THE US ARMY

COMBAT VEHICLE MODERNIZATION STRATEGY

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Foreword

From the Vice Chief of Staff of the Army

Our Army's differential advantage over enemies derives from combinations of well-led, well-trained Soldiers and teams coupled with technology. Army forces must be prepared to overmatch the enemy in close combat. Combat vehicle's speed, protection, and lethality, and their ability to work in concert with many other types of ground forces, have provided our Army a critical advantage in defeating enemy militaries, removing hostile regimes, combating insurgents, and establishing security. Combat vehicles are critical to mission success across the range of military operations, from counter insurgency to conventional combat against every conceivable adversary. Combat vehicles enable forces to seize, retain and exploit initiative in expeditionary or forcible entry operations. *Combat vehicles enable Army commanders to maneuver,* gain positions of relative advantage, strike the enemy with fire, protect Soldiers from harm, and impose a tempo of events and multiple simultaneous dilemmas on the enemy to overwhelm enemy effectiveness. Trends indicate combat vehicles are growing even more important, as urbanization complicates tactical problems and sophisticated technologies boost the lethality of weapons. Army formations need combinations of mobility, protection and lethality to seize, retain and exploit the initiative against all potential adversaries.

Our Army must fight increasingly capable and elusive enemies in complex environments; therefore, it requires leaders adept in a range of formations with complementary capabilities, and the ability to task organize dynamically based on mission variables. Each formation requires the appropriate combination of mobility, protection and lethality to accomplish its mission. The Army requires both new combat vehicles and incremental technological improvements to existing vehicles to provide multiple options to combatant commanders and pose multiple dilemmas to the enemy.

Because of the increased velocity of human interaction and the pace of technology change, Army combat vehicle modernization must support continuous adaptation of the current fleet and innovation to develop future capabilities. The Army must ***sustain*** existing fleets, ***improv***e existing vehicles as science and technology produces new capabilities, ***develop*** new vehicles to meet emerging requirements, ***replace*** obsolete platforms to gain efficiency, and continuously ***assess*** capabilities, requirements and formations as conditions change.

Investments in combat vehicles are critical to mission success and reducing risk. As our Army becomes smaller, combat vehicles play an increasingly significant role. This strategy establishes the ends for combat vehicle modernization, aligns the ways and prioritizes means. It guides Army programing and budgeting activities and provides the vision for future combat vehicle development.

Daniel B. Allyn
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Section I
Winning Complex Fights: Mobility, Lethality, and Protection

Purpose

This document provides an enduring U.S. Army combat vehicle modernization strategy (CVMS). The strategy establishes the ends, ways and means to modernize Army combat vehicles in the near-, mid- and far- terms to meet the mobility, protection and lethality capability requirements of future Army formations.

Scope

The CVMS assesses current combat vehicle fleet and combined arms formation capabilities, and prioritizes across formations and timeframes. Timeframes are defined as near- (2016-2021), mid- (2022-2031) and far- (2032-2046) but are not fixed, and can adjust to acquisition and programming timelines. The CVMS does not address tactical wheeled vehicles, dismounted Soldier capabilities, integrated fires, network or mission command capabilities, or maneuver support systems. It is limited to brigade combat team (BCT) organizations under current Tables of Organization and Equipment, but addresses the possibility of future organizational change.

Section II
The Army Needs Modern Combat Vehicles

Introduction

Combat vehicles provide Soldiers and units with the combinations of mobility, lethality, and protection necessary to defeat enemy forces, seize, occupy and defend land areas, and achieve positional and psychological advantages over the enemy.[1] A modern and ready combat vehicle fleet is essential to achieve overmatch, which is the combination of capabilities that prevent enemy organizations from successfully using their equipment or employing their tactics.[2] While fighting against increasing capable and elusive enemies, maintaining overmatch requires combat vehicles that are resistant to enemy anti-armor systems, are able to maneuver to positions of advantage across a wide variety of terrain, and provide advantages to commanders and Soldiers across the full range of military operations.

> ***A modern combat vehicle fleet is a critical component of Joint Force success, as well as our Army's ability to reduce casualties in battle.***

Combat vehicles are essential to joint combined arms operations, operations that integrate infantry, armor, artillery, engineers, aviation, and joint capabilities. Combat vehicles have proven their value in all types of terrain and tactical environments from open desert to mountains, jungles, and cities. Combat vehicles provide general capabilities to Soldiers that enhance their ability to fight, including networked communications, load carrying, and power generation. They also fulfill roles essential to seizing, retaining and exploiting the initiative in battle. These include close combat, reconnaissance, protected Soldier and leader transportation, indirect fire, route clearance, obstacle reduction, mission command and communications, medical evacuation, maintenance, and sustainment.

The Need for Light, Medium, and Armored Capabilities: A Historical Perspective

The Army fought World War II with the M4 Sherman as its primary tank. The Sherman was optimized for infantry support, reliability, and ease of manufacture, while the Army relied upon the unproven concept of purpose built tank destroyers to fight enemy Armor. In combat, the Sherman quickly found itself overmatched by German panzers designed for fighting other tanks. After investing in a flawed concept, the Army had to adapt tactics to counter superior German tanks with the Sherman. While combined arms, tactical air support, and overwhelming sustainment and numbers enabled Army divisions to maneuver to defeat the German Army, American tankers typically lost three or four Sherman's for every German tank they destroyed. As we develop combat vehicles, we must test concepts regularly to ensure that American Soldiers possess modern equipment and are able to overmatch potential enemies in close combat.

TRADOC Pam 525-3-1, The U.S. Army Operating Concept: Win in a Complex World (AOC), describes how the Army will operate in the future, emphasizing expeditionary maneuver Expeditionary maneuver requires the rapid deployment of task-organized combined arms forces capable of transitioning quickly from deployment to combat, and conducting operations of sufficient scale and ample duration to achieve strategic objectives. Army forces must arrive prepared to fight.

Combat vehicles allow forces to seize the initiative against the enemy through speed and surprise. Air-deployable vehicles provide mobility, protection, and lethality to initial entry forces during joint forcible entry operations to ensure they are able to fight against capable and numerically superior enemies until reinforcing entry forces or follow on entry forces such as armored BCTs and Stryker BCTs either arrive by sea or draw prepositioned vehicles. Mobile, protected, precision firepower allows lighter forces to defeat defending enemies and ensure freedom of movement and action for infantry in close combat.

Stryker BCTs provide commanders high operational mobility allowing rapid expansion to exploit initial entry success. However, they lack sufficient lethality to maneuver against determined enemies with modern weapons. Armored BCTs overmatch fully alerted enemy forces and enable commanders to retain freedom of action, defeat enemy forces, and consolidate strategic gains. They also require continuous modernization to retain this overmatch against the full range of evolving threats. To ensure that the Army remains prepared to fight and win across all types of terrain and against a broad range of enemies, this CVMS maximizes the combat capability of all maneuver formations.

Investment Challenge

Increased investment in combat vehicle modernization is necessary to reverse a growing trend towards obsolescence and ensure overmatch over current and future enemies. Army acquisition efforts must simultaneously develop new solutions that provide mobility, protection, and lethality to our future formations while maintaining current fleet investments and long lead-time improvement programs.

Combat Vehicles Essential to Expeditionary Maneuver: Mali, 2013:

"Joint/combined arms combat is the key to tactical success. The tempo of operations was high …. For the land component, all the operations were characterized by the dynamic of joint and combined arms operations. *SERVAL* made it clear that…in coercive action, tactical success lies in a maneuver combining surprise, audacity, and taking advantage of all the effects of available combat power…reach, firepower, mobility, and armor vehicle deterrence appeared as the key factors to success."

Cahier du Retex: Lessons Learned from Operation SERVAL (Mali Intervention) (January – May 2013) Leader's Guide

During the last fourteen years of war, modernization efforts logically focused on fielding vehicles designed for counterinsurgency operations in Iraq and Afghanistan. Army investment in combat vehicle modernization diminished, slowing the pace and scope of Army modernization efforts comparable to allies, as well as potential adversaries.

New vehicle programs such as Future Combat System (FCS) and ground combat vehicle (GCV) were cancelled and did not deliver new capabilities to the force. Meanwhile, observations of recent combat experiences (Israel in Lebanon and Gaza; France in Mali, U.S. in Sadr City, Russia and Ukraine) have highlighted the criticality of combat vehicles, and expose gaps in U.S. Army capabilities. Future missions will require Army BCTs, operating as part of the Joint Force, to win against well-armed state, non-state, and hybrid threats across a range of operations. Therefore, there is urgency in refocusing the Army's combat vehicle modernization strategy and a need to increase investment to prepare for existing and emerging threats. Plans and programs must increase formation capabilities to defeat emerging threats, mitigate the challenges of age and obsolescence in the current fleet, and remain within the constraints of diminished funding.

The Combat Vehicle Challenge

Combat vehicle modernization efforts must solve the "combat vehicle challenge;" that is, designing combat vehicles that protect Soldiers against threats and deliver precision lethality, while providing both tactical mobility and global responsiveness within the limitations of vehicle cost and weight.[3] Cost and weight factors limit the attributes of protection, lethality, and mobility possessed by any combat vehicle.[4]

Modernizing the Army's combat vehicle fleet introduces some problems. How does the Army-

- Maintain and enhance advantages in mobility, protection, and lethality over increasingly capable potential enemies?
- Enable the globally responsive Joint Force to conduct expeditionary maneuver and joint combined arms operations to win against determined, elusive, and increasingly capable enemies?[5]
- Overcome the challenges of increasing combat vehicle cost and fiscal constraints?

The Army CVMS describes vision, goals and ways forward to attain required capabilities within available means (manpower, dollars, and time) for the near-, mid-, and far- terms. The strategy also assesses risk and identifies opportunities to mitigate those risks.

Section III
The Modernization Strategy: Aligning Ends, Ways, and Means

Ends

Army BCTs possess the lethality, mobility, and protection to achieve overmatch during joint expeditionary maneuver and joint combined arms operations.

Ways

Modernize combat vehicles according to three tenets of modernization: evaluate trends, innovate, and prioritize. Drawn from the AOC's future force development principles, the tenets guide the CVMS.

Evaluating trends involves the careful observation and analysis of the operating environment, to include the emergence of new technologies and asymmetric threats.

Innovation is the conversion of ideas into valued outcomes, and must be encouraged and promoted in a manner that rewards originality and intelligence.

Prioritization requires balancing needs with limited resources to advance the most important modernization projects in the near-, mid-, and far-terms. To modernize consistent with these three tenets, the Army applies the tangible resources of funding and technology with the intangible factors of leadership and political will. The Army combines emerging technologies with new organizational concepts. Army planners develop new solutions or identify commercial off-the-shelf (COTS) options. Research and development initiatives are flexible to react to emerging, dynamic threats.

Future Force Development First Principles

1) Retain capacity and readiness to accomplish missions that support achieving national objectives.
2) Build or expand new capabilities to cope with emerging threats or achieve overmatch.
3) Maintain U.S. Army asymmetrical advantages.
4) Maintain essential theater foundational and enabling capabilities.
5) Prioritize organizations and competencies that are most difficult to train and regenerate.
6) Cut unnecessary overhead to retain fighting capacity and decentralize capabilities whenever possible.
7) Maintain and expand synergies between the operating force and the institutional Army.
8) Optimize performance of the Army through a force mix that accentuates relative strengths and mitigates weaknesses of each component.

TRADOC Pamphlet 525-3-1

Means

The means to effective combat vehicle modernization include the simultaneous performance of five tasks: The Army ***sustains*** current vehicles, ***improves*** existing systems, ***develops*** new capabilities, ***replaces*** obsolete vehicles, and ***assesses*** new technologies and concepts across the doctrine, organization, training, materiel, leadership, personnel, facilities, and policy (DOTMLPF-P) construct. Together, these five tasks combine to form the ***SIDRA*** process, which links the ways of modernization and the means to modernize. This process supports the tenets of modernization derived from the AOC's future force development first principles: Evaluate trends, innovate, and prioritize.

The SIDRA Process: Linking Ways and Means

Sustain *current vehicles*
Improve *existing systems*
Develop *new capabilities*
Replace *obsolete vehicles*
Assess *new technologies and ideas*

Modernization and SIDRA

Israel's Modernization

In 2006, Israel invaded southern Lebanon, leading their attack with combined arms formations. They encountered a layered, hybrid Hezbollah defense, which defeated their formations through synchronized attacks with advanced anti-tank guided missiles, rocket propelled grenades, improvised explosive devices, and rocket artillery. Since then the Israeli Defense Force (IDF) has engaged in a dedicated combat vehicle modernization program. They developed new vehicles to enable infantry mobility ("Namer" Heavy APC), modernized their Merkava IV main battle tanks with a hostile-fire-detection and active protection system, fielded advanced precision airburst munitions, dramatically improved blast underbelly protection, and networked their entire formation onto an advanced battle management system. With these modernizations implemented through a dedicated training program, the IDF again confronted terrorist threats in a complex urban environment in Operation PROTECTIVE EDGE during the summer of 2014. Their tactical operations in Gaza were overwhelmingly successful, with tanks spearheading every move by IDF formations. The key lesson learned was the ability of modernization efforts to return tactical maneuver to their ground forces, enabling them to confront and overwhelm advanced third generation anti-tank threats.

Evaluating trends. The CVMS considers the future operational environment and emerging threat, enemy, and adversary capabilities. Future enemies will employ traditional, unconventional, and hybrid strategies to threaten U.S. security and vital interests. Threats may emanate from nation states or non-state actors such as transnational terrorists, insurgents, or criminal organizations. Enemies will continue to apply advanced as well as simple and dual-use technologies to exploit perceived U.S. vulnerabilities and avoid U.S. strengths. Adversaries will invest in technologies and fight in innovative ways to counter U.S. systems and tactics.

Threats to U.S. security and vital interests will demand short-notice operations in environments characterized by complex and restricted terrain, often devoid of front lines, and with insecure flanks. All operations will require forces with strong operational and tactical mobility. The ability to transition swiftly between offensive, defensive, and security operations will prove essential to mission success. Urbanization increases the likelihood of operations in complex and urban terrain. Potential enemies will exploit complex and urban terrain to maneuver close to friendly forces, restricting vehicle mobility and reducing engagement ranges for weapons and target acquisition systems. Future enemies will fight among civilian populations, requiring U.S. leaders to apply firepower with discipline, precision, and discrimination.

Army forces executing expeditionary maneuver must overcome adversaries employing anti-access (A2) and area denial (AD) capabilities to contest U.S. power projection and limit U.S. freedom of action. In high anti-access and area denial environments, dispersion allows future Army forces to evade enemy attacks, deceive the enemy, and achieve surprise. Even when operating dispersed, mobile combined arms teams are able to concentrate rapidly to isolate the enemy, attack critical enemy assets, and seize upon fleeting opportunities. U.S. forces conduct continuous reconnaissance and security operations to seize, retain, and exploit the initiative over the enemy while protecting the force against dangers. Initial entry forces must be able to attain overmatch quickly while maintaining freedom of maneuver to avoid becoming fixed and defeated by larger enemy forces.

Threats to Army combat vehicles are growing rapidly. Nations are modernizing conventional armored forces. Combat vehicles across the world are nearing or surpassing parity with U.S. vehicles. Concerns include proliferating anti-tank guided missiles (ATGM) and advanced tandem-warhead rocket propelled grenades (RPGs), advanced improvised explosive devices (IEDs) and explosively formed penetrators (EFPs), light armored vehicles with powerful medium caliber cannons, 'smart' munitions, unmanned aerial systems, lasers, chemical and biological agents, advanced electronic warfare, and even cyber threats. Proliferation of low- to high-technology weapons allows non-state and hybrid actors to emulate more traditional military formations.[6] U.S. combat formations must remain capable of defeating enemy combined arms formations, overmatching irregular and hybrid threats, and maneuvering through complex and urban terrain.

Innovate. To innovate, the Army must simultaneously pursue short-term solutions for current challenges while developing new capabilities over the mid- to long- terms to ensure overmatch in future missions. True innovation requires linking Soldier experience and input with projected mission requirements to determine the most pressing needs and design solutions. By identifying and acquiring COTS equipment, capabilities, and vehicles, the Army sustains existing formations' capabilities against rapidly evolving threat tactics and technology. Leveraging emerging technology improves current formations ability to prevail against future opponents. Research and experimentation will develop new technologies for future modernization efforts. As new vehicle capabilities enter service, the Army must replace obsolete systems. By evaluating research and development efforts and analyzing outcomes of operations, simulations, and training center rotations, the Army assesses current vehicle and formation effectiveness while refining future force needs. Innovation enables the deployment of the most effective combat vehicles possible over time.

Learning activities are critical to effective combat vehicle modernization. Army learning encompasses the intellectual (studies, analysis, and concept and capabilities development) and the physical (experimentation, evaluations, exercises, modeling, simulations, and war-games). The Army Warfighting Challenges (AWFCs) form the analytical framework that integrates learning, modernization and force design efforts across warfighting functions. Learning activities help leaders integrate future capabilities and develop solutions to these warfighting challenges.[7]

Experimentation allows Army leaders to understand user needs, identify technological opportunities, assess materiel solutions, and integrate new capabilities, providing a cost effective method to determine which technologies offer the greatest utility. Near-term experimentation and analysis determines how to improve deployability without sacrificing mobility, protection, lethality, and overall capability in our formations. Mid- and far- terms experimentation and analysis prioritize science and technology efforts, refine future concepts, and identify emerging gaps or shortfalls in capability as well as opportunities to maintain overmatch against future enemies. These efforts must seek new doctrinal, organizational, training, leadership, personnel, facilities, and policy approaches to future problems, to limit reliance on expensive materiel solutions. Experimentation and analysis efforts must connect data and lessons learned with materiel decisions. The Army will rigorously link experimentation, analysis, and learning activity outputs to materiel development and acquisition decisions[8].

Prioritize. Budgetary uncertainty and fiscal constraints mean the CVMS prioritizes the capabilities in near-, mid- and far- terms. The Army prioritizes according to the principles of value and risk. Combat vehicle modernization must enhance the value of the formation by enabling the Joint Force to accomplish assigned missions. The Army also places first priority on formations most vulnerable, that is, those facing the greatest risk when employed. Thus, in the near- term, Army combat vehicle modernization efforts emphasize the development of improved capabilities for the infantry BCT. This BCT’s mission accomplishment is at greatest risk without increased mobility, protection, and lethality. Priorities for combat vehicles employed by less-vulnerable units fall in mid- and far- terms modernization efforts.

Modernization initiatives must provide lighter, more reliable vehicles to increase expeditionary capabilities. Expanding threat capabilities increase the need for more protection, driving up weight, power required, and cost to operate while simultaneously limiting tactical mobility, and challenging strategic deployment and sustainment. Deploying maximum maneuver capability rapidly requires minimizing tactical and operational sustainment burdens. Lower vehicle weight, more reliable and repairable components, and more energy efficient systems, all support increasing total formation capability. Additionally, these initiatives drive down total vehicle life-cycle costs, allowing the Army more resourcing flexibility. In prioritizing combat vehicle modernization, leaders compare the benefits of lower weight and higher efficiency with limitations to protection and increasing development cost.

