ASA(ALT))

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Interim first Year Recommendations (2 of 3)

- AFC should, in parallel with the pre-acquisition effort, determine the requirement for the 5th Generation Combat Vehicle informed by (among other considerations) the above technical effort. This team believes a stand-alone activity should be established for this effort. This effort should include an AoA. (CG AFC)
- Any program to establish the technology base for a 5th Generation Combat Vehicle should ensure a competitive industrial base. (CG AFC, ASA(ALT))

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Interim first Year Recommendations (3 of 3)

- The Army should, as it did in the pre-acquisition program for the M1, look outside the Army for technology that would further the capabilities of a 5th Generation Combat Vehicle. It should investigate technical areas (e.g. energetics, materials, modeling and simulation) where increased investment would significantly improve the development and employment of a new vehicle (CG AFC).
  - Allies (Israel, Great Britain, France, Germany, South Korea, Japan)
  - Department of Energy
  - Industry / Commercial Sector
  - DARPA
- DARPA should be engaged to help the Army explore high risk technology advancements and assist in assessing technical characteristics of the future battlefield. MOUs and programs between Army and DARPA are already in place. (DUSA, CTO AFC, ASA(ALT))
  - Information Science
  - Robotics
  - Smart Munitions including Hypersonics
  - Artificial Intelligence

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Questions and Comments

APPENDIX H. ACRONYMS

5GenCV	Fifth generation combat vehicle
A2/AD	Anti-Access/Area Denial
AFC	Army Futures Command
AFV	Armored Fighting Vehicles
AI	Artificial Intelligence
AMRDEC	Aviation and Missile Research, Development and Engineering Center
AMSAA	Army Materiel Systems Analysis Activity
AoA	Analysis of alternatives
APS	Active protection system
ARDEC	Armament Research, Development and Engineering Center
ARL	Army Research Laboratory
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics and Technology
ASB	Army Science Board
ASM	Armored System Modernization
AT/AV	Anti-tank/anti-vehicular
ATR	Automotive test rig
ATGM	Anti-tank guided missiles
BCT	Brigade Combat Team
BLOS	Beyond line-of-sight
BTG	Battalion Tactical Group
C2	Command and control
C3D2	Camouflage, concealment, cover, deception, and deceit
C4	Command, Control, Communications, and Computers
C5ISR	Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance
CAA	Center for Army Analysis
CASCOM	Combined Arms Support Command
CCTT	Close Combat Tactical Trainer

CE	Chemical energy
CG	Commanding General
COA	Course of action
COE	Common Operation Environment
COTS	Commercial, off-the-shelf
CSA	Chief of Staff, Army
DAC	Data and Analysis Center
DARPA	Defense Advanced Research Projects Agency
DEW	Directed energy weapons
DRFM	Digital radio frequency memory
DUSA	Deputy Under Secretary of the Army
ECM	Electronic countermeasures
EEA	Essential elements of analysis
EFP	Explosively formed penetrators
ELOS	Extended line-of-sight
EM	Electromagnetic
EMD	Engineering and Manufacturing Development
EO/IR	Electro-optic/infrared
ERA	Explosive reactive armor
ERDC	Engineer Research & Development Center
ERP	Enterprise resource planning
EW	Electronic warfare
FCS	Future Combat System
FFV	Future Fighting Vehicle
FRAG	Fragmentation
GCV	Ground combat vehicle
GLATGM	Gun-launched anti-tank guided missiles
GVSC	Ground Vehicle Systems Center
GVW	Gross vehicle weight

HAB	Heavy assault bridge
HE	High explosive
HET	Heavy equipment transporter
IFPC	Indirect Fires Protection Capability
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
ITN	Integrated Tactical Network
IVAS	Integrated Visual Augmentation System
JWA	Joint Warfighter Assessment
KE	Kinetic Energy
LER	Loss exchange ratio
LOS	Line-of-sight
LPD	Low probability of detection
LRPF	Long-range precision fires
LRU	Line replaceable units
LWR	Laser warning receivers
M&S	Modeling and simulation
MAPS	Modular Active Protection Systems
MBT	Main battle tank
MCoE	Maneuver Center of Excellence
MDO	Multi Domain Operations
MFoSC	Mounted Family of Computer Systems
MGV	Manned ground vehicles
MHE	Material handling equipment
MLRS	Multiple rocket launcher systems
MOE	Measure of effectiveness
MOP	Measure of performance
MP/CE	Multi-Purpose/Chemical Energy
MP-ERM	Multi-Purpose Extended Range Munition

MSIC	Missile and Space Intelligence Center
MSR	Main supply routes
MTBF	Mean time between failure
MTTR	Mean time to repair
MUM-T	Manned Unmanned Teaming
NBC	Nuclear, biological, and chemical
NERA	Non-explosive reactive armor
NGCV CTF	Next-generation combat vehicle Cross-Functional Team
NGIC	National Ground Intelligence Center
NIE	Network Integration Environment
NTC	National Training Center
NVESD	Night Vision and Electronic Sensors Directorate
OMFV	Optionally Manned Fighting Vehicle
OPFOR	Opposing force
PEO C3T	Program Executive Office Command Control Communications-Tactical
PEO GCS	Program Executive Office Ground Combat Systems
PEO IEW&A	Program Executive Office for Intelligence, Electronic Warfare & Sensors
PNT	Position, navigation, and timing
POM	Program Objective Memorandum
PSI	Pound per square inch
R&D	Research and development
RAKE	Rocket-assisted kinetic energy
RCCTO	Rapid Capabilities and Critical Technologies Office
REC	Radio electronic combat
RF	Radio frequency
RHAe	Rolled homogeneous armor equivalent
RSV	Robotic servant vehicles
RWR	Radar warning receivers
SECARMY	Secretary of the Army

SEP	System Enhancement Package
SIGINT	Signal intelligence
SMDC	Space and Missile Defense Command
SoS	System of systems
SoSIL	System of systems integration laboratory
SWAP-C	Size, weight, power, and cost
TARDEC	Tank Automotive Research, Development and Engineering Center
TOR	Terms of Reference
TOW	Tube-launched, Optically tracked, Wire-guided
TSC	Tandem shaped charge
UAS	Unmanned aerial systems
UAV	Unmanned aerial vehicles
UGV	Unmanned ground vehicles
V&V	Verified and validated

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