Resource availability cannot dictate the ends required for the Army, but it defines both the ways and means to achieve those ends. An option to enhance capabilities while mitigating the risks of low funding levels is to adopt mixed modernization. This approach prioritizes a smaller, high-readiness fleet of vehicles modernized to the fullest extent possible while ensuring sufficient modernization of the majority of combat vehicles to allow rapid upgrade in a crisis when funds become available. Army leaders make decisions concerning mixed modernization based on future force operational concepts and available funding. Mixed modernization is also critical to ensure that vehicle fleets remain interoperable and close enough in capability for training commonality. This allows Soldiers to transition readily between vehicle models. Mixed modernization complicates logistical support, challenges the training institution, and retains aging vehicles in service. However, the approach is necessary to provide a modern base of vehicles to build upon later. If sufficient funds become available, the Army will again pursue complete modernization across each of its combat vehicle fleets.

Army Combat Formations

Combat vehicles are essential to joint combined arms operations.

The Army organizes combat forces into BCTs with 4,500 to 5000 Soldiers. There are three types of BCTs: infantry, Stryker, and armored; trained, organized, and equipped for complementary roles in combat. Each BCT is comprised of a brigade headquarters to provide mission command; three maneuver battalions that provide combined arms operations capability; a cavalry squadron for reconnaissance and security missions; a field artillery battalion to provide lethal fire support; an engineer battalion for mobility, counter-mobility and survivability; and a support battalion for sustainment, logistics, and key enabling capabilities. Inherently flexible, BCTs task-organize routinely to support specific mission requirements, either accepting units that bring needed capabilities or providing parts of the BCT to other organizations. Combat vehicle-equipped formations are scalable and tailorable.[9] A full BCT formation requires substantial support and logistics.

I*nfantry BCT combat vehicle shortfalls*.

The infantry BCT is optimized for rapid deployment and dismounted operations in restrictive terrain (urban, mountainous, forested, subterranean, jungle). The Army has more infantry BCTs than other combat formation. Infantry BCTs conduct entry operations or deploy by ground, air-land, airborne, and/or air assault.

The infantry BCT's greatest limitation is its tactical and operational mobility once deployed. This capability shortfall (or gap) is especially critical in joint forcible entry scenarios that rely upon swiftly seizing key terrain or facilities to establish a lodgment for follow-on forces. Because potential adversaries possess A2 and AD capabilities that prevent direct seizure of air- or sea-ports, the infantry BCT must maneuver from greater distant, into undefended locations, and then maneuver rapidly to seize entry points for follow on forces. This type of movement requires tactical mobility for infantry squads to move quickly, on or off road, to attack from multiple directions more swiftly than enemies can respond.

The infantry BCT lacks a lightweight combat vehicle that provides mobile protected firepower (MPF) to enable freedom of movement and freedom of action, which are essential to expanding a lodgment and preventing enemy counterattack. This vehicle is essential to defeating local fortifications, point defenses, and blocking positions to maintain momentum. Without the combat vehicle, the infantry BCT requires reinforcement with heavier armored vehicles for close combat against capable enemies.

As a final point, the infantry BCT cavalry squadron lacks the ability to secure vulnerable light infantry during movement, transition between mounted and dismounted reconnaissance techniques, or to fight for information over extended tactical distances. This lack of mobility, protection, and lethality limits the formation's ability to create operational depth, develop situational understanding, preserve options, and sustain operational tempo and freedom of maneuver. [10] The infantry BCT's combat vehicle requirements are the most pressing across the Army and require the highest priority.

Stryker BCT combat vehicle shortfalls.

The Stryker BCT couples a strong dismounted fighting capability with significant operational mobility. The Army equips Stryker BCTs with more than three hundred flat-bottom hull, (or double-V hull), Stryker 8-wheel multi-role combat vehicles. The Stryker provides Soldiers with protected mobility against IEDs, small arms, RPGs, and artillery or mortar fragments. Stryker BCTs support nine different mission roles including infantry carrier, mortar carrier, engineer support, medical evacuation, reconnaissance vehicle, anti-tank guided missile carrier, mobile gun system, nuclear, biological, chemical, reconnaissance vehicle, and command and control. The double-V hull variant provides greater IED protection, at the cost of greater weight. The Stryker BCT is capable of moving mounted to positions of advantage rapidly and fighting dismounted to defeat enemy forces.

The Stryker BCT faces challenges as potential adversaries improve their capabilities. The Stryker infantry carrier vehicle, the primary maneuver vehicle in the Stryker BCT, lacks the sensors and weapons to detect, recognize, identify and suppress or defeat threats at extended ranges or provide fire support for infantry as they dismount in close proximity to the enemy. The lack of sufficient mobile protected direct fire support throughout the formation makes it difficult to maintain freedom of movement and action, and makes the formation's Soldiers vulnerable to surprise encounters with the enemy. Moreover, force protection improvements to protect the Stryker from IEDs and RPGs in Iraq and Afghanistan have significantly reduced the vehicle's tactical mobility. Continued modernization of the Stryker BCT's combat vehicles is required to regain its mobility and increase its ability to employ precision long-range direct fire.

The Stryker BCT requires almost the same strategic lift assets to deploy as an armored BCT. Deployability depends upon reliability, logistics demand, nearly as much as vehicle weight and size. Supplies and support assets outside the BCT account for over 80% of sealift space during deployment. Reducing demand for parts and fuel improves the Stryker BCT's deployability.

Armored BCT combat vehicle shortfalls.

The armored BCT provides the Army with a powerful mix of combined arms capabilities and the mobility, protection and lethality necessary to seize, retain, and exploit the initiative. Equipped with Abrams main battle tanks, Bradley infantry fighting vehicles, Paladin self-propelled howitzers, and over a hundred other tracked supporting vehicles, the armored BCT is the Army formation most capable of prevailing against the full range of threats and the only formation capable of conducting combined arms operations both mounted and dismounted. The armored BCT operates equally well in heavily populated urban areas or on open rolling terrain. The formation's MPF has proven essential to success across a broad range of operations.

Despite advantages in mobility, protection, and lethality, the armored BCT presents numerous future challenges. While air movement of some elements of the armored BCT allows for the reinforcement of lighter and more rapidly deployable joint forces, it is time and cost prohibitive for deploying and sustaining the armored BCT through air assets alone. The armored BCT's ability to overmatch enemies is in jeopardy as several core combat vehicle platforms reach or approach obsolescence.

Challenges to the Bradley fighting vehicle, in particular, are increasing. The Bradley lacks sufficient protection against underbelly threats. Many enemy combat vehicles outgun it, and it has lost mobility due to the increasing weight of theater-specific force protection upgrades. The M113 family of vehicles is obsolete, because of inadequate protection and electrical generation capability. Evolving protection requirements have increased the Abrams' weight beyond the capacity of recovery and transportation assets, while increasing formation fuel demands. All armored BCT vehicles require substantive improvement to host current and emerging networking solutions for mission command, and because potential enemies are upgrading their weapon systems, all armored BCT fighting vehicles require improvement to retain lethality by detecting, recognizing, identifying, and destroying threats at longer ranges.[11]

New technologies maintain the armored BCTs' overmatch through increased lethality, mobility, and protection, while reducing logistical demand and the weight of the overall formation. Advanced material science can reduce vehicle weight and enhance mobility without sacrificing protection. New precision munitions enhance lethality and potentially reduce collateral damage as networking and sensors extend our forces' reach and vision. Active protection systems that can intercept or spoof incoming projectiles before they strike U.S. vehicles promise to defeat a broad array of threats, allowing forces the freedom to maneuver while exposed to enemy fire. However, technological improvements increase both cost and program risk, and require strategic prioritization to gain the greatest increase in overall capability.

The range of potential enemies, operating environments, and missions demand dynamic combinations of infantry, Stryker, and armored BCTs, but the future Army must equip and potentially organize its forces differently. Emerging technologies can reduce logistics and transportation demands and better enable sustained land campaigns. Prioritized investment in combat vehicles will allow the Army to equip Soldiers with vehicles that are more lethal, better protected, lighter, and easier to deploy and sustain. As we modernize combat vehicles to enhance the strength of combat formations, we simultaneously address those formation's weaknesses. As new formation capabilities grow from modernization efforts, the Army continuously assesses BCT organizations, seeking new combinations of capabilities that can better execute new concepts and are easier to deploy, employ, and sustain.

Prioritizing Ways and Means in the Near-, Mid-, and Far- Terms

The Army establishes combat vehicle modernization priorities in the near- (next five years), mid- (next ten years), and far- (following ten to fifteen years) terms. Priorities align with the defense budgetary system while allowing program or fiscal adjustments to meet emerging requirements. Since the future budgetary environment is difficult to predict, this strategy describes the means or resources available as priorities rather than actual funding levels. Wherever possible, the Army will implement broad technological enhancements across multiple platforms through horizontal technology insertions, gaining greater total return on modernization dollars. The Army emphasizes divestiture of unneeded or obsolete systems, retaining only the needed quantities of materiel to conserve resources.

Near- term (Present–FY 2021)

In the near-term, the Army's first priority is to enhance the infantry BCT's shortfalls in mobility and lethality.

As the formation that is most rapidly deployable formation within the BCT framework, the infantry BCT deploys more rapidly than the others do, so it faces the most threats and performs the most diverse range of combat operations. The Army must therefore improve tactical mobility by acquiring and integrating new lightweight vehicles that enable rapidly deployable expeditionary maneuver. The Army must also develop light reconnaissance vehicles that provide operational depth, enable both mounted and dismounted reconnaissance, and provide an interim solution to the infantry BCT's lethality shortfall. As the Army obtains more capable squad and reconnaissance vehicles, it will replace the up-armored high-mobility multipurpose-wheeled vehicle, which is too small to carry an infantry or scout squad, lacks tactical mobility, and is incapable of fighting for information.

The squad is the foundation of tactical operations; therefore, the Army will sustain squad-level overmatch by linking individual Soldier skills with squad dismounted and mounted capabilities while modernizing the infantry BCT with combat vehicles. Once fielded, the Army will assess how the combination of lightweight squad combat vehicles and light reconnaissance vehicles functions at the formation level and refine the need for lightweight engineer or mobile lightweight indirect fires capabilities. Assessments must consider that the infantry BCT will conduct joint forcible entry operations to meet the requirements articulated in the AOC, particularly transitioning rapidly to offensive operations, which underpins expeditionary maneuver. Learning activities currently and in the near-term must determine the capability value of new platforms at the formation level to confirm whether early efforts are yielding the desired level of improvement.

Simultaneous with improving infantry BCT tactical mobility, the Army will sustain and improve Stryker and armor BCT capabilities.

The Army will improve Stryker vehicle protection by completing platform enhancements in the form of engineering change proposals (ECPs) and lethality upgrades. The armored BCT must sustain its current modernization program, which further enhances force protection, network capabilities, and direct fire lethality. The Army must also continue its program to replace the M113 family of vehicles. In addition, near-term research and experimentation must develop systems to protect vehicles and formations from modern anti-armor systems.

As the Army modernizes its current formations, it must continuously assess the utility of existing formation constructs to determine the organizational structure and doctrine required for future formations, including the identification of roles and missions for autonomous systems and other emerging technologies. The Army must develop and assess autonomous manned and unmanned systems along operational and developmental lines of effort. The operational line of effort will improve the capabilities of current autonomous systems while reducing the cognitive demand on the Soldier and the sustainment and support burden on the unit. The operational emphasis will improve the capability of current systems to execute tasks. The developmental line of effort will determine the specific high-payoff areas to integrate existing, mature technologies to support the current force while using operational modeling and simulation to identify the functional focus for future autonomous technology.

Mid-term (FY 2022–FY 2031)

In the mid-term, the Army's highest priority is to improve the limited mobile protected firepower capabilities within the infantry and Stryker BCTs.

While the infantry and Stryker BCTs provide the Army's greatest expeditionary potential and operational mobility respectively, both lack direct fire capability that allows these formations to gain overmatch when facing capable enemies in close combat. The Army must improve infantry and Stryker BCTs maneuver capabilities by adopting an interim MPF capability, while developing an objective MPF solution. The Army fulfills the interim requirement by modifying an existing combat vehicle or purchasing an off the shelf solution in modest quantities.

In the mid- and far- terms, infantry and Stryker BCTs require a vehicle possessing exceptional all-terrain mobility and powerful stabilized direct-fire (while moving) weapons, with sufficient protection to resist small arms fire and active or reactive protection to defeat anti-armor rockets and missiles. A highly mobile precision direct fire platform allows both the infantry and Stryker BCTs to counter most immediate threats encountered during joint forcible entry. In the mid-term, the Army will sustain the tactical mobility advantages developed in the near-term and replace the infantry BCT's obsolete tactical wheeled vehicles. Army analysis and experimentation efforts must assess interim vehicle performance against threshold requirements.

While MPF for infantry and Stryker BCTs is a top priority, the Army develops this capability concurrently with modernization improvements to all combat vehicle fleets. In the mid-term, the Stryker BCT will sustain its existing fleet of vehicles to mitigate increasing cost of aging vehicles. Stryker BCTs must improve vehicle and formation lethality by fielding developed solutions. Testing of the interim MPF capability may lead to the replacement of the Stryker mobile gun system and anti-tank platforms.

The focus for the armored BCT is to develop a future fighting vehicle (FFV) capability for infantry and cavalry squads, eventually replacing the Bradley. The armored BCT must also sustain main battle tank and infantry fighting vehicles pending long-term replacement and develop future platform variants, including engineer and mobile indirect fire platforms. The Army must replace the M113 family of vehicles, synchronizing divestiture with acquisition to maintain essential capabilities and prevent capability gaps. The Army must improve the armored BCT's existing capabilities through the introduction of autonomous ground systems that eliminate (or significantly reduce) the need for tele-operation (direct, continuous remote control by an operator). Such systems must conduct substantial portions of their mission profile without reliance on direct human control.

Finally, the Army will assess the technologies and organizational constructs that best enhance future BCT formations by conducting in-depth operational and technical experimentation to identify specific technologies for incorporation. Technologies planned for far-term implementation include the large-scale adoption of autonomous (manned and unmanned) systems. Mid-term assessments must therefore determine how to link individual Soldier skills with autonomous and semi-autonomous systems, and manned and unmanned vehicles.

Far-Term (FY 2031–FY2046)

In the far-term, the Army's first priority is enhancing the armored BCT's ability to deploy rapidly, while improving the formation's mobility, protection, and lethality.

The armored BCT must improve its expeditionary capability by fielding new direct and indirect fire systems. This initiative will include the full-scale incorporating autonomy enabled or robotic systems. As the armored BCT fields new systems, it will replace main battle tanks, howitzers, and mortar indirect fire platforms. Far-term initiatives aim to solve the absence of the armored BCT's ability to deploy rapidly. The Army assesses the feasibility and application of autonomous or semi-autonomous sub-systems, manned and unmanned teaming, and autonomy-enabled combat platforms. Such systems will significantly enhance the formation's reconnaissance and security capabilities provide limited lethality capabilities in discrete formations that are predominantly unmanned, with small manned planning and command and control elements.

As armored BCT modernization proceeds, the Army must simultaneously sustain expeditionary maneuver capabilities of other formations provided by the combined arms employment of lightweight squad combat vehicles, light reconnaissance vehicles, and the MPF system introduced in the near- and mid- terms. The Army will also replace the interim MPF with the objective MPF and improve individual Soldier mobility by developing robotic and autonomous systems further, thereby producing the best combinations of skilled Soldiers with emerging technological capabilities (see appendix G).[12]

As modernization initiatives change formation capabilities, the Army continuously *assesses* organizational structures, tactical doctrine, and organizational concepts to adapt to changing conditions. The Army may organize future formations differently, but all will require appropriate combinations of mobility, lethality and protection to execute combined arms maneuver and accomplish their missions. Concurrently with all modernization initiatives, the Army needs to continuously divest and eliminate obsolete vehicles and their support infrastructure to save resources and focus capital on required capabilities. Ultimately, the Army must train, equip, resource, and organize to optimize individual Soldier skills, autonomous and semi-autonomous systems, manned and unmanned vehicles, and Joint Force capabilities into formations that can fight and win in a complex world.

Failing to Modernize Army Combat Vehicles Creates Risk

> ***Failing to modernize the U.S. Army's combat vehicles creates a serious and striking amount of strategic risk.***

In the near-, mid-, or far- terms, obsolete combat vehicles will prevent Army units from succeeding at their designated missions. Such a technical phrase obscures the reality of failed modernization: dead Soldiers and embarrassing defeat.

Based on the capabilities required to win against capable and elusive enemies in a complex environment, the infantry BCT faces the greatest near-term risk. The Army can mitigate this risk by procuring off-the-shelf solutions to enhance infantry BCT tactical mobility. Special operations forces have proven the utility of commercially available light military vehicles, and common solutions provide greater interoperability for general-purpose forces. This approach is quick and low cost, freeing time and resources for other priority efforts.

Failure to maintain Stryker or armored BCT capabilities in the mid-term represents the second highest risk. Programs that address Stryker and armored BCT capability requirements currently exist. These programs represent significant investments in time and money, and must continue simultaneously with infantry BCT initiatives. To defend the Nation, the Army must field new capabilities when they are required, not when they are expedient; modernization efforts must match or exceed adversary advances. The Army must balance improvements to existing platforms against the development of new capabilities. Meanwhile, modernization efforts must ensure sufficient technological integration on legacy vehicles simultaneously to provide necessary capabilities on the future battlefield.

The development of new concepts and platforms must permit integration and mutual support with the platforms that we sustain into the future. Senior leaders must prioritize doctrinal, organizational, and tactical interoperability to provide combined arms capability to the joint force. In the far-term, the Army must reach a level of autonomous system integration that will allow unmanned systems and formations to accomplish key tasks, freeing up manned systems and formations for those missions that require human interaction and cognition. Formations composed largely of autonomous systems will conduct tactical tasks such as, screen and resupply, as well as countering rocket and missile attack. Soldiers must provide sustainment and the command and control elements; the operational arm may be composed almost entirely of autonomous systems.

Overcoming Risk

There is also risk in a single or limited number of approaches. If conditions change, the Army may find it has invested all its resources into a capability that does not meet evolving requirements with no time to fix the problem. Furthermore, a commitment to a single overarching priority may bleed resources from other efforts that could have provided mitigation.

It is impossible for any single combat vehicle system to perform all desired missions equally well. The Army should reject a "one-size-fits-all" approach to combat vehicle modernization and instead embrace a series of modernization efforts designed to produce the combinations of Soldiers and equipment within each type of BCT that best prepare the BCT for the missions that it is most likely to perform. Managing modernization with limited resources requires adopting incremental improvements throughout the force and managing fleets with various degrees of improvement applied. Strategic planning must account for a force that includes a mix of capabilities across each platform or family of vehicles. Managing modernization also requires simultaneous development of new vehicles, to prevent, for example, having highly modern tanks but obsolete infantry carriers. The Army must accept and manage different degrees of modernization to all of its combat vehicles until funding increases or an emerging threat dictates modernization of the entire fleet.

The Russian Invasion of Ukraine

In the aftermath of its annexation of Crimea in March 2014, Russian forces began supporting separatists in Eastern Ukraine with advanced weaponry, fire support, and special and conventional forces. This ongoing conflict offers important insights for the U.S. Army about the lethality of the modern battlefield; lethality the U.S. Army has not faced since World War II. Russian and separatist forces are employing combined arms warfare with advanced weapons to devastating effect. Russian artillery, particularly rocket launchers with conventional, thermobaric, and cluster munitions—using unmanned aerial systems (UAS), both for target location and battle damage assessment—is particularly effective against Ukrainian light armor and infantry formations. Additionally, the Russians are using their most advanced tanks in the Ukraine, including the T-72B3, T-80, and T-90. All of these tanks have 125mm guns capable of firing a wide range of ammunition, including antitank/anti-helicopter missiles with a six-kilometer range, and advanced armor protection, including active protection on some models. Finally, the Russian air defense systems (man-portable and vehicle mounted) have made it all but suicidal for the Ukrainian Air Force to provide air support to ground forces. Thus, the battlefields of Eastern Ukraine are similar to those envisioned by the U.S. Army during the Cold War, but with more mature technologies. It is a battlefield that requires armor for maneuver. Light skinned vehicles, including BMP infantry fighting vehicles, have proven vulnerable to both artillery and tank fire. Dismounted infantry in defensive positions risks becoming fixed by fire and either isolated or overrun by maneuvering units supported by tanks. In short, the Ukrainian battlefield is a harbinger of the complex environment the U.S. Army will face in the future; a battlefield that requires mobile protected firepower, the integration of all arms, and counters to long-range artillery, UAS, air defenses, and tank protection systems.

The Russian Invasion of Ukraine, written exclusively for this strategy, by Dr. David E. Johnson

To manage modernization efforts effectively, Army leaders ensure that the requirements process itself does not dictate or constrain the Army's ability to adapt to changing conditions and threats. To do so, the Army must reexamine and reinterpret the Joint Capabilities Integration and Development System (JCIDS) to adopt flexible Army supporting processes, and push for updates and changes to the joint system when required. To modernize the combat vehicle fleet, the Army will adapt its processes to the conditions of the contemporary complex world or risk failure in future war.

Section 4
Conclusion

Combat vehicles are a consistent feature on an inconsistent landscape. They appear in all theaters, in all tactical environments, and in all conflicts, spanning the full range of military operations, and they confer a decided advantage to those who successfully apply their significant capabilities.

With modernized combat vehicles, the Army will deploy rapidly around the world and sustain combat operations for extended periods in a variety of operational environments against state, non-state, and hybrid threats. Modernization efforts, if followed through earnestly and judiciously, provide a significant advantage to Army leaders as they strive to win on future battlefields.

Appendix A
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Appendix B
(S) CLASSIFIED THREAT
See proponent for eligibility, authorization, and permissions.

Appendix C
Combat Vehicle 101: A Primer on Tradeoffs in Combat Vehicle Design

Chariot Development Challenges

The problems faced by chariot designers were surprisingly similar to those that confront today's tank designers. The logisticians and strategists who build and support today's tank forces and prepare to take them into battle face problems that would be familiar to their counterparts of the chariot era. Should the chariot carry one, two, three, or four men? Should two or four horses propel it? How much weight of armor in treated-hide shields should it carry? As weight was added, there was a loss of speed and mobility. Doubling the number horses to pull the additional weight meant compounding the logistics problems - doubling the task of acquiring, breeding, training, and feeding horses in a society where they were not widely used in agriculture.

-Orr Kelly, King of the Killing Zone

The Combat Vehicle

The battlefield performance of the U.S. Army's combat vehicle platforms from the Cold War through the wars in Southwest Asia reflects understanding and application of complex tradeoffs involved in designing fighting vehicles. The Abrams tank and Bradley fighting vehicle remain premier fighting platforms more than 30 years after their original fielding, and have proven adaptable to missions and environments not envisioned when originally designed in the 1970s. These systems have continued to be adapted successfully, while their intended replacement efforts (armored systems modernization (ASM), FCS, and GCV) have not; the reasons tie to the operating and fiscal environments in which the new systems were developed, and the design approaches for the vehicles.

Understanding the complexities involved in combat vehicle design help inform the requirements and strategies for future efforts and increases the likelihood that future programs will succeed. This appendix is a primer on combat vehicle design that discusses the tradeoffs inherent in new vehicles. The CVMS discusses design parameters, their interactions, and how the cost and schedule affects the overall success of a combat vehicle program.

In combat vehicle design, the operating concept drives system requirements, which cause tradeoffs in various system design parameters and performance attributes that then drive the overall cost and complexity of a combat vehicle system. This process is iterative; available solutions or cost limitations can inform tradeoffs in performance attributes that may subsequently require modification of system requirements. There is seldom an "optimal" design solution; the best protection might come at excessive weight where a reduced weight solution comes at excessive cost. A successful design strikes a balance between various competing parameters to be both effective and affordable. Ultimately, however, the resulting system must support the operating concept and its intended design purpose.

Clarity and focus in the operating concept are the first requirements for successful combat vehicle design. The combat vehicles role, (fighting vehicle, infantry carrier, support vehicle), and the conditions under which it operates set the priorities for the systems requirements and design parameters. Mismatch between operating concept and operating environment results in the first significant failure point of some programs, resulting in requirements for systems either intended to do too many things (and thus performing poorly at many of them), or to do the wrong things.

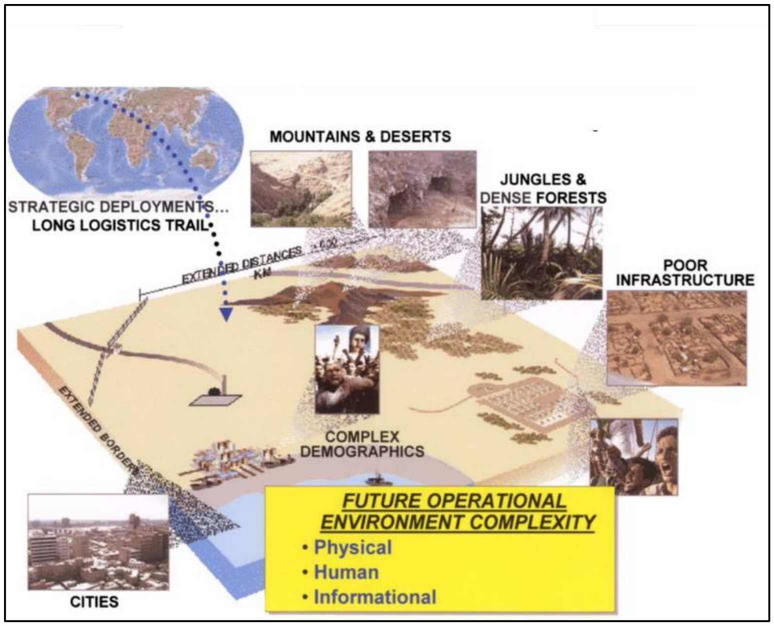

Figure C-1. The future operating environment

The M1 Abrams tank, designed to defeat Soviet armor on the plains of Northwest Europe, prioritized protection, lethality, and tactical mobility while trading off size and air deployability. This close match between operating concept and requirement priorities resulted in an extremely effective design. Contrast that with the design challenges of the Bradley fighting vehicle (balancing requirements to carry infantry; fight from inside the vehicle; swim; small, light, and move quickly as a scout; defeat heavy armor in support of deep offensive operations) and the result was a vehicle that while successful was limited by the design compromises needed to meet all requirements. Mismatched operating concept-to-environment was a factor in the demise of the ASM, which attempted to next-generation the Cold War systems via the Block III tank, Crusader artillery system, and future infantry fighting vehicle. This attempt occurred at a time when the Soviet threat driving the increased capability waned, and the FCS was not prepared to address the asymmetric threats arising in the post-9/11 environment.

The operating concept drives system requirements: personnel capacity, level of protection, amount of firepower, necessary mobility, ease of transport, and others. Prioritization of, and balance between, these requirements results either in design tradeoffs leading to a successful vehicle or in an unacceptable system. System requirements break down into design specifications that suggest the specific technical solutions to be used, but the requirements are vehicle capabilities, not technical solutions. Mismatch between these two can have negative second order effects. Some design parameters, such as size and weight, derive from required capabilities, but might also be design constraints; for example, if a system has air or rail transport requirements that limit allowable size or weight.

Prioritization of system requirements, protection, lethality, mobility, deployability, and affordability, drives design. However, some parameters carry significantly more importance than others regardless of requirements prioritization. Volume under-armor–the amount of protected personnel and component space, at what level of protection–is the most significant design driver in combat vehicle design. The number of personnel, both crew and passengers, along with mobility components and other under armor mission equipment, sets the initial vehicle envelope. The level of protection those personnel require from which threats under what conditions, (from small arms to tank rounds, from RPGs from the front or from attacks from below), determine the range of design approaches applied around that volume. Since fully reliable, active protection systems are not yet fielded and cannot defend against all threats, that protection drives passive armor weight that sets an initial weight for the vehicle.

Protecting the personnel volume requires tradeoffs. Protecting from underbelly attacks, for example, favors a heavy vehicle with the maximum possible standoff above the threat, to dissipate as much energy as possible before the blast affects the personnel inside. This requires interior space that allows personnel and seats to move in a blast without hitting the vehicle roof or receiving injuries from floor deformation. Underbelly protection requires a larger personnel volume, thus a large vehicle, which is higher off the ground and presents a larger, easier target to hit for direct fire attacks.

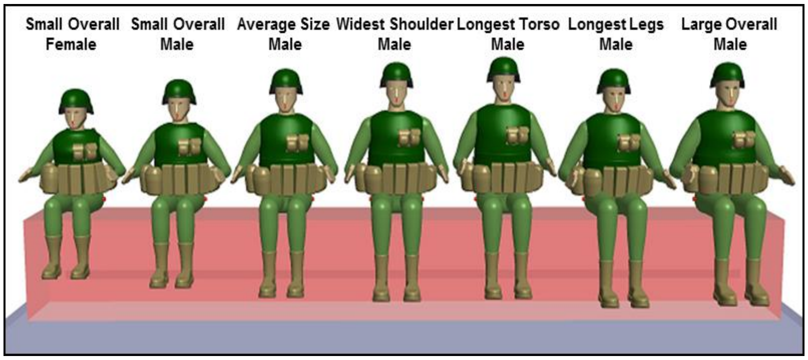

Figure C-2. Human dimension scale

Protecting against direct fire attacks requires a smaller vehicle profile to avoid detection, engagement, and contact, which requires smaller vehicle volume placed close to the ground. However, if the vehicle is hit, greater volume of armor to prevent penetration of the crew compartment by deflecting, disrupting, or defeating the attack, is required, which drives a larger, heavier armored volume. Using active protection to reduce vehicle mass increases vulnerability to underbelly attacks.

Under armor personnel volume and the resulting vehicle weight class, compared to the system's mobility requirements, drives decisions on powertrain and suspension such as, wheeled or tracked, engine or transmission size, and others. A combat vehicle requires a large ground contact patch to reduce ground pressure for movement on soft and wet soils, which favors tracked systems in heavier vehicles. However, the larger contact area makes high-speed road movement more difficult. Wheeled systems with their smaller contact areas tend to be more efficient for long-range, high-speed, operational-level movement. Turning radius and obstacle climb and clearance requirements typically favor tracked systems, but are dependent on final vehicle design; it is possible to achieve small turning radius or greater obstacle performance with wheeled systems given appropriate tradeoffs. Current technology drives vehicles above the 20 to 30-ton range to tracked solutions if off-road, soft soil mobility is important.

Placing powertrains under armor in combat vehicles prevents loss of the system to a mobility kill. This means that the under armor envelope must expand to include the powertrain, thus increasing vehicle size and weight. To keep vehicle size to a minimum, combat vehicle powertrains seek to be power dense, offering the most power for the smallest volume.[13] This results in the technical challenge to cool a tightly packed high output engine in a heavily armored space, where access to cooling air and points to radiate heat are restricted. This challenge means that commercial engines and transmissions are poor solutions. Military combat vehicles have made-to-order, low volume, and expensive powertrains.

Once powertrains are in place, the combat vehicle is armored, protected, and moving Soldiers at some required mobility level. Other capabilities, such as weapons, sensors, communications, and situational awareness are added. Lethality systems require a structure level that supports the weapons system and mitigates recoil. These systems receive some level of protection, (from equivalent to the personnel space down to no protection), and require protected volume for ammunition and fire control. The volume of ammunition and level of protection required for the weapon and associated components adds to volume under armor, which drives increased size and weight. Additional size and weight increases automotive and suspension requirements. Sensor performance to enable lethality requires some armored volume (long-range performance, particularly through obscurants, drives large sight apertures, meaning larger sensors) and sufficient electrical power capacity to power the sensors. Network and communications equipment, situational awareness systems and displays, chemical, biological, radiological, and nuclear (CBRN) defensive systems, and other required subsystems have space and weight requirements that add to vehicle volume under armor, and bring electrical power requirements to operate.

Electrical systems generate heat, which increases the vehicle's cooling burden.[14] The heat must dissipate for the crew to continue to function for long periods. Therefore, either the electrical systems receive point cooling, which does not benefit the crew, or the vehicle requires system-level environmental controls. Either approach requires electrical power and interior volume to allow cooling air or fluids to exchange heat with the outside environment. Poor implementation of cooling systems reduces combat functionality, and increases the vulnerability of the vehicle by increasing its thermal signature.

Electrical power for sub-systems operations and the power needed to cool the subsystems subtract from available vehicle automotive power. Thus, high electrical or cooling requirements drive the need for more power generation, which drives the need for more automotive power. The power need then requires more volume for a larger powertrain and powertrain cooling systems. Different powertrain approaches, such as hybrid-electric drives, can create more electrical power under certain conditions, but regardless of technical approach, the vehicle's total power generation requirement is the sum of its automotive mobility requirements plus its other electrical system requirements and the energy required to run cooling systems to reduce the associated heat output. Improved power and heat efficiency or reduced base power requirements can reduce this total power challenge.

Adding vehicle capabilities that increase under armor volume have negative effects on the overall system design, as each increment of required protected volume brings subsequent and increasing automotive and electrical requirements that drive third-order volume increases. Requirements that specify how to achieve a solution restrict design choices further and negatively affect design. Two examples of specific requirements include turret configuration and Soldier size assumptions.

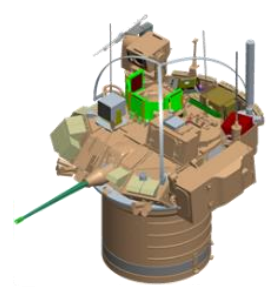

Figure C-3. Manned turret

Turret configurations create significant size and weight tradeoffs. There are three basic turret configurations: manned turrets, where the turret crew rotates with the weapons system; unmanned turrets, which operate remotely but maintain some level of armored protection for the weapon and may allow some access or operation by personnel from within the vehicle; and remote weapons stations, which are typically unprotected and inaccessible from the vehicle interior. Manned turrets drive large structural and protection requirements and consume protected volume, which translates to increased vehicle size and weight. However, manned turrets facilitate crew observation as well as operation of the weapons system.

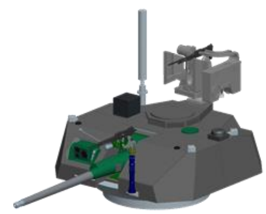

Figure C-4. Unmanned turret

Unmanned turrets have reduced weight and integration burdens compared to manned turrets and can usually sacrifice some protection, but are more complicated to access, operate, and repair.

Remote weapons stations typically sacrifice protection for the weapons systems and usually require an exposed operator to reload or service the weapon; they have the lowest structural and weight impact because there is no crew to protect. Remote weapons stations tend to have degraded performance compared to manned or unmanned turrets for large weapons systems due to lower mass available to handle firing loads even assuming implementation of comparable fire control and stabilization solutions.

Figure C-5. Remote turret

Turret selection also drives second order design challenges such as antenna placement, physical clearance of hatches and roof-mounted equipment. Turret choice may result in difficult tradeoffs determining which systems are placed in the turret with the weapons system. If a manned crew requires access to ammunition for reloading, or to communications systems, this increases the required turret volume with a subsequent growth in total vehicle size and weight.

Soldier size requirements set total vehicle volume requirements. Army systems are designed to be operable by the central 90% of the population–from the 5th (smallest) percentile female to 95th (largest) percentile male. Soldiers tend to fall along a normal distribution. In an average group of Soldiers, about one in 20 will be of the largest size range, and a similar number in the smallest size range, with

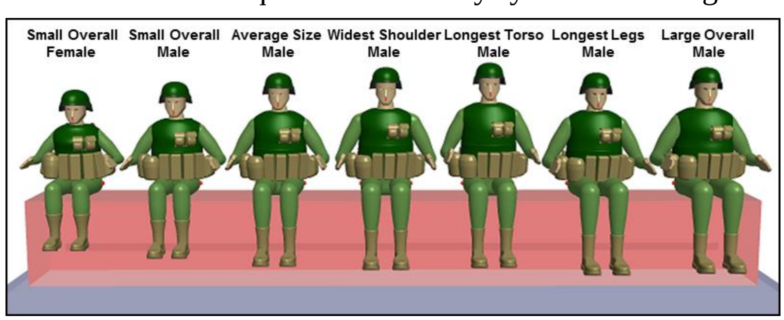

Figure C-6. 5^{th} to 95^{th} percentile

most falling closer to the center of the size range. However, if every Soldier position in a combat vehicle accommodates the 95th percentile male, the vehicle will be much larger than a vehicle designed to fit a distribution of Soldiers. Further, this size affects parameters such as weight, protection requirements, automotive requirements, and others. The requirement for all Soldier positions to accommodate 95th percentile Soldiers combined with increased protection levels explains why initial GCV designs were almost double the weight of the Bradley fighting vehicle it was to replace, despite carrying only two extra personnel.

Current combat vehicles have grown 25 to 30% in weight and power over their service lifetimes. Future growth requirements in space, weight, electrical and automotive power, or cooling add to the size-weight-volume-power challenge. In this case, components must be overdesigned to handle future weight growth; automotive systems must have power margin, and interior room most allow for future space growth. This overdesign to allow for future capability increases the initial size and weight of the vehicle.

Other design attributes affect combat vehicle design differently. Deployability and transportability requirements are initial design constraints. Though the Army moves large formations by sea where vehicle weight is not a major deployability driver, setting limits on vehicle, size, and weight affects the ability to deploy those systems by air and rail and affect tactical mobility. If a vehicle must be sized to deploy by air in a specific aircraft, this sets a maximum weight and volume that the vehicle cannot exceed.[15] A vehicle whose size grows behind a certain point challenges rail movement in some parts of the world due to tunnel clearances; road clearance under bridges while riding on vehicle transporters, and movement across bridges provide additional size and weight constraints. While vehicles under 20-tons weight can access over 97% of the world's road networks, that number falls to 81 to 97% for 30 to 40-ton range vehicles, and 81 to 95% for 60-ton weight class vehicles, and so on as size and weight increase. Size and weight also affect tactical mobility as they limit maneuverability in streets and alleyways in urban environments, and drive the technical choices in propulsion and mobility systems needed for off-road mobility.

Figure C-7. Future concept art

The supportability of a system is both a function of design and a second order effect of other design parameters. Larger, heavier vehicles tend to have lower fuel economy and larger and heavier spares increase the logistics burden. Technical solutions can improve fuel economy or improve reliability to reduce spare part requirements. However, these changes are not enough to provide the level of performance of a lighter weight class vehicle. For example, a 40-ton vehicle can be made fuel efficient for a 40-ton vehicle, but not to the point where it is better than a 20-ton vehicle. Lighter weight classes use smaller and lighter components, allowing greater use of commercial components, and simplifying maintenance.

Reliability is a function of initial design point. Vehicles can be designed for a level of reliability independent of weight class. Reliability can improve over the life of a vehicle or as other constraints are relaxed. For example, the Stryker double-V hull, gained reliability when C-130 transportability requirements dropped, which allowed the use of more robust components. However, as a vehicle gains weight and capability, its reliability usually decreases if actions are not taken to maintain reliability.

The preceding discussion has focused on combat vehicle design tradeoffs in requirements and performance parameters. However, there are two other parameters that affect the Army's ability to procure a combat vehicle that derive from requirements: cost and schedule. Cost is the biggest driver; an unaffordable but perfect system provides no capability to the force. Affordability was a primary or secondary factor in the demise of ASM, FCS, and GCV, both at the individual vehicle level and the Army's combat vehicle fleet portfolio level. Controlling cost is paramount to delivering capability.

For simplicity, cost is broken into three groups that make up the total system cost for the vehicle: development cost, procurement cost, and operating and sustainment cost.[16] Roughly, 70% of the total cost of a system is set when making requirements tradeoffs, before detailed engineering design begins, because operating concept and system requirements drive design trades and remain relatively fixed once design begins. One way to reduce cost throughout the design process is to re-evaluate requirements that prove to be cost drivers. A combat vehicle's development cost is a small fraction of procurement cost, which is a fraction of operating, and sustainment costs.

System complexity and development time drive cost primarily, since the largest fraction of development cost goes to paying the personnel conducting the detailed design and management of the program. Greater complexity requires more personnel; and, more time increases the period over which the salaries are paid. The second largest driver in development cost is the number of prototypes and amount of testing, as prototypes are typically very expensive compared to final production articles and required testing drives total development time.

Vehicle design complexity and the number of total systems procured over a specific time drive procurement cost. Producing a greater number of systems in a sustained manner drives down cost; increased production speed reduces production cost by reducing the carrying costs associated with operating production facilities for long periods. For example, the Bradley A3's production cost declined by 25% over its lifetime as the total number procured increased from 588 to 2561 and the rate of production per year increased to approximately 700 at peak production. Thus, some procurement costs can decrease while a system is in production, but by how much depends upon the system's initial procurement costs.

The starting point for procurement costs is the complexity of the system driven by the size and weight of the system and its number and level of required capabilities. Because larger and heavier systems require more material; bigger, more robust, and more expensive subsystems; more complex manufacturing techniques; and larger and more capable production facilities, increased size and weight directly correlates to increased system cost. Of the top five cost drivers in combat vehicle design, survivability systems, power package and drivetrain, and hull structure are direct results of the system's size and weight. Other cost drivers result from vehicle capability (sensors, fire controls, armament, and others). While commercial advancements in computing components are reducing cost and increasing capability in each new generation of equipment (aided by large production volumes in the commercial sector); this does not happen for armor, engines, weapons, and structures, where more capability equals higher cost.

Initial system design determines sustainment costs and are a function of system operating requirements (fuel economy, other consumables), the amount the system is used, the reliability of the system, and the level of system capability. Capable components translate to expensive spares. Systems designed initially for higher reliability and graceful degradation tend to increase development time and both development and procurement cost. If well balanced, these initial costs translate to life cycle cost savings. Sustainment costs decrease over time if system reliability improves in service, but typically not much beyond the initial design point. System durability and frequency of use becomes more important the longer the system remains in operation, as these parameters drive how often and to what extent the vehicle must be overhauled. Electronic complexity further increase sustainment cost over time, as electronic components become obsolete requiring vehicle subsystems to be redesigned and replaced if the vehicle is maintained over an extended operating period.

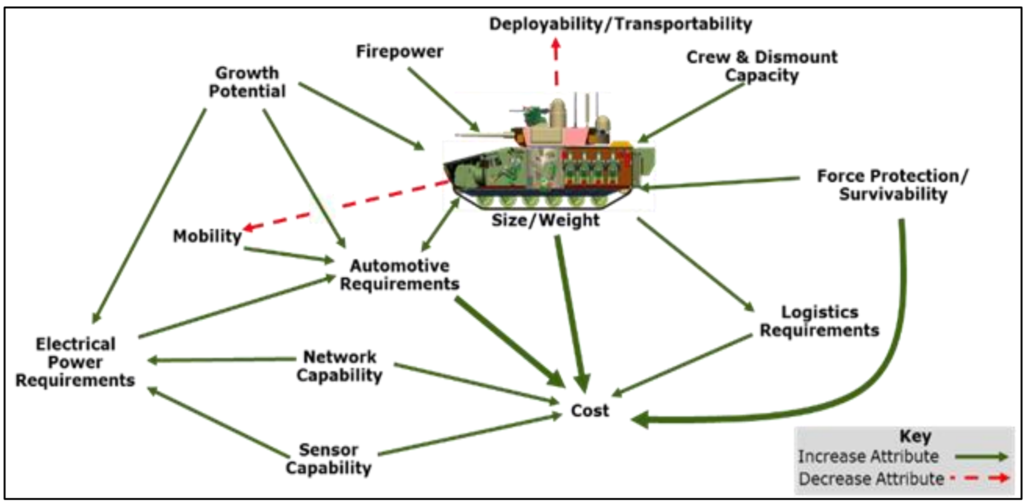

Figure C-8. Platform trade analysis chart

System schedule, the time it takes a vehicle to go from concept to production, is a function of system complexity and process requirements. A highly capable, complex system, which requires components that are more advanced, requires more design and integration time than a simpler system with fewer capabilities. New designs usually require more design time than modified designs, but only to a point. An extensively modified off-the-shelf vehicle can require more design time than new, as the modifications must be adapted to an existing vehicle's limitations. More capabilities translate to increased testing requirements, as each capability is tested and evaluated against system requirements.

Testing time is the largest single schedule driver for a combat vehicle, driven primarily by the need to accumulate sufficient operating time to assess the vehicle's durability and reliability with an appropriate degree of statistical certainty to predict how it will perform when fielded. Reducing test requirements or producing more prototypes to allow parallel testing (with an increase in cost) can shorten test time. Test scheduling is a careful balancing act between time available, costs associated with available prototypes, and the value of information gained during testing that leads to earlier improvements in capability.

Process requirements also drive the schedule. Requirements can include everything from decision gates and reviews, which require multiple levels of stakeholder review and decision before the program can move forward, to the volume of documentation generated, reviewed, and approved to meet statutory and regulatory requirements. Process requirements drive specific test events and engineering activities that affect scheduling significantly. For example, validating both prototype performance and production article performance drives two complete rounds of testing for combat vehicles, which can equate to four years of program schedule.

While many process requirements take place in parallel with other vehicle program activities, they do contribute to the overall length of the schedule. A Program Executive Office GCS analysis of statutory and regulatory requirements, called the “Null Program,” concluded that an Acquisition Category I program that met all statutory and regulatory requirements but required just one day of development and one day of production still had five years of process-generated schedule and related costs. Changes that affect vehicle design, whether at the operating concept, requirements, or design tradeoffs level, will increase the cost, schedule, or performance risk of a vehicle program, and the later those changes occur in the program the greater the risk. Stability in requirements, unless the source of instability is a lessening or elimination of requirements, is key to keeping cost, schedule, and performance factors predictable and under control.[17]

Selection of specific technologies to meet design requirements and balance competing design priorities affects vehicle cost and performance. Application of new, high technology solutions enables more design trade space and may increase capability, but often at the risk of significantly increased cost. For example, the GCV program explored advanced material armors that could reduce system weight by up to eight-tons, but at an increased per-vehicle cost of almost $1 million per ton saved. Ultimately, affordability constraints forced GCV back to heavier conventional materials. The lesson learned is the application of high technology solutions will not make an unaffordable system affordable, but technology can assist in resolving otherwise incompatible requirements or increasing capability to meet future objective requirements.

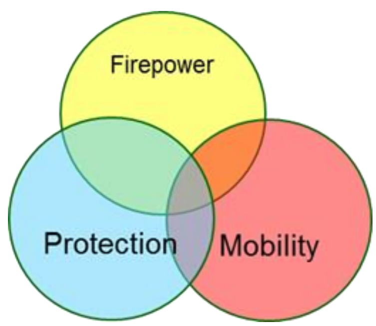

Figure C-9. Capabilities balance chart

The operating concept drives the selection and prioritization of system requirements for combat vehicles. When the operating concept is disconnected from the operating environment, as occurred with both ASM and FCS, there is a high probability that system requirements will not deliver an effective system. System requirements define the design tradeoffs for the vehicle. Volume under armor, driven by level of protection and number of protected personnel (along with associated mobility components and mission equipment), set the base system size, which then must meet mobility, lethality, and other requirements while remaining within deployability or other constraints. Performance requirements might require tradeoffs to keep these attributes in balance.

System size, weight, and capability drive the majority of system costs. As capability is added to a system, or requirements for capability or protection increase protected volume, the cost of the system increases. The second order effects of a size or weight increase can cause continuing increases in size, weight, and cost that can result in an unaffordable system at either the platform or combat vehicle portfolio levels. A negative reinforcement loop that occurred in ASM, FCS, and GCV, suggested the underlying system assumptions for those programs were partly to fault. Risk requires clear and compelling linkage between operating concepts and system requirements, as well as requirements and design choices informed by cost and drive a positive reinforcement loop of reducing size, weight, and cost while delivering an acceptable capability level.

Appendix D
Decision Support and Capabilities Needs Analysis 17-21 Linkage

Introduction

As the Army's integrated capabilities based assessment (CBA), the capabilities needs analysis (CNA) identifies gaps and opportunities for development of the future force. The CNA is TRADOC’s analytical tool for assessing the Army's operational effectiveness and prioritizing capabilities development activities. The CNA is TRADOC's integrated CBA and drives force modernization priorities and informs resourcing decisions. The CNA provides an operationally focused, risk-based assessment of the Army's ability to meet the challenges of the warfighter, articulated as first-order required capabilities (RCs) or AWFCs in the AOC. The AWFC framework informs the CNA by providing traceability from joint and Army concepts to solutions that span DOTMLPF-P activities. See figure D-1.

The CNA assesses the Army functional concepts’ RCs by determining the tasks the Army can accomplish with the current and programmed force, to determine what the Army cannot accomplish, or capability gaps. The CNA then identifies and assesses solution approaches to solving the most critical capability gaps (see table D-1.). The CNA identifies opportunities for the Army by highlighting those solutions that represent the greatest overall contribution to mission accomplishment.

Following this framework, the CNA establishes capability- and risk- based prioritization of DOTMLPF-P capability solutions and capability gaps, respectively. The lists and their capability and risk values provide meaningful inputs to G-8 resourcing and planning decision models and Assistant Secretary of the Army for Acquisition, Logistics, and Technology portfolio review decision models (such as the Program Objective Memorandum (POM) and the Long-Range Investment Requirements Analysis (LIRA). The CNA results are the instruments by which TRADOC informs and influences the Army Planning Guidance, and the Army Equipment and Modernization Strategy, which is part of the Total Army Plan.

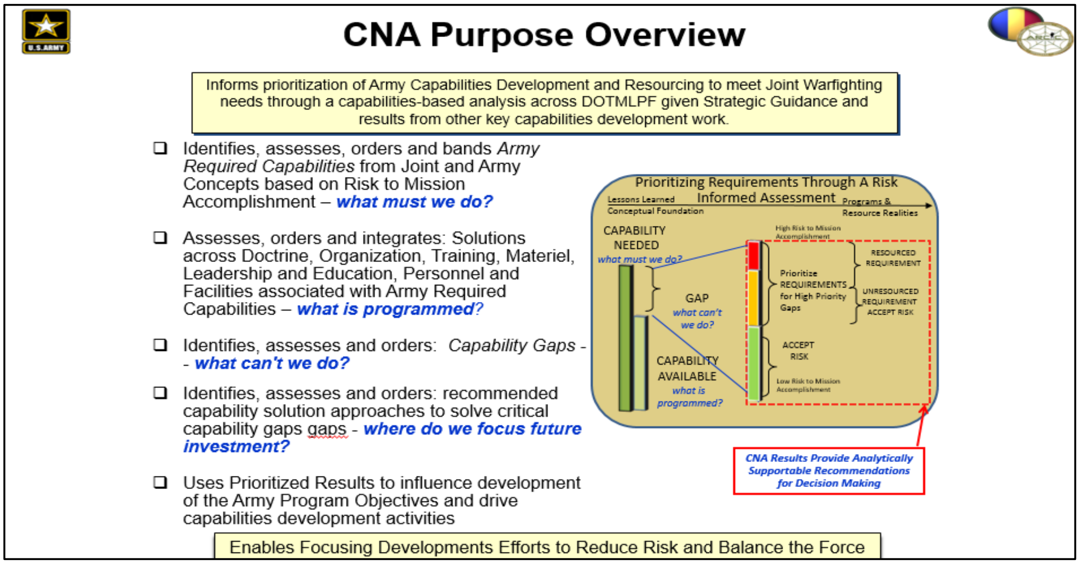

Table D-1. CNA overview

CNA prioritized fielded and programmed solutions are based on each solution's ability to meet and accomplish the RCs through accomplishing their associated tasks in the context of missions and threats represented in Defense Planning Guidance derived scenarios. Fielded and programmed solutions at the top of the list contribute the most to mission accomplishment.

CNA gap prioritization is based on the gap's risk to accomplishing the Army's RCs in the context of missions and threats represented in the scenarios. Gaps at the top of the list represent the greatest risk to mission accomplishment across the scenarios, potentially highlighting areas of parity or erosion of U.S. overmatch.

CNA prioritized recommended solution approaches to critical capability gaps are based on each solution's feasibility and ability to mitigate critical capability gaps presented in scenarios.

Maneuver Center of Excellence (MCoE) Approved Level 1 Critical RCs: CNA 17-21

Table D-1 lists approved Level-1 critical RCs for CNA 17-21. The table describes capabilities prioritized by MCoE based on the risk, likelihood, and consequence methodology as outlined in Army Techniques Publication 5-19, Composite Risk Management. This analysis uses the Army Capabilities Integration Center (ARCIC)-provided five situational scenarios as the framework for determining prioritization of those requirements.

Table D-1
CNA 17-21: Level 1 Critical RCs

RC#	CNA 17-21 Level 1 Critical RCs
3.1	Future Army maneuver forces require a versatile mix of networked combined arms organizations capable of conducting decisive action in unified land operations.
3.2	Future Army maneuver forces require the capability to maneuver and survive in close combat with and defeat enemy organizations.

3.3	The Army must conduct reconnaissance and security to enable friendly forces freedom of maneuver to exploit success at the operational and tactical levels and to deny enemy forces freedom of maneuver.
3.4	Future Army maneuver forces must be able to conduct decentralized combined arms operations in the execution of decisive action.
3.5	Future Army maneuver forces must be capable of conducting joint entry operations, forcible or unopposed, in a high A2 and AD environment from strategic distances and rapidly transitioning from deployment to employment to move to positions of advantage to defeat enemy forces, control and influence populations, and establish conditions that achieve the joint force commander's mission.
3.7	Future Army maneuver forces must be capable of conducting armed ground and aerial reconnaissance with the man-in-the-loop decider forward and of fighting for information, and of integrating intelligence and ground maneuver actionable combat information to shape the battlefield and win the close fight.
3.8	Future Army maneuver forces must be to conduct movement and maneuver of combat-configured Soldiers and equipment in tactical formations from land or sea bases to tactical and operational depths, utilizing austere points of entry to overcome enemy anti-access and area denial efforts and achieve a position of advantage in relation to the enemy.
3.9	Future Army maneuver forces require precision lethal and nonlethal capabilities integrated with intelligence to engage targets effectively at extended range in both the land and cyber domains to shape the fight and reduce collateral damage.
3.10	Future Army maneuver forces must be able to conduct effective air and ground integration with manned and unmanned systems while conducting reconnaissance and security operations.
3.11	Future Army forces require unimpeded mobility to enable freedom of maneuver.
3.12	Future Army maneuver force platforms require the capability to acquire and identify targets beyond enemy direct fire ranges and perform unexploded ordnance, mine, IED, and chemical, biological, radiological, nuclear, and high yield energy (CBRNE) detection to enable tactical maneuver.
3.14	Future Army forces must be able to identify friendly, enemy, and neutral forces, and non-combatants to effectively engage enemy organizations and reduce collateral damage.
3.17	Future Army forces must be able to integrate unmanned systems and sensors to detect, recognize, and identify targets.
3.18	Future Army reconnaissance squadrons must be capable of conducting simultaneous mounted and dismounted reconnaissance and surveillance operations to maintain the tempo of operations.
3.20	Future Army maneuver forces must be able to detect, collect, analyze, exploit, disrupt, and neutralize adaptive enemy networks across the range of military operations in order to support and influence friendly and neutral networks.
RC#	**CNA 17-21 Level 1 Critical RCs**
3.21	Future Army forces require the capability to detect, identify, and rapidly defeat enemy unmanned aerial systems with lethal and nonlethal means.

3.22	Future forces require the capability to conduct sustainment operations at the end of extended and contested lines of operations during high tempo, decentralized operations.

MCoE Level 1 Critical RC Gap Prioritization

In the finalized version of CNA 17-21, the MCoE reported over 40 critical capability gaps in relation to the required Level 1 critical RCs currently assessed as 'high risk' across infantry, Stryker, and armored formations. Further analysis indicated that 18 of the RCs are directly addressed and influenced by the CVMS effort. This illustrates the capability requirement gaps identified in CNA 17-21 are prioritized from both an overall and MCoE perspective, along with the MCoE-provided rationale for justifying these gaps.

Critical Requirement Capability Gap Mitigation Strategy

The results of CNA 17-21 indicate that several materiel solutions, ideas, and concepts are being developed currently as part of the overall capability gap mitigation strategy. These potential solutions are designed to mitigate critical gaps over near-, mid-, and far- terms and are assessed based on the extent of their projected impact. The overall risk mitigation, given the fielding and implementation timelines for each of these solutions, is indicated.

Appendix E
Analytical and Experimentation Support to Combat Vehicle Modernization Strategy

Purpose
The purpose of this appendix is to establish, execute and apply analytical and experimentation support to enable a successful CVMS.

Description
Learning activities such as studies and analysis, experimentation, research, lessons learned, and others, are deliberate and sustained parts of the CVMS designed to mitigate the risk of poorly informed decisions. This appendix is a living document that describes what is known about combat vehicle modernization, assesses what needs to be learned to enable prudent decision-making, charters learning activities synchronized to program decisions, and transitions results through senior leader decisions into action. This document establishes roles and responsibilities supporting analysis and experimentation for the CVMS. It provides a running estimate for the CVMS including key decisions, presents the learning demands required to support those decisions, and an integrated learning plan to accomplish those learning demands. These efforts are part of Force 2025 Maneuvers and are synchronized with other supporting learning activities.

Problem Statement for Analytical and Experimentation Support

The Army requires formations (currently the infantry, Stryker, and armored BCTs) that overmatch known and projected threats, with appropriate combinations of lethality, mobility, and protection, capable of expeditionary and joint combined arms maneuver, and that enable Army forces to win in joint combined arms operations. The Army's current combat vehicle fleets do not achieve this end-state fully and require further sustainment, improvement, new vehicle development, and replacement. The Army must determine across the near-, mid-, and far- terms what changes to the combat vehicle fleets are required, and what routine assessments and adjustments are needed to ensure the desired end-state over time.

Scope and Structure

The required learning activities for the CVMS fall into four broad categories: supporting the need for combat vehicles and a combat vehicle strategy; justifying the elements of the strategy itself; implementing the strategy through various DOTMLPF development efforts; and, integrating DOTMLPF development efforts to realize the desired end state for the CVMS. For development efforts, material development activities follow a well-documented path. The Defense Acquisition University (www.dau.mil) provides information on required documentation for each milestone of a formal acquisition program. Therefore, this appendix does not duplicate these efforts, but instead focuses on the foundational need for combat vehicles and the CVMS and on DOTMLPF integration across programs or lines of effort. The specific structure of this appendix follows the development and integration of DOTMLPF solutions into one of four formations (infantry, Stryker, armored, and reconnaissance and surveillance BCTs) in the near, mid and far timeframes, using each formations' corresponding operational and organizational (O&O) document as the vehicle for integration. [1]

Roles and Responsibilities

This section describes learning activities roles and responsibilities of CVMS stakeholders. This document does not establish new or additional roles and responsibilities, but does propose to leverage the establishment of a general officer review for oversight, guidance, and action of the CVMS.

This appendix depends on stakeholders to feed the results of their events back through the CVMS review to update running estimates, evolve learning demands, and refine integrated learning plans.

1. **Force Modernization Proponents.**[2] TRADOC and Army force management proponents are responsible for concept development, including the sources of required capabilities for CVMS. These proponents are also responsible for capabilities developments leading to JCIDS requirements and for developing doctrine, organizational, training and leader development products.[3] Each proponent has experimentation and analysis capacity to support the spectrum of concept to capabilities development. This capacity will be applied to the CVMS as required, and further, each proponent will integrate CVMS efforts with their associated AWFCs.

[1] At present, personnel issues are not addressed, and facilities issues are restricted to stationing considerations.
[2] AR 5-22.
[3] JCIDS products include initial capabilities documents, capabilities development documents, and others)

2. **ARCIC.** ARCIC will consolidate information from CVMS stakeholders and update this appendix as required, providing recommendations for new or adjusted learning activities for senior leader approval (through F2025).[4] ARCIC is responsible for several Army-level learning venues to include Unified Quest (a futures wargame series); Unified Challenge (operationally-focused game-based and simulation-based experimentation), Army Expeditionary Warfighting Experiment (live prototyping experiments at small-unit level), Army Warfighting Assessments (AWA), and network integrated evaluations (NIE) (live, brigade-sized events supporting evaluation and test activities). ARCIC organizations, through their mission areas, will further facilitate integration of science and technology, studies and analysis, O&O development, experimentation and capability development activities into the CVMS.

3. **TRADOC Analysis Center (TRAC).** TRAC serves as the TRADOC lead for Force 2025B analytical framework development, leads analysis of Army high-priority studies (as directed by TRADOC and Army Senior leaders), and supports combat vehicle modernization through the conduct of analyses for capability development and acquisitions (i.e. Analysis of Alternatives (AoAs)). TRAC ensures analyses conducted in support to combat vehicle modernization remain consistent with CVMS and overarching F2025B activities, products (e.g. Operational & Organizational (O&O) concepts), and decisions.

4. **Materiel Developers.** The CVMS includes S&T developments (Army Material Command and the Research Development and Engineering Command (RDECOM) as well as formal acquisition program developments (program evaluation officers (PEOs) and program managers (PMs)). S&T developers provide information on relevant emerging capabilities for the CVMS and all supporting efforts and formations. PEO and PMs provide critical milestones and decision points that require information or learning venues from outside their program (such as, threshold and objective values for key performance parameters, basis-of-issue plans, and others) to support CVMS synchronization.

5. **Test and Evaluation.** The Army Test and Evaluation Command conduct their activities per Army Reg 73-1. Their involvement with the CVMS centers around the normal suite of test and evaluation activities associated with acquisition programs, up to and including the NIE and AWAs that are potential learning venues for addressing CVMS issues. A number of those issues will be internal to acquisition programs; again, CVMS will focus on cross-program and DOTMLPF integration.

6. **Office of Primary Responsibility (OPR) for learning demands**. This is the organization responsible for specifying the learning demand, chartering the necessary learning activities, and transitioning the results into action.

Combat Vehicle Modernization Strategy Running Estimate

[4] General Order 2006-4 and TR 10-5-2.

The need for and structure of the CVMS has robust extant support, leaving two key areas for ongoing investigation: the specific balance between the elements of the triad, and the feasibility of the strategy.[5]

1. **Rebalancing the Triad.** The CVMS defends the need for a mix of combat power but does not discuss the specific balance between mobility, protection, and lethality. This balance is based on evolving understanding of the future operational environment and the emerging state of technology, a defensible balance of the CVMS triad will change over time. ARCIC should instigate an assessment prior to major acquisition milestones for CVMS programs, including missions, threats, technologies, and gaps.

Learning Demand*:* What are the impacts of the future battlefield of 2030 on mobility (including deployability), protection, and lethality of the force?

- Justification: The state of the future battlefield is uncertain; armor proponents tend to emphasize active protection systems while opponents point to the effectiveness of current IEDs and potential capabilities of future ATGMs. The need to have many tons of armor is a defining characteristic that affects everything else: deployment, air-ground integration, sustainment (such as, fuel), survivability, and others. There are numerous perspectives and there is no one single correct answer. CVMS programs need a holistic and objective assessment that presents the consequences of different choices clearly. Further, over the lifetime of the CVMS these answers are likely to change, so prudence dictates a periodic re-assessment of the operational environment and its impact on the mobility, protection and lethality triad.
- Product / Decision Supported: CVMS programs, at major milestone decisions.
- OPR: ARCIC Capabilities Developments Directorate (CDD) and TRADOC G-2.
- Latest Time Information is of Value (LTIOV): Periodic, 1-plus year prior to major milestone decisions for CVMS programs.

2. **Feasibility of the CVMS**. Assuming the validity of the balance for the CVMS, the overall elements of the strategy are crafted to address a minimal set of critical requirements for future forces as a collective solution. However, emerging work in one study indicates that resourcing the first four (chronologically) elements of the strategy will require sacrificing the FFV program.[6] If this is ultimately the case, it will creates a paradoxical condition that to execute the strategy the Army must sacrifice the strategy. The logical recommendation is therefore to change the Army's total obligation authority to make the FFV affordable.

Learning Demand*:* What are potential trade-offs within the Army and Department of Defense (DOD) to resource the CVMS?

- Justification: Increased threats to the heavy force require immediate focus on protection for those platforms. Resourcing this and the first four elements of the CVMS exceed the Army's total obligation authority, constraining resourcing for the FFV.[7] As described in the CVMS this introduces an unacceptable risk to national military strategy. Balancing

[5] *Strategic Landpower: Winning the Clash of Wills* provides a defense for the fundamental and enduring requirements for land power (see http://www.tradoc.army.mil/FrontPageContent/Docs/Strategic%20Landpower%20White%20Paper.pdf). The CVMS base document itself provides a sound & well supported outline for the elements of the strategy.

[6] An ongoing effort by RAND Corporation; note that any observations from this work are premature until subsequent validation.

[7] Ibid.

these requirements is fundamentally an integration activity; whatever choices made in one area must be accommodated in others, and assessed at the Army level.
- Product / Decision Supported: Inform POM decisions (resourcing of FFV).
- OPR: ARCIC CDD.
- LTIOV: 1 QFY, to inform initial POM builds.

3. **Counter A2 and AD.** Since the Army must deploy to fight, the threat will oppose entry. The Army has two basic ways to gain entry: land where the threat is, and defeats them by force; or land where they are not and defeat them by force and maneuver. The former requires a heavier force to be lethal and survivable; the latter requires a heavier force as some form of tactical maneuverability is necessary.

Learning Demand: Based on the assessment of future force mobility, lethality, and protection, what is the design approach to countering A2 and AD? Given this, does the future force land on the objective, or offset from it; and if so, by air or sea (or both)?
- Justification: Consider an excerpt from the RAND study on the FCS: The operational and tactical feasibility of long-distance, large-scale (up to several brigade-sized "battle forces" at a time) aerial maneuver into enemy airspace was based on assumptions that Joint Force and national intelligence systems were capable of finding enemy air defenses which would then be suppressed or avoided. This assumption was also rather problematic because by definition air mechanized forces would have to descend into the envelope of low-altitude air defense systems, at least at the end of their mission as they prepared to debark their troops and vehicles. Because low-altitude air defenses generally do not need emitting radars to find and engage targets, (they tend to be optically and infrared guided), they are difficult to locate before they open fire. These systems are also relatively easy to hide because they are generally not very large (such as, shoulder-fired missiles and 20-35mm anti-aircraft guns). The Air Force and Navy approach to dealing with this threat is to fly above its range. An air mechanized force cannot do that, at least not for the final part of its flight into enemy territory.[8]
- Product / Decision Supported: CVMS programs, at major milestone decisions.
- OPR: ARCIC CDD.
- LTIOV: 1 year prior to major milestone decisions.

a. ***Learning Demands:*** In what scenarios do the increased combat power available in theater (via lighter platforms) in the first 30-45 days change the strategic outcome? In what scenarios are friendly casualties reduced significantly by having additional combat power on the ground (via lighter platforms) in the first 30-45 days? In what scenarios do the decreased capability (protection, lethality, and/or carrying capacity) of the lighter vehicles over the course of the campaign negatively affect the strategic outcome? In what scenarios are friendly casualties increased significantly by having lighter combat vehicles with less capability on the ground over the course of the campaign?
- Justification: The impact of CVMS on the battlefield will depend on the situation. The outcome for rebalancing the triad will depend on assessing a suite of standard scenarios.

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[8] Lessons from the Army's Future Combat Systems Program. Rand Corporation. See references.

To the extent possible, this should include standard scenarios in multiple combatant commands.

- Product / Decision Supported: CVMS programs, at major milestone decisions.
- OPR: ARCIC CDD.
- LTIOV: 1 year prior to major milestone decisions.

4. **Infantry BCT**

Near-term. The Army will improve infantry BCT tactical mobility by acquiring and integrating new lightweight vehicles providing enhanced tactical mobility for the squad to enable rapidly deployable expeditionary maneuver. Light reconnaissance vehicles must provide operational depth, enable mounted reconnaissance, and provide an interim solution to the IBCT's lethality shortfall. Once fielded, the Army must assess how the combination of lightweight squad combat vehicles and light reconnaissance vehicles functions at the formation level, and refine the need for lightweight engineer or mobile lightweight fires capabilities.

Assessments must consider that the IBCT will conduct operations through JFEO to meet the goals articulated in the AOC, particularly the requirement to transition rapidly to offensive operations, which underpins expeditionary maneuver. Infantry BCT learning activities now and in the near term must determine the capability value of new platforms at the formation level to confirm whether nascent efforts are yielding the desired level of improvement. The principal POR for the IBCT are the MPF and the lightweight reconnaissance vehicle.

DOTMLPF-P Assessment

1. Doctrine and organization. The Infantry BCT has a draft O&O concept.[9] It does not specify learning demands for either doctrine or organization but does list specific capability gaps. The O&O should be assessed and validated prior to handoff, and should be updated prior to each major acquisition milestone. This will require identifying the key risk areas for the O&O, and developing the associated learning demands to mitigate those risks across the DOTMLPF change domains.

2. Materiel. Provide acquisition program support for the MPF and lightweight reconnaissance vehicle. This support consists largely of information requirements and requests typical of acquisition programs and will be addressed by the appropriate PM and TRADOC Capabilities Manager.

3. Other implications. Revisions to the O&O will typically have implications for other change domains (Training and leader development, personnel, facilities and policy) which must be developed concurrent with the above.

Learning Demand: What are the key risk areas in the O&O concept?

- Justification: The O&O proponent identifies the key risk areas in order to establish the priority for learning and risk mitigation. To the extent possible, these should be specific, measurable, and actionable risk areas with clearly stated desired outcomes.

[9] Infantry BCT 2025 O&O Concept, 02 April 2015, Version 1, TRADOC Capabilities Manager-Infantry BCT.

- Product / Decision Supported: CVMS Review Decision (T).
- OPR: O&O proponent.
- LTIOV: Approximately 1 year prior to major acquisition milestones.

Mid-term. In the mid-term, the Army's highest priority is to improve the limited expeditionary MPF capabilities within the infantry and Stryker BCTs. While both BCT provide the greatest expeditionary potential within the current force structure, they lack a direct fire capability that would allow these formations to gain overmatch across the full spectrum of combat operations.

The Army must improve infantry and Stryker BCT combined arms maneuver capabilities by adopting an interim MPF capability, while developing an objective MPF solution. This will require a lightweight tank or similar vehicle possessing exceptional all-terrain mobility and powerful direct-fire weapons, with at least sufficient protection to resist small arms fire and active or reactive protection to defeat anti-armor rockets and missiles. In the mid-term, the Army will sustain the tactical mobility advantages developed in the near-term and replace the infantry BCT's obsolete tactical wheeled vehicles. Army analysis and experimentation efforts must assess interim vehicle performance against threshold requirements.

DOTMLPF-P Assessment

1. Doctrine and Organization. In the mid-term both the infantry and Stryker BCTs will have approved O&O concepts that will update based on the introduction of the capability for interim and objective MPF and replacement of tactical wheeled vehicles.

2. Materiel. Continue acquisition program support for MPF and the lightweight reconnaissance vehicle. Develop and validate threshold requirements for interim MPF and tactical wheeled vehicle performance.

3. Other implications. Revisions to the O&O will typically have implications for other change domains (training, leader development, personnel, facilities, and policy) which must be developed concurrent with the ones above.

Learning Demand: What are the material and non-material solutions for MPF and tactical wheeled vehicles?

- Justification: The infantry BCT proponent must re-interpret the required capabilities from Army concepts within the evolving construct for rebalancing the triad and, in concert with material developers, determine material and non-material solutions for MPF and tactical wheeled vehicles. The key issue is to look ahead and ensure that the solutions delivered will be timely, appropriate for the operational environment, and feasible given material developments.
- Product / Decision Supported: Major acquisition decisions.
- OPR: IBCT proponent.
- LTIOV: 1 year prior to acquisition milestones.

Learning Demand: What are the DOTMLPF impacts of MPF and replacing obsolete tactical wheeled vehicles?

- Justification: The IBCT proponent must conduct a DOTLPF assessment (of proposed material and non-material changes) supporting a holistic update of the O&O plan providing a robust operational context for acquisition decisions. This assessment should identify specific learning demands for O&O revisions.
- Product / Decision Supported: O&O revision.
- OPR: Infantry BCT proponent.
- LTIOV: 6 months prior to acquisition milestones.

Far-term. The Army will replace the interim MPF with the objective MPF and improve individual Soldier mobility by further developing robotic and autonomous systems, thereby producing the best combinations of skilled Soldiers with emerging technological capabilities.

DOTMLPF-P Assessment

1. Doctrine and organization. In the far-term, the infantry BCT will have an approved O&O concept that must be updated based on the introduction of objective MPF capabilities.

2. Materiel. Continue acquisition program support for MPF; develop and validate threshold requirements for objective MPF performance.

3. Other implications. Revisions to the O&O will typically have implications for other change domains (training, leader development, personnel, facilities, and policy) which must be developed concurrent with the above.

Learning Demand: What are the material and non-material solutions for objective MPF?

- Justification: The infantry BCT proponent must re-interpret the required capabilities from Army concepts within the evolving construct for rebalancing the triad and, in concert with material developers, determine material and non-material solutions for objective MPF. The key issue is to look ahead and ensure that the solutions delivered will be timely, appropriate for the operational environment, and feasible given material developments.
- Product / Decision Supported: Major acquisition decisions.
- OPR: Infantry BCT proponent.
- LTIOV: 1 year prior to acquisition milestones.

Learning Demand: What are the DOTMLPF impacts of objective MPF?

- Justification: The infantry BCT proponent must conduct a DOTLPF assessment (of proposed material and non-material changes) supporting a holistic update of the O&O plan providing a robust operational context for acquisition decisions. This assessment should identify specific learning demands for O&O revisions.
- Product / Decision Supported: O&O revision.
- OPR: Infantry BCT proponent.
- LTIOV: 6 months prior to acquisition milestones and force design decisions.

5. **Stryker BCT**

Near-term. The Stryker BCT will improve vehicle protection by completing platform enhancements in the form of ECPs and lethality upgrades. Force modernization proponents will assess impacts of ECPs, adapt O&O concepts, and assess the results in order to support acquisition and force design decisions.

DOTMLPF-P Assessment

1. Doctrine and organization. The Stryker BCT has approved doctrine that must update based on the introduction of Stryker lethality upgrade and ground mobility vehicle capabilities.

2. Materiel. Continue acquisition program support for the Stryker lethality upgrade ECPs and ground mobility vehicle program.

3. Other implications. Revisions to the O&O will typically have implications for other change domains (training, leader development, personnel, facilities, and policy) which must be developed concurrent with the above.

Learning Demand: What are the material and non-material solutions for Stryker lethality upgrades and ground mobility vehicle?

- Justification: The Stryker BCT proponent must re-interpret the required capabilities from Army concepts within the evolving construct for rebalancing the triad and, in concert with material developers, determine material and non-material solutions for the Stryker lethality upgrade and ground mobility vehicle.
- Product / Decision Supported: Major acquisition decisions.
- OPR: Stryker BCT proponent.
- LTIOV: 1 year prior to acquisition milestones.

Learning Demand*:* What are the DOTMLPF impacts of Stryker lethality upgrade ECPs and the ground mobility vehicle program?

- Justification: The Stryker BCT proponent must conduct a DOTLPF assessment (of proposed material and non-material changes) supporting a holistic update of the O&O plan providing a robust operational context for acquisition decisions. This assessment should identify specific learning demands for O&O revisions.
- Product / Decision Supported: O&O revision.
- OPR: Stryker BCT proponent.
- LTIOV: 6 months prior to acquisition milestones and force design decisions.

Mid-term. Stryker BCTs must improve vehicle and formation lethality by fielding developed solutions. Testing of the interim MPF capability may lead to the replacement of the Stryker mobile gun system and anti-tank platforms. Mid-term assessments must determine how to link individual Soldier skills with autonomous and semi-autonomous systems as well as manned and unmanned vehicles.

DOTMLPF-P Assessment:

1. Doctrine and organization. In the mid-term, the Stryker BCT will have an approved O&O concept updated based on the introduction of new capabilities, including developed solutions and the integration of autonomous and semi-autonomous systems, and manned and unmanned vehicles.

2. Materiel. Use of developed solutions has the potential to introduce integration issue and will require the continued involvement of acquisition program managers for numerous Stryker BCT systems.

3. Other implications. The integration of autonomous and semi-autonomous systems, and manned and unmanned vehicles will have significant implications for other change domains (training, leader development, personnel, facilities and policy) which must be developed concurrent with the above.

Learning Demand: What are ways to improve Stryker BCT vehicle and formation lethality by fielding developed solutions?

- Justification: The Stryker BCT proponent must re-interpret the required capabilities from Army concepts within the evolving construct for rebalancing the triad and, with material developers, determine potential solutions for improving vehicle and formation lethality.
- Product / Decision Supported: Incremental force design and acquisition decisions.
- OPR: Stryker BCT proponent.
- LTIOV: To be determined; synchronized to Total Army Analysis (TAA) and POM timelines.

Learning Demand: What are ways to link individual Soldier skills with autonomous and semi-autonomous systems, and manned and unmanned vehicles?

- Justification: The Stryker BCT proponent must charter learning activities to determine potential capabilities from integrating autonomous and semi-autonomous systems, and manned and unmanned vehicles. This assessment should identify specific learning demands for O&O revisions.
- Product / Decision Supported: O&O revision.
- OPR: SBCT proponent.
- LTIOV: To be determined; synchronized to TAA and POM timelines.

Far-term. The Army must assess the viability of the medium formation to develop new combinations of materiel, organizational structures, and doctrinal concepts that enable the Army to accomplish its missions. The force modernization proponent must understand the interplay between mobility, protection, and lethality along with the projected capabilities of S&T to design (if possible) a feasible, suitable, and acceptable medium formation.

Learning Demand: What is the viability of the medium formation for accomplishing the Army's missions in the projected operational environment?

- Justification: The Stryker BCT proponent must re-interpret the required capabilities from Army concepts within the evolving construct for rebalancing the triad and, in concert with material developers, determine material and non-material solutions providing critical capabilities for the medium formation. This may be driven by significant shifts in policy (such as changes in national military strategy) or by changes in the operational environment.

- Product / Decision Supported: Major force design decisions.
- OPR: SBCT proponent.
- LTIOV: Situational depending on the drivers for change but synchronized to TAA and POM.

6. **Armored BCT**

Near-term. The armored BCT must sustain its current modernization program, which further enhances force protection, network capabilities, and direct fire lethality. The Army must also continue its program to replace the M113. In addition, near-term research and experimentation must develop systems to protect vehicles and formations from modern anti-armor systems. As the Army modernizes its current formations, it must continuously assess the utility of existing formation constructs to determine the organizational structure and doctrine required for future formations, including the identification of roles and missions for autonomous systems and other emerging technologies. The Army must develop and assess autonomous manned and unmanned systems along two lines of effort: the operational and developmental. The operational line of effort will improve the capabilities of current autonomous systems while reducing both the cognitive demand on the Soldier and the sustainment and support burden on the unit. The operational emphasis will improve the capability of current systems to execute their tasks. The developmental line of effort will determine the specific high-payoff areas to integrate existing, mature technologies to support the current force while using operational modeling and simulation to identify the functional focus for future autonomous technology.

DOTMLPF-P Assessment:

1. Doctrine and organization. The armored BCT proponent must accommodate the changes introduced by replacing existing systems as well as the introduction of new capabilities through autonomous systems. This will require both organization and how-to-fight adjustments which can be approached incrementally through wargaming, experimentation and evaluation. O&O development (in FY16) will provide a baseline for assessment as incremental changes are evaluated and incorporated into force designs.

2. Materiel. The principal program is the replacement of the M113, but multiple programs may introduce autonomous and semi-autonomous capabilities requiring both developmental and operational context.

3. Other implications. The M113 replacement and integration of autonomous and semi-autonomous systems will have significant implications for other change domains (training, leader development, personnel, facilities, and policy) which must be developed concurrent with the above.

***Learning Demand*:** What material and non-material solutions can protect vehicles and formations from modern anti-armor systems?

- Justification: The ABCT requires near-term capabilities to retain viability of principal platforms against increasingly robust threats. This allows retaining the baseline heavy capability of the force while addressing other key capability gaps, a critical component of the CVMS itself.
- Product / Decision Supported: O&O refinement and subsequent acquisition and force design decisions.
- OPR: Armored BCT proponent.
- LTIOV: To be determined, but synchronized to TAA and POM timelines.

Learning Demand: What are the organizational structures and doctrine required for future formations, including the identification of roles and missions for autonomous systems and other emerging technologies?

- Justification: The overall impact of emerging autonomous and semi-autonomous capabilities is not understood fully yet and may require significant study, including innovative DOTMLPF approaches. Absent a more robust understanding, this requires a dual approach focused on both operational and developmental components.
- Product / Decision Supported: O&O refinement and subsequent acquisition and force design decisions.
- OPR: ABCT proponent.
- LTIOV: To be determined, but synchronized to TAA and POM timelines.

Learning Demand: How can the capabilities of current autonomous systems improve while reducing both the cognitive demand on the Soldier and the sustainment and support burden on the unit?

- Justification: Insights from several past learning venues (for example, Unified Challenge) indicates that while autonomous systems bring additional capability to the fight it often comes at the cost of increased demands on Soldiers, and introduces additional sustainment demands on units. Integrating these capabilities effectively will require a holistic approach including assessment of multiple approaches to manage the additional demands.
- Product / Decision Supported: O&O refinement and subsequent acquisition and force design decisions.
- OPR: Armored BCT proponent.
- LTIOV: To be determined, but synchronized to TAA and POM timelines.

Learning Demand: What are specific high-payoff areas to integrate existing, mature technologies to support the current force?

- Justification: Institutional processes must regularly assess emerging technologies in a structured manner, both to inform future concepts and to satisfy projected requirements. This assessment should run concurrent with rebalancing the CVMS triad.
- Product / Decision Supported: O&O refinement and subsequent acquisition and force design decisions.
- OPR: Armored BCT proponent.
- LTIOV: To be determined, but synchronized to TAA and POM timelines.

Learning Demand: What is the functional focus for future autonomous technology?

- Justification: Future versions of the AOC must provide additional guidance on the functional focus for autonomous and semi-autonomous technology. This is essential to frame guidance for S&T developers as to the intended conceptual role of such capabilities. The more uncertain the environment, the more difficult the role for autonomous systems. The inherent uncertainty in warfighting creates a challenging situation for combat developers. This is an area suited well for innovative experimentation along multiple approaches.
- Product / Decision Supported: Army concepts and S&T guidance.
- OPR: ARCIC CDLD.
- LTIOV: TBD but synchronized to TAA and POM timelines.

Mid-term. The focus for the Armored BCT is to develop an FFV capability for infantry and cavalry squads, eventually replacing the Bradley. The armored BCT must also sustain main battle tank and infantry fighting vehicles pending long-term replacement and develop future platform variants, including engineer and mobile indirect fire platforms. The Army must replace the M113, synchronizing divestiture with acquisition so that we maintain essential capabilities and prevent capability gaps.

The Army must improve armored BCT existing capabilities through the introduction of autonomous ground systems that eliminate (or reduce) the need for tele-operation (direct, continuous remote control by an operator). The Army will assess the technologies and organizational constructs that will enhance future BCT formations by conducting in-depth operational and technical experimentation to identify specific technologies for incorporation. Technologies planned for far-term implementation include the large-scale adoption of autonomous (manned and unmanned) systems.

Learning Demand: How does the Army synchronizing divestiture of the M113 with acquisition so that we maintain essential capabilities and prevent capability gaps?

- Justification: This learning demand is programmatic, but as this requires synchronizing multiple programs to prevent introducing gaps across DOTMLP it should be supported by a deliberate learning activity, with the results adjusting the CVMS itself and the TAA and POM as required.
- Product / Decision Supported: CVMS.
- OPR: Armored BCT proponent.
- LTIOV: Based on acquisition and divesture timelines.

Learning Demand: How does the Army improve armored BCT existing capabilities through the introduction of autonomous ground systems that eliminate (or reduce) the need for tele-operation (direct, continuous remote control by an operator)?

- Justification: The more uncertain the environment, the more difficult the role for autonomous systems so the inherent uncertainty in warfighting creates a challenging situation for combat developers. This is an area suited well for innovative experimentation along multiple approaches.
- Product / Decision Supported: O&O refinement, and relevant acquisition programs.
- OPR: ABCT proponent.
- LTIOV: TBD but synchronized to TAA and POM timelines.

Learning Demand: What are the technologies and organizational constructs that will best enhance future BCT formations by conducting in-depth operational and technical experimentation to identify specific technologies for incorporation?

- Justification: This is essentially a deliberate call to maintain and extend a document such as this one – providing a means to assess emerging technologies and ideas through focused experimentation.
- Product / Decision Supported: CVMS refinement.
- OPR: ARCIC.
- LTIOV: Synchronized to rebalancing the triad.

Far-term. To maintain overmatch in the future, the armored BCT requires an FFV as a replacement for the Bradley fighting vehicle. Decision Point one for the infantry fighting vehicle is in FY16; Decision Point 2 will be in FY18. As such, detailed analytical data is required by end 2nd Qtr., FY16 to support decisions. If milestone B remains in FY21, the current timeline allows for an FFV CDD to be staffed and validated by FY21.

Appendix F
Science and Technology Prioritization and Insertion Criteria

Introduction

Success in the future operational environment will be based on the ability to deploy an expeditionary force with firefight ending capabilities and compel the enemy to our will. To achieve these ends, the combat vehicle fleet must increase strategic deploy ability and expeditionary maneuver through weight savings, and improved protection capability in anti-access environments while bringing improved lethality and situational understanding to ensure dominance across the range of operations. The development and integration of advanced technologies that revolutionize combat vehicle capabilities and behaviors are critical to the Army's vision of a combat force postured to maintain relative advantage over its adversaries and win in a complex world. This appendix lays out advanced technologies and areas of development needed to create a lighter, faster, easily deployable, lethal, and well-protected force in the near-, mid-, and far- terms.

The Army's S&T community is tasked to conduct research, develop and mature advanced technologies and demonstrate the performance of technologies in relevant environments. As the warfighting community develops future operational concepts and requirements, the S&T community informs them on the current state of capabilities and the realm of possibilities. As operation concepts and technology capabilities drive future platform requirements, the acquisition community then executes future programs of records (POR) to deliver the capability to the Army. It is through strong partnerships between the three communities that the Army can deliver the right material solutions to address operational challenges and drive future capability within the combat vehicle fleet.

The Army's ground vehicle S&T strategy drives three major thrust areas that are synchronized with the CVMS's approach on how to modernize the Army's combat vehicles.

Develop new capabilities for future programs of record. The first S&T thrust area drives future operational capabilities through advanced technology application and demonstrations. Efforts under this thrust area seek to utilize technology to create capabilities that improve or change how the Army fights and in doing so drives future materiel requirements.

Drive advanced capability to existing systems. The second S&T thrust area adds capability into current formations to ensure their relevance in the future, as well as reducing sustainment costs. This thrust ties intrinsically with the LIRA process and seeks to synchronize technology and system development into transition paths planned for PORs.

Provide world-class analytical tools, processes, people, and expertise to support the Army's ground vehicle fleet. The final S&T thrust area supports the Army's in-house capability to concept, analyze, simulate and evaluate all aspects of military ground vehicles across their life-cycle from inception to production to disposal. Army S&T has the organic capability to work with the warfighter and generate future platforms based on technology projections. Using advanced modeling tools, Army S&T community can virtually integrate concepts into vehicle systems; characterize those future vehicle performance attributes (mobility, lethality, survivability, power and energy and others). The S&T community also ensures the human is considered early in design, and assess the impact to human performance using techniques, such as virtual environments, to evaluate how Soldiers, squads, and battalions use the advanced systems, to understand the operational value of the new capabilities. This is done for technologies not available for 10-20 years. This collaboration between S&T and warfighter communities to project future technologies onto representative platform concepts has great potential to inform and shape future S&T investment as well as shape future warfighting operational concepts, future doctrine and future vehicle requirements.

While the Army has significant S&T investment, it is one small part of global research. To ensure the Army benefits from these global investments, Army laboratories and research centers track state-of-the-art relevant technologies around the world and develop programs to share research with allies. This effort helps to ensure the Army's ground vehicle concepts and requirements are informed by global technology work, not just U.S. investments.

Establishing long-term (out to 2045) technology development plans informed by this joint TRADOC and S&T future concepts and analysis allows the community to target future technological capabilities to the ground vehicle fleet while simultaneously adjusting for changes in threats, evolution of operational and organizational doctrine and technology breakthroughs. Technology development is rarely linear and the technologies listed below are shown as representative technology progressions (especially in the out-years), not funded programs. The technology list below is not inclusive, but gives examples of what capabilities technology could bring to the future combat fleet. Capabilities are organized by timeframe of technology maturation (demonstrated in a relevant environment or technology readiness level (TRL) 6 in the near-, mid- and far- terms and binned across the primary warfighting function affected (with the understanding that technologies typically affect more than one warfighting function).

Near-Term Effort (FY16-21)

In the near-term, the Army must explore the areas of technology that can likely be deliver to the force. The technologies discussed in this area should be at TRL 6 within the near-term period (system and subsystem model or prototype demonstration in a relevant environment) with a transition path to PORs. The emphasis is on providing technologies into already identified ECPs to ensure as the Army upgrades existing programs; it is providing the best possible capability, at a reasonable cost. The Army is seeking ways to use technology to provide greater deployability and lethality to formations, through light weighting of current platforms, rapidly developing integrated solutions of existing technologies, or with novel approaches such as autonomous systems.

The priority effort in the near-term in the CVMS is to enhance infantry BCT's mobility and lethality. S&T in this area focuses primarily on analysis and characterization of modified COTS hardware solutions acquired quickly to fill the near-term gaps. Lightweight protection and lethality solutions will mature to meet emerging light reconnaissance vehicle requirements as well as system level vehicle assessment to support requirements' document generation. S&T also looks to implement early autonomous capabilities to automate Soldier tasks such as driving through the implementation of kitted autonomy approaches initially on tactical systems in the BCT. The next priority in the near-term is to sustain and improve Stryker and armored BCT capabilities. S&T supports this through a number of technology developments targeting the combat fleet that influence improved size, weight, and power margins on the platforms, improve lethality, and reduce platform weight. Specific example technologies are covered below. The combat vehicle prototyping effort covers a significant portion of the Army's ground vehicle S&T investment portfolio and includes many of the efforts listed below. The combat vehicle prototyping program seeks to develop modular and scalable combat vehicle technologies across a wide range of vehicle capabilities (mobility, survivability, lethality, and vehicle architecture) to provide leap-ahead capability to support vehicles across the combat fleet, for all BCTs and from current vehicles to future platforms.

Below are highlights of the S&T investments designed to enhance systems mobility, lethality, protection, and command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) capabilities to provide additional capability to the combat vehicle fleet at a TRL 6 by FY21. These technologies have applicability to current fleet upgrades, as well as to leap-ahead technology for the next generation of combat vehicles.

Movement and Maneuver

Next-generation powertrains. These technologies include scalable family of integrated next-generation combat engines, integrated starter and generators, and advanced transmissions delivering a 50% increase in power density over the current platforms. These higher density powertrains allow for smaller and lighter combat vehicles while enhancing mobility or payload performance and provide significantly more electrical power (10-times over current alternator solutions).

Durable, Lightweight Track. Lightweight track systems address a significant cost driver for the tracked combat fleet by reducing labor-intensive maintenance cycles and reducing weight of the track system. New track systems transitioned to Bradley have extended the durability of the track to more than 2,000 miles and reduced the weight by approximately 1,000 lbs. Current S&T efforts target a similar lightweight track system in the Abrams weight class. Track is the number 2 maintenance cost driver for the Abrams behind the turbine engine. The S&T effort is reducing this cost by 50%.

Fires

Next-generation large caliber cannon technology. Building upon the already improved capabilities of the XM813 30mm medium caliber cannon, the advanced lethality and accuracy for medium caliber program develops a cannon that fires the family of 50mm Supershot ammunition using the automated ammunition handling system (AAHS) and a scenario-based fire control system to assist U.S. overmatch of current and future threats. The future 50mm enhanced Bushmaster III cannon loaded with the precision airburst munition and scenario-based fire control system will provide an increase in lethality over the 30mm Mk310 precision airburst munition.

3rd generation improved forward-looking infrared. This TRL 6 effort will transition into a current POR. The system will allow operators to see farther and identify the enemy quicker. This improved capability will provide a relative advantage over the adversary and allow for a more favorable engagement.

Network-assisted global positioning satellites (GPS). This capability allows platforms to launch precision guided munitions in a GPS-denied environment by providing needed navigation data to the munition via the existing fires network. (GPS operations center to the Army field artillery tactical data system to the platform). This near-term technology (planned for Capability Set 16/17 Platform Software implementation) increases precision fires mission availability, reliability, and success and supports assured position, navigation, and time lethality requirements. Network-assisted GPS requires software updates to existing systems only and will be transparent to the user.

Enhanced energetics. The development of insensitive, green, energetic materials through the future requirements of enhanced energetics program enables increased lethality, range, precision, and the utility of munitions while providing focused and variable effects through tailored energy release. These advanced energetic materials increase crew survivability, reduce logistical burden while providing scalable effects, and enhanced lethality. Integrated technologies for focused scalable effects will develop to a TRL 5 by FY16.

Protection

Modular Active Protection System (MAPS). This effort focuses on developing and demonstrating lightweight, cost effective technology that defeat RPGs and ATGMs. MAPS is developing and demonstrating an integrated system with a softkill and/or hardkill active protection capability utilizing a core modular controller, enabling best-of-breed sensor and effector subsystems integration on all classes of vehicles. This effort also defines the safety certification procedures required to get active protection systems fielded on current and future combat fleets.

Occupant-centric survivability. This effort focuses on developing, demonstrating, and documenting technologies and system designs that improve protection of combat vehicles from under-body blast threats. Occupant-centric survivability provides the mechanisms to develop, design, demonstrate, and document an occupant centered Army ground vehicle design philosophy that improves vehicle survivability and force protection by mitigating Soldier injury due to underbody IED and mine blast, vehicle rollover, and crash events. This design philosophy considers the Soldier first, integrates occupant protection technologies, and builds the vehicle to surround and support Soldiers and their mission. Numerous technologies to include blast seats, floor designs, restraints, active blast hulls, hull shaping and forging techniques will be transitioned across the combat fleet to improve underbody blast protection.

Advanced armor. This effort focuses on decreasing combat vehicle armor weight affordably, while maintaining performance using passive and electric armor technology approaches. Armor packages developed will save approximately 10 % of current armor system weight while maintaining protection performance through advanced composite and electrified armors.

Pre-shot counter sensor. This effort provides capability to detect threat imaging sensor systems prior to engagement thereby retaining sensor overmatch under conventional and asymmetric rules of engagement. Technology integrated with existing ground vehicle targeting and acquisition sensors aims to counter the worldwide proliferation of thermal imaging systems.

Sustainment

Autonomous Mobility Appliqué System (AMAS). This effort provides scalable autonomy onto existing vehicles in a single material solution agnostic of platform. This is accomplished by integrating two kits: a vehicle unique by-wire kit, and a common autonomy kit. The by-wire kit provides the actuation and an interface for the autonomy kit. The autonomy kit will be common across the platforms and provide the necessary hardware and software to implement various levels of autonomy. This program will strive to reduce Soldier injuries and deaths due to military vehicle crashes and poor situational awareness. The program will reduce Soldier fatigue by off-loading simple driving and control functions to the vehicle. Near-term focus is on tactical systems across all BCTs.

Advanced energy storage systems. Lithium-Ion vehicle batteries that are drop in replacements to current lead acid batteries provide up to 4 times the available energy storage, at half the weight and extended durability.

Next-generation vehicle electronic architecture. This effort produces a common advanced vehicle data, electronic and power architecture that revolutionizes how ground platforms use, generate, and share information, and enables more flexibility and future upgrade capability as component technologies mature. This effort will build on the existing VICTORY architecture and provide additional capabilities beyond the current standard.[18]

Radio frequency hardware and software convergence. This effort deconstructs C4ISR and electronic warfare systems to enable the sharing of common modular hardware across the platform in order to reduce size, weight and power requirements, cut lifecycle costs, and enable rapid technology insertion.

Intelligence

Long range, unmanned reconnaissance, surveillance, and target acquisition (RSTA). This activity provides the capability to project unmanned ground assets to execute RSTA missions in contested and CBRN environments. Teaming unmanned ground with unmanned aerial assets can enable ground platforms significant operational reach without putting Soldiers in harm's way.

360-degree local situational awareness for ground degraded visual environment (DVE). This technology will increase local situational awareness and maneuverability in all conditions and environments, to include degraded visual environments (such as, dust and smoke) for ground vehicles. It will develop scalable technologies, integrated with hostile fire localization, for multi-platform applications.

Mid-Term Effort (FY22-31)

Midterm S&T goals for combat vehicles are focused on increased lethality and vehicle light weighting. S&T is focused on providing increased lethality systems with reduced recoil to enable their use on lightweight expeditionary platforms. A comprehensive light weighting campaign will drive vehicle weight reduction across all sub-systems on combat vehicles. Powertrains will be modernized to reduce under armor volume significantly. Active protection technologies (adaptive armors, hardkill and softkill active protection systems, active blast techniques) will be used to change the protection equation on platforms in combination with lighter-weight armor solutions. Lightweight structural materials and advanced manufacturing techniques reduce platform weight while meeting structural loading requirements.

In the mid-term, autonomy will provide flexibility and tailorability to the combat vehicle force. Autonomy-enabled platforms will demonstrate all weather, on/off road mobility capabilities with less user control required to maneuver the platform. Autonomous behaviors will achieve mounted and dismounted manned-unmanned teaming in cluttered, dynamic, and contested environments. Air-ground cooperation with manned-unmanned teaming platforms is demonstrated by the integration of payloads to detect, track, assess, and defeat enemy assets and achieve desired effects. Army S&T will drive sensor fusion on platforms to advance autonomous-platform perception capabilities and provide Soldiers with intuitive, actionable intelligence without excessive cognitive load.

The Army will need enhanced platform computing and government-owned software architectures to assist industry innovation on app-like software upgrades for future autonomous behaviors. To enable new capabilities, the network must resolve latency, bandwidth, range, information assurance, cyber issues, and the mapping and planning data linkage with a-priori information to direct unmanned assets across multiple environments and multiple areas of interest.

In the mid-term, the broad potential of autonomous technologies will be demonstrated, and, working with TRADOC's campaign of learning, will have the offset potential for future operational concepts and doctrine.

Below are example technologies forecasts beyond the current POM. They are not resourced beyond the current funding cycle and there is no guarantee they will be funded. They are based on current technology, threat, and environmental projections that will change as forecasts meet reality. They are S&Ts current understanding of the key focus areas that will drive the capability of the next generation of combat vehicles.

Movement and Maneuver

Next-Generation Hybrid Powertrains. These technologies include a scalable family of integrated next-generation combat engines, integrated starter and generators, advanced series hybrid drivelines and advanced energy storage systems that provide greater than 50% improvement in current platform power density. These higher density powertrains allow for the design of smaller and lighter combat vehicles without sacrificing mobility or payload performance. Hybrid technology enables greater packaging flexibility for the platform with no mechanical driveline and the ability to have limited silent mobility through all-electric mode.

High-Capacity Band Track. This technology develops a new, high-capacity band track for applications up to 50-tons. This system would allow for a novel, lightweight, low rolling resistance track solution that offers reduced maintenance to the next generation of combat vehicles. This reduces vehicle running gear weight, decreases rolling resistance to cut fuel usage, reduces track system maintenance requirements, and reduces life cycle costs.

Predictive and Adaptive Suspensions. This technology incorporates active suspension systems that can change their damping characteristics to achieve superior off-road mobility at higher speeds. Coupling these suspension systems with information coming from advanced autonomy terrain sensors (laser radar, advanced terrain mapping, and others) will enable suspensions to predict optimal ride quality before the vehicle hits an obstacle. This further enhances off-road performance, which translates to an ability to avoid enemy detection and engagement.

Heavy Air Drop Capability. This technology seeks to develop the aerial delivery package for combat platforms up to 24-tons to enable airdrop of two combat vehicles from a C-17. Minimizing the size and weight of the aerial delivery package to provide space for the vehicle platform is critical to airdropping the MPF capability defined in the CVMS.

Fires

Extended Range Cannon Artillery (ERCA) with Automated Ammunition Handling System (AAHS). ERCA with AAHS provides lethality overmatch for 155mm artillery systems by allowing extended range capability with improved accuracy and increased rates of fire for both self-propelled and towed Howitzers. Using lightweight, high-strength materials, structures and advanced manufacturing processes for the cannon, mount and autoloader, ERCA will be able to achieve lethality overmatch at extended ranges and at reduced size, weight, power, and cooling. When used in conjunction with concurrently developed ammunition, the system will be capable of achieving extended ranges over current capabilities while maintaining compatibility with the current modular artillery charge system propelling charge.

Next-Generation Large Caliber Cannon Technology. The XM360 next-generation 120mm tank cannon integrated with the AAHS will provide the M1Abrams a capability to fire the next generation of high-energy and smart-tank ammunition at beyond line-of-sight (LOS) ranges. The XM360 could also incorporate remote control operation technologies to allow its integration on autonomous vehicles and vehicles with reduced crew size. For lighter weight vehicles, recoil limitations are overcome by incorporating the larger caliber rarefaction wave gun technology while providing guided, stabilized LOS, course-corrected LOS, and beyond LOS accuracy.

Combat Vehicles Advanced Fire Control. The integration of advanced sensors and new computational algorithms to fire control solutions, such as the Fire Control Integration of Down-Range Wind Sensor, Digital Fire Control Module, and Small-Arms Ballistic Kernel, will continue to increase the probability of first round hit for existing and future combat vehicles. This will apply to both the primary weapon systems and any secondary weapon systems on the platform. Additional size, weight, power, and cooling enhancements will be realized as micro-fire control system processors will be used to replace large, bulky, and no longer supportable fire control computers.

Automated Direct Indirect Fire Mortar. Systems such as this provide short-range indirect fire support for maneuver forces through novel, automated, breech loaded, soft recoil, direct and indirect fire mortar with integrated fire control systems that connect to the battlefield network. Through constant updates in position and navigation control, seamless integration on light vehicle platforms, and enabled remote control operation, tactical flexibility will be maintained with smaller crew sizes than needed on conventional mortar systems.

Protection

Adaptive and Cooperative Armor. Adaptive and cooperative armor development takes a leap-ahead approach, providing the ability to modify armor initiation, activation and defeat strategy dynamically. This effort focuses on the design of adaptive armor concepts, development and maturation of solutions, and integration to meet future vehicle protection requirements. Adaptive armor approaches enable up to 15% armor and system weight reduction.

Holistic Protection Systems. This effort builds off the MAPS architecture and creates strategies to combine armor and occupant protection suites to give holistic vehicle protection strategies that defeat multiple threat classes to include kinetic energy, long-rod rounds, underbody blasts, explosively formed penetrators, and anti-armor missiles. The effort will focus on the integration architecture to enable an adaptable protection strategy to allow for long-term ground platform modularity and flexibility.

Autonomy-Enabled Systems. This effort provides perception, intelligence, control, and tactical behavior technologies for autonomous collaborative unmanned systems to conduct safe operations in complex operational environments, laying the foundation for future manned-unmanned teaming strategy. This technology offers permits Soldiers to expand their spheres of influence. This technology may be used at both the platform and formation level to reduce the operational risk to Soldiers and must consider human factors, system resiliency, and graceful degradation modes of operation. There are multiple operational uses for these types of systems.

Scalable Reconfigurable Optical Designs for Advanced Sensor Protection. This effort provides innovative, scalable, reconfigurable optical designs for advanced sensor protection.

Sustainment

Advanced Radio Frequency Hardware and Software Convergence. This technology's TRL 6 demonstration provides real-time coordination between communication, electronic warfare, cyber, and shared general purpose computing. Modular plug-and-play sensors, such as radars, will be added to increase radio frequency coordinated functionality. The integrated solution allows modular hardware to reconfigure automatically based on mission and load demands.

Intelligence

Advanced Image Processing. This technology will advance low power signal and image processing and algorithm development. The signal and image processing technologies and algorithms will support autonomy enabled systems, counter IEDs nominations, and neural processing capabilities.

Sensor Interoperability Architectures. Advanced sensor architectures that increase sensor interoperability and allow the sharing of sensor data between combat vehicles and other platforms will be developed. These technologies will improve strategic and tactical situational awareness while reducing response times, integration complexity, and life cycle costs.

Next-Generation Adaptive Read-Out Integrated Circuits. This technology will provide unparalleled and game-changing sensor performance, when developed and deployed. These large format read-out integrated circuits provide three-dimensional image fusion and multifunction image processing capabilities.

Far-Term Effort (FY32-46)

Predicting specific technologies relevant to the fight in the deep future is challenging and ultimately futile due to the changing landscape of technology, threat, and operational environment. Instead of focusing on specific technologies, the far-term focuses on the capabilities most likely available in the future based on current projections. The far-term CVMS priorities focus on enhancing the next generation of armored BCT with rapid deployability while improving the formation's mobility, protection, and lethality. The broad integration of autonomous technology across the ground fleet is also a far-term goal.

Technology forecasting, future system conceptualizing and future operational concept development are most effective when executed in a synchronized, deliberated process. A recurring and systematic approach between the S&T and warfighting communities to look into the future and pull together representative future platforms based on fundamental warfighting challenges is critical to shaping the Army's ground vehicle S&T strategy. The Next Generation Close Combat Vehicle Study (NGCCVS) between the Research Development and Engineering Command RDECOM and TRADOC demonstrated how working together, fundamental challenges, such as; What does a rapidly deployable, armored BCT look like in 2040-2050?, can be visualized into a future BCT of combat platforms.

Army S&T has the capability to virtually prototype platforms based on our technology experts forecasting where ground vehicle technology will be in the future. The performance of these concept platforms can then be predicted using S&T's physics-based modeling and simulation analysis tools. Working with ARCIC and their early synthetic prototyping capability, these future concept platforms can be evaluated by Soldiers in the Virtual Battle System gaming environment. Utilizing this non-traditional operational assessment allows the Army to understand the operational effectiveness of the new concept platforms and to see how Soldiers use their new capabilities potentially influencing future doctrine.

The focus of the NGCCVS was to develop a future expeditionary close combat BCT that maximized aerial delivery of the platforms while maintaining capability to deliver an operationally relevant force to the battle. Basic vehicle weight and size classes were defined by transport modes (vertical lift, fixed wing airdrop, and fixed wing roll-on/roll-off) across forcible entry, early entry, and campaign operations. Central to the NGCCVS platform concepts was a modular protection capability that enabled platforms to grow survivability once deployed, and lethality systems with low recoil to ensure platforms were protected and lethal to remain operationally relevant while keeping the weight and size within transportability requirements.

The NGCCVS also noted that mixing of manned and unmanned systems with systems able to operate manned as an option is critical to enabling the required capabilities on the platforms within the deployment constraints of vertical lift aircraft and airdrop capable systems. The ability to remove Soldiers from autonomous wingman lethality systems enables more stowed kills with larger caliber weapon systems than is possible on manned systems of the same class. Autonomous capability becomes a critical enabler to ensuring the expeditionary BCT concept embodied in the NGCCVS can remain operationally relevant once deployed, especially in forcible and early entry operations.

The process defined by the NGCCVS should be accomplished periodically to enable material and combat developers to iteratively envision the future around major AWFCs. These future platform conceptual activities allow the Army to constantly and deliberately challenge their assumptions on the future, take new feedback on changing threat environments, and continuously improve the Army's vision of future warfighting capability.

Current thinking from S&T and user communities has platforms requiring the following characteristics and capabilities:

Movement and Maneuver

High-performance off-road capability with adjustable suspensions to enable extreme mobility to enhance terrain accessibility and mission flexibility.

Ample onboard electrical power to enable required mission equipment packages advanced directed energy lethality and survivability technologies as well as future growth.

Precision airdrop capability for platforms up to 24-tons to enable forced entry operations with more capable ground platforms.

Fires

Wide range of options to provide significant lethality from very lightweight platforms (very low recoil) and the ability to provide LOS and no LOS effects from the same weapon system, which fire from manned or unmanned platforms working together in teaming formations.

Manned and unmanned teaming of both ground and air platforms to enable advanced autonomous maneuvers such as swarming and unmanned wingman behaviors.

Novel warheads that utilize spherical lethality zones for increased probability of hit and incapacitation of targets, resulting in reductions to stowed ammunition while enabling scalable lethality effects. Extremely high impetus propellants for hyper-velocity projectiles will provide increased anti-materiel defeat range.

Electric fires capability, which may include high-energy lasers, high power microwaves, electromagnetic launch, and plasma weapons to provide scalable, lethal, precise, low cost effects across a range of operations.

Significantly advanced targeting and sensing systems that will have the ability to provide targeting data with minimal latency through the Network, assist in rapid target acquisition and identification, and provide innovative sensing approaches that surmise intent (using complex data mining and metric calculations) of perceived threats granting unparalleled situational awareness.

Protection

Advanced adaptive vehicle survivability systems give the Army the ability to provide protection based on situational encounters and can be changed out and/or adapted in real time to support a given mission. Holistic protection systems (active protection, active armor, and active occupant-centric survivability techniques) will use real time sensing and vehicle intelligence to allow these protection suites to adapt on the move as the operational situation around the vehicle changes. This will allow for intelligent decision-making based on the situation and the protection suite available on the platform. The goal would increase vehicle protection significantly across a wide range of threats at much lighter weights than current platforms.

Modular armor strategies that enable platforms to adapt across the spectrum of conflict while still enabling air deployability for early entry operations.

Collaborative defense strategies across platforms allow shared protection across multiple manned and unmanned vehicles. Utilize unmanned platforms to reduce the risk to Soldiers and augment manned system protection.

Advanced signature management techniques and rapid vehicle agility will enable Soldiers to shape the battlefield and avoid detection from the enemy.

Sustainment

Power-dense and efficient hybrid electric powertrains that maximize power to the running gear maximize fuel efficiency on platforms and sized for growth between early entry and campaign modes.

Vehicle architectures as common, modular and scalable between different platforms to increase supportability within the formation and drive down cost with economies of scale.

Predictive condition-based maintenance capability on platforms to drive down sustainment costs and improve readiness of formations.

Intelligence

The network must be secure and robust from cyber threats and have enough bandwidth to support significant data throughput for autonomous systems and sensors across the battlefield. If the network goes down, platforms need to have fail-safes to ensure the mission is successful.

Offensive cyber capability to take down enemy networks and C4ISR systems to include unmanned weapon and RSTA systems.

Advanced sensor fusion that provides actionable intelligence to all levels and provides an advanced situational awareness to vehicles in all operational conditions including natural and manufactured DVE.

Provide significant onboard computing for platforms to reduce cognitive load on vehicle operators and automate tasks that do not require Soldier supervision to include navigation, target tracking, condition-based maintenance cycles.

Future sensors for combat vehicles will provide 360° high-resolution situational awareness, targeting and driving and will combine the sensor functions developed in the mid-term. Ultra-small pixel, very large format electro-optic and infrared detectors will be developed. Single, multifunction sensors will provide long-range identification for gunnery, location of hostile fires, detection and tracking of threat unmanned aerial systems (UAS), counter IED indicators for increased mobility, automatic threat nominations, and operations in DVE.

Wide field of view, color, see-through collimated displays will be developed to increase situational awareness and reduce cognitive burden.

Conclusion

A comprehensive and integrated Army S&T effort is critical to the achievement of the goals articulated in the CVMS. S&T breakthroughs cannot be scheduled nor can the combat developer in isolation understand how future technology-enabled capability can change the operational environment of the future fight. It is through continuous engagement, analysis, and experimentation between the material and combat developers that the full potential of future technologies, developed in tandem with future doctrine and tactics, be realized for the future combat vehicle fleet.

Affordability, reliability and maintainability must be key tenants to any Army S&T program to ensure both procurement and life-cycle costs do not make transition of capability to the Soldier fiscally impossible. The LIRA must continue to be a key tenant for the Army's ground vehicle S&T strategy and it must continue to evaluate trends, innovate, and prioritize investments to ensure relevant, scalable, leap-ahead technology-enabled capabilities are brought to the combat fleet. Through active partnership between combat and material developers, the Army will have the right capabilities to be able to deploy rapidly around the world and sustain combat operations for extended periods in a variety of operational environments against state, non-state, and hybrid threats.

Appendix G
Integrating Robotic and Autonomous Systems (RAS) Technology in Combat Vehicle Modernization

Introduction

Shifts in the methods by which armies fight often derive from tactical and technological innovation. The need to resolve urgent capability shortcomings on the battlefield often drives technical innovation. The first successful use of large numbers of tanks at the Battle of Cambrai in 1917 demonstrated the tactical potential of innovative technologies to address tactical needs.

Using coordinated attacks with artillery and infantry, the British tanks at Cambrai broke through defenses, which were "…supposed by the Germans to be impregnable."[19] With many innovations, however, new technology is used initially merely to augment existing tactical and operational methods. Tanks in their earliest forms acted as enablers to traditional infantry methods of attack. Only a few visionaries in 1918 foresaw the potential of what the armored force would become years later during World War II.

Like the tank in World War I, new robotic and autonomous system (RAS) platforms have shown similar promise for the exploitation of rapid technological innovation in both the Iraq and Afghanistan campaigns. In the near future, RAS may help the U.S. Army resolve its most pressing battlefield dilemmas. For example, RAS provides a way to deliver wide ranging, protracted presence with a deployed force small enough to avoid creating friction as it operates in the midst of a foreign culture yet retain enough tactical and operational overmatch capability to remain credible. RAS enables the Army to design military formations that are economical enough to leave in the field for an extended time. RAS enables the Army to equip forces to survive in environments replete with sensors, precision targeting, and cheap but effective weapons widely available to even the most common infantryman or insurgent. Finally, robotic platforms permit the Army to "bring mass back to the fight" by augmenting manned combat platforms with large numbers of lower cost semi-autonomous robotic systems.

As the Army moves forward with its development of manned and unmanned teaming capabilities, RAS has the potential to provide manned air platforms with enhanced sensor and shooter capability, and to provide manned combat vehicles with extended remote sensors and enhanced weapons standoff capabilities. This would permit the Army to expand the number both sensors and shooters in its BCTs.

Mobility and Firepower

"The victory will belong, in this war, to the one of the two belligerents who will be the first to succeed in mounting a 75 mm gun on a vehicle capable of moving in all types of terrain".

--French Colonel Jean Baptiste Eugène Estienne,

Since leaders at the tactical level can accept more risk without a human onboard every combat platform, RAS can create better tactical options for Soldiers. When the risks are high, commanders will be able to balance the survivability of their Soldiers against the cheaper cost of expending machines. As technology improves, robotic capabilities will also improve and the procurement of these systems will become more affordable. This will permit the Army to procure larger numbers of these systems, displacing Soldiers to other important missions, and creating greater opportunities to exploit these new capabilities. For Force 2025 and beyond, the potential of robotic platforms to reshape how the U.S. Army fights is feasible.

When paired with a small number of troops, or operating alone, RAS provides a long-term presence in an area of operations in a more economical and politically palatable way. When paired with manned combat platforms operating in mutual support, semi-autonomous robotic wingman platforms may provide several capability enhancements. RAS platforms provide improved situational awareness without exposing human scouts to battlefield hazards. Situational awareness diminishes risk to Soldiers, who often must fight for information. Unmanned systems, operating between manned systems, enhance the maneuver formation's ability to see and fight across extended distances. Army formations will operate widely dispersed while maintaining mutual support.

RAS capabilities will provide the Army with the ability to make contact with the enemy under favorable conditions and the ability to sustain high tempo operations at the end of extended and contested lines of communication. RAS platforms will provide the ability to establish and maintain security across wide areas and the ability to pose enemy forces with multiple dilemmas while reducing risk to our own Soldiers and units. Such an evolution in capability will require a commensurate shift in the creation of effective concepts and organizations designed to exploit these new technologies.

An Argument for RAS

The AOC states that science and technology must continue to focus on automation and autonomy to improve the capabilities of UAS and enable the development and fielding of optionally manned systems and manned-unmanned teaming capabilities. Optionally manned platforms must also be more efficient and possess increased reliability to reduce the size of the logistical footprint and allow those platforms to operate out of austere locations alongside ground forces. Furthermore, the application of emerging technology creates the potential for affordable, interoperable, autonomous, and semi-autonomous systems that improve the effectiveness of Soldiers and units.

Autonomy-enabled systems will deploy as force multipliers at all echelons from the squad to the brigade combat teams. Future robotic technologies and unmanned ground systems (UGS), while not intended to replace Soldiers initially, will augment Soldiers and increase unit capabilities, situational awareness, mobility, speed of action, and ultimately extend the operational reach of units of all sizes. Artificial intelligence will enable the deployment of autonomous and semi-autonomous systems with the ability to learn. Automated decision aids will reduce the cognitive burden and help leaders make rapid decisions and process the large amount of data with the objective of providing relevant information to the point of need at the speed of war.

Robotic and Autonomous Systems Force Development First Principles

1) RAS must reduce cost through commonalities within classes of systems
2) RAS must leverage commercial technology and introduce autonomy into units where feasible
3) RAS must be incorporated into the training base and permit Soldier feedback within technology development
4) RAS must protect the force at increased standoff distances
5) RAS must lighten the warfighters' physical and cognitive workload
6) RAS platforms that entirely replace manned platforms must perform at a level that meets or exceeds the manned capability they displace.
7) RAS must sustain the force with increased distribution, throughput and efficiency
8) RAS must facilitate maneuver in joint combined arms operations and wide area security
9) RAS must facilitate conducting lethal and nonlethal engagements where manned systems are limited, denied entry, or unavailable
10) RAS must be able to operate in a hostile electronic warfare environment

Artificial intelligence may allow robots and automated systems to act with increased autonomy. Robotics will enable the future force by extending the operational area of units of all sizes, contributing to force protection, and providing increased capabilities to maintain overmatch. If the U.S. Army's ground forces are to remain capable of expeditionary maneuver and joint combined arms operations in the distant future, it will be RAS that provides formations with an appropriate combination of situational understanding, mobility, protection, lethality, and flexible sustainment to overmatch current and future enemy maneuver capabilities. Both allies and potential threats to U.S. interests have already demonstrated their willingness to invest in unmanned technologies today.[20] The U.S. Army must also invest in the research, experimentation, and development of RAS technologies in the near-term, if it wants to preserve technological dominance against potential future adversaries.

Near-Term Robotic Efforts and Technologies Influencing Potential Future Combat Vehicles

The Army seeks to preserve overmatch against its future adversaries by enhancing its capabilities through 2025 and beyond. The Army continues to pursue RAS technologies as a means to that end. The AOC's description of Army science and technology investment areas, the Army states clearly that technologies will-

> ...enable manned and unmanned teaming in both air and ground maneuver through investments in scalable sensors, scalable teaming, Soldier-robot communication, and shared understanding through advancements in machine learning. Technologies will improve the autonomy of unmanned systems. Unmanned cargo delivery via air and ground robotic platforms will enable the squad to reduce and lighten Soldier loads. Investments in micro autonomous air and ground systems will also enhance platoon, squad, and Soldier situational awareness.[21]

The Army also articulated accomplishments to bring robotic systems into the force, and the way ahead to chart a new course for the future. In 2015, the ARCIC robotics research team produced a comprehensive study describing the Army's vision for how it procured, trained, employed, repaired, and recovered robotic systems over a decade of war. The study defined past lessons learned and served as the point-of-departure for future RAS procurement efforts. The ARCIC Director further tasked ARCIC to write an Army concept and strategy for RAS to help guide the future of RAS development. Per the DOD Unmanned Systems Integrated Roadmap, the end state for the Army's vision on robotics is "…an affordable, modernized force, as a manned-unmanned team, with improved movement and maneuver, protection, intelligence, and sustainment."

Current near-term efforts to develop and insert autonomy in Army robotic platforms are focus on tactical wheeled vehicles rather than armored maneuver platforms. In 2014, the Army conducted demonstrations of the AMAS in several locations. The AMAS technology enables unmanned convoy operations to operate in varying terrain to include urban areas and complex road networks. The AMAS and autonomous convoy system (ACO) technologies currently imbedded in the wheeled convoy Joint Capability Technology Demonstration experiments have demonstrated great promise in the potential of applying these technologies toward eventual application to off-road, combat platforms. As the Army seeks to pursue future development of robotic combat vehicles as potential wingmen to manned systems, these efforts must lead first through the perfection of the requisite technologies embedded in the tactical wheeled vehicles associated with current autonomous convoy experimentation.

The Army demonstrated semi-autonomous platforms utility in conducting small-unit tactical resupply missions. Substitute mission payloads instead of supply cargo and the potential of these systems as maneuver enablers is apparent. Live demonstrations of semi-autonomous robotic systems working together to deliver cargo, show the potential of autonomous resupply systems to extend the range of manned combat platforms. Rotary wing external-load cargo delivery UAS systems demonstrate the value and feasibility of semi-autonomous aerial resupply, and the utility of semi-autonomous resupply was demonstrated by the squad mission support system unmanned ground system. Both air and ground systems worked together, independent of direct human presence and control during demonstrations conducted in 2014. This level of technology is achievable in the near-term, and could be a test bed for robotic MPF payload capabilities.

Mid-Term Robotic Efforts and Technologies Influencing Potential Future Combat Vehicles

The AOC specifies several expectations for autonomy-enabled systems in the mid-term. The AOC states, that the application of emerging technology creates the potential for affordable, interoperable, autonomous, and semi-autonomous systems that improve the effectiveness of Soldiers and units.[22] Autonomy-enabled systems have the potential to serve at all echelons from the Squad level to the brigade combat teams. Future robotic technologies and UGS will augment Soldiers and increase unit capabilities, situational awareness, mobility, and speed of action. Artificial intelligence will enable the deployment of autonomous and semi-autonomous systems with the ability to learn. Decision aids will reduce the cognitive burden and help leaders make rapid decisions. Artificial intelligence may allow robots and automated systems to act with increased autonomy. Robotics will enable the future force by making forces more effective across wider areas, contributing to force protection, and providing increased capabilities to maintain overmatch.[23] For future combat vehicles, the following attributes most directly apply to their integration with RAS.

Protection. UGS provide small units with standoff from potentially lethal threats. The proliferation of chemical, biological, radiological, nuclear, and high-yield explosives (CBRNE) threats requires increased use of robotic technologies to secure the force and civilian populations. The development of autonomous capabilities enhances protection by allowing unmanned systems to operate in areas difficult for humans to access, where threats demand standoff for manned teams, or where the duration of the operation dictates employment of UGS. In the far-term, UGS will require development of suitable autonomous or semiautonomous behaviors, preventing the need for constant Soldier input required in current systems. The ability to assign tasks to UGS and passively control or over-watch multiple assets simultaneously is critical.

Expeditionary Capability. Use of unmanned platforms in mounted and dismounted maneuver formations leads to smaller, mobile, and transportable manned and unmanned vehicles, enabling greater expeditionary capability. UGS will be deployed to the support battalions to reduce manpower needs in expeditionary environments and conduct routine maintenance and autonomous re-supply operations. Decreasing the Soldier-to-robot controller ratio provides significant gains in unit effectiveness and manpower savings. By designing easily deployable, modular systems with low maintenance demands, robotics adds capability options to commanders and reduces support demands as well. Connected to the reporting system and equipped to execute assigned tasks to support the maneuver force, UGS will be integral parts of a support structure that allows commanders to retain the initiative during high tempo decentralized operations. Rapidly deployable UGS capable of establishing mission command systems enables mission command on the move and then transition to offensive operations after initial entry.

The S&T community will invest its resources in the near-term to set the conditions for success in the mid- and far- terms. The Army will seek to exploit a promising tele-operated technologies and limited autonomy ground security platforms currently in existence. Research and development in these systems merit limited purchase, experimentation, and fielding to shape what the Army wants for its long-term objectives from autonomous combat vehicle platforms. This has direct implications for the Army's current efforts to develop and field new MPF platforms. While initial MPF concepts envision solely manned platforms in the near term, early investment in the technologies discussed above will enable future evolutions of MPF to provide either unmanned or optionally manned variants in the far-term.

Far-Term Robotic Efforts and Technologies Influencing Potential Future Combat Vehicles

Future live experimentation efforts will play a role in shaping the future of RAS combat vehicle platforms. Experiments such as that performed during AWAs, Army Expeditionary Warrior Experiments, and NIEs will be critical to transitioning autonomous and semi-autonomous concepts to capabilities. However, virtual experimentation, such as that performed by early synthetic prototyping can also employ game environments to generate ideas, flesh-out concepts, and explore opportunities and challenges before applying significant resources to materiel solutions. Live and virtual exercises together will refine how the Army employs and integrates UAS and UGS. These RAS vehicle capabilities will serve primarily as intelligence, surveillance, and reconnaissance (ISR) sensor platforms; however, over time they can be augmented as weapons platforms with lethal capability payloads.

As the Army develops and refines autonomous navigation, obstacle avoidance, tactical inferential decision making capabilities, development of advanced tactical artificial intelligence programs linked with preventative threat detection sensors and programs will begin to permit detection of the enemy, avoidance of threats, and maneuvering both manned and unmanned platforms to positions of advantage. As experimentation and development in artificial intelligence increases, DOD Directive 3000.09 will limit any lethal autonomy capabilities. The directive prohibits the employment of lethal autonomous function in any U.S. military owned RAS platform.

The long-term vision for mounted combat includes robotics working alongside Soldiers as full team members; not just tools. The long-term vision of RAS in the U.S. Army includes integration of robotics across all formations and multiple mission templates, including those below.

Reconnaissance and Security. Armor and cavalry formations conduct reconnaissance and security missions using RAS assets to protect follow-on BCT elements from various threats. Mounted scouts, augmented with their own vehicle-launched semi-autonomous UAS platforms, will detect various threats along the BCT axis of advance before follow on forces can be surprised or decisively engaged. Dismounted scouts, augmented with common light autonomous reconnaissance robotic sensors will use autonomous robotic ISR platforms. These RAS systems will "swarm" to feed real-time data to both mounted and dismounted scouts.

Urban Operations. Individual squads and platoons employing micro and nano UAS, and UGS in urban terrain will likely make contact on their own terms, thus reducing the need for their formations to maintain a 6 to 1 attacker-to-defender ratio. Platoons and squads will use these systems to conduct ISR in three dimensions, including subterranean environments and complex urban structures, by simply establishing an RAS screen to protect the platoon's movement. UAS sensor platforms loitering overhead, working with UGS platforms on the ground will provide integrated enhanced situational awareness and protection. Robotic wingmen RAS platforms will augment manned combat platforms, making use of autonomous navigation, sensors, and obstacle avoidance technologies developed and perfected under the AMAS and ACO programs.

Mounted Offensive Operations. Manned armored and mechanized platoons, with their robotic wingmen and optionally manned MPF platforms, will maneuver utilizing their assigned UAS and UGS to conduct route, zone, and area reconnaissance missions at ranges beyond line of sight of the platoon's lead element, allowing them a better chance at making contact on their own terms. RAS platforms will enable maneuver units to mass effects rather than forces. Advanced tactical artificial intelligence programs linked with preventative threat detection sensors and programs will assist manned platforms and units with detecting the enemy, avoiding threats, and maneuvering both manned and unmanned platforms to positions of advantage. Though DOD Directive 3000.09 officially prohibits the employment of lethal autonomous function in any RAS platform, the long-term vision for robotic wingman platforms projects RAS systems that are capable of performing nearly every other task autonomously including, navigation, obstacle avoidance, target sensing, tracking, and weapons orientation. All of these capabilities work together to enable integrated manned-unmanned teaming between manned combat vehicles and RAS to provide decisive overmatch against enemy grounds forces.

Autonomous Resupply. The long-term vision for supply chain management envisions sophisticated automated software that tracks status of vehicles, fuel, ammunition, and automated warehouses and robot-assisted supply nodes that predict and anticipate supply shortages and move the proper logistics and resources forward on time. Platoons and squads will enjoy extended range and duration of missions by incorporating robotic platforms that lighten the Soldiers' load and free them to execute other missions outside of protecting routine supply runs. At extended ranges or in terrain that is non-permissive to UGS, unmanned cargo UAS platforms provide aerial resupply at forward locations, relieving manned aircraft to execute other missions.

Glossary

Section I
Abbreviations

A2	anti-access
AAHS	automated ammunition-handling system
ACO	autonomous convoy system
AD	area denial
AMAS	autonomous mobility appliqué system
ASM	armored systems modernization
AWFC	Army Warfighting Challenges
AOC	Army Operating Concept
ATGM	anti–tank guided missile
ARCIC	Army Capabilities Integration Center
BCT	brigade combat team
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CBA	capability-based assessment
CBRNE	chemical, biological, radiological, nuclear, and high yield
CDD	Capabilities Development Directorate
CNA	capability needs assessment
CVMS	Combat Vehicle Modernization Strategy
COTS	commercial off-the-shelf
DOD	Department of Defense
DOTMLPF-P	doctrine, organization, training, materiel, leadership, personnel, facilities, and policy
DVE	degraded visual environment
ECP	engineering change proposal
EFP	explosively formed projectile
ERCA	extended range cannon artillery
FCS	Future Combat System
GCV	ground combat vehicle
GPS	global positioning satellite
IDF	Israeli Defense Forces
IED	improvised explosive device
ISR	intelligence, surveillance, and reconnaissance
JCIDS	Joint Capabilities Integration and Development System
JFEO	joint forcible entry operations
LIRA	long-range investment requirements analysis
LTIOV	last time information is of value
MAPS	modular active protection system
MCoE	Maneuver Center of Excellence
MPF	mobile protected firepower
NGCCVS	Next Generation Close Combat Vehicle Study
OPR	office of primary responsibility

PEO	program evaluation officers
PM	program manager
POM	program objective memorandum
POR	program of record
RAS	robotic and autonomous system
RC	required capability
RDECOM	Research Development and Engineering Command
RPG	rocket propelled grenades
RSOI	reception, staging, onward movement, and integration
RSTA	reconnaissance surveillance, and target acquisition
S&T	science and technology
SIDRA	sustain, improve, develop, replace, and assess
TAA	Total Army Analysis
TRAC	TRADOC Analysis Center
TRADOC	Training and Doctrine Command
TRL	technology readiness level
UAS	unmanned aerial system
UGS	unmanned ground system
U.S.	United States

Section II
Terms

active protection system
System designed to prevent line-of-sight anti-tank missiles, and projectiles from acquiring and/or destroying a target.

adversary
A party acknowledged as potentially hostile to a friendly party and against which the use of force may be envisaged.

anti-access
Those actions and capabilities, usually long-range, designed to prevent an opposing force from entering an operational area (Joint Operational Access Concept).

area denial
Those actions and capabilities, usually of shorter range, designed to limit an opposing force's freedom of action within an operational area (Joint Operational Access Concept).

assessment
A continuous process that measures the overall effectiveness of employing joint force capabilities during military operations.

asymmetric

Warfare in which opposing groups or nations have unequal military resources, and the weaker opponent uses unconventional weapons and tactics, as terrorism, to exploit the vulnerabilities of the enemy.

autonomy
Level of independence that humans grant a system to execute a given task in a complex environment; the condition or quality of being self-governing to achieve its assigned mission based on the robotic system's own situational awareness (integrated sensing, perceiving, analyzing) planning and decisionmaking.

brigade
A unit consisting of two or more battalions and a headquarters company or detachment.

brigade combat team
A combined arms organization consisting of a brigade headquarters, at least two maneuver battalions, and necessary supporting functional capabilities.

capability
The ability to achieve a desired effect under specified standards and conditions through combinations of means and ways to perform a set of tasks.

capabilities development
Identifying, assessing, and documenting changes in DOTMLPF that collectively produce the force capabilities and attributes prescribed in approved concepts, concept of operations, or other authoritative sources.

close combat
Warfare carried out on land in a direct-fire fight, supported by direct and indirect fires and other assets.

combat vehicle
A vehicle, with or without armor, designed for a specific fighting function. Armor or armament mounted as supplemental equipment on noncombat vehicles will not change the classification of such to combat vehicles.

combat power
The total means of destructive and/or disruptive force, which a military unit/formation can apply against the opponent at a given time.

combined arms
The synchronized and simultaneous application of arms to achieve an effect greater than if each arm was used separately or sequentially.

complex terrain
A geographical area consisting of urban center larger than a village and/or of two or more types of restrictive terrain or environmental conditions occupying the same space.

depth
The act or practice of positioning successive mutually supporting lines of defense in a given area.

dispersion
The deliberate or accidental reaction to adversary capabilities to spread out or break up forces, reduce the targetable mass of friendly forces, more effectively cover terrain in an area of operations, and gain operational and tactical flexibility.

direct fire
Refers to the launching of a projectile directly at a target within the line-of-sight of the firer. The firing weapon must have a sighting device and an unobstructed view to the target, which means no objects or friendly units can be between it and the target.

doctrine
How military forces contribute to campaigns, major operations, battles, and engagements. It is a guide to action, rather than hard and fast rules.

endurance
Is the time for which a military system can remain in combat before having to withdraw due to depleted resources.

ends
Objectives that if accomplished create, or contribute to, the achievement of the desired end state at the level of strategy being analyzed and, ultimately, serve national interests

enemy
A party identified as hostile against which the use of force is authorized.

expeditionary
The ability to deploy task-organized forces on short notice to austere locations, capable of conducting operations immediately upon arrival.

expeditionary maneuver
The rapid deployment of task-organized combined arms forces able to transition quickly and conduct operations of sufficient scale and ample duration to achieve strategic objectives.

experimentation
A test under controlled conditions that is made to demonstrate a known truth, to examine the validity of a hypothesis, or to determine the efficacy of something previously untried.

freedom of action
Offensive action is the most effective and decisive way to attain a clearly defined common objective. Offensive operations are the means by which a military force seizes and holds the initiative while maintaining freedom of action and achieving decisive results.

freedom of movement
Is the degree to which individuals or groups have—and perceive that they have—the ability to move from place to place within a given environment as well as into and out of that environment.

horizontal technology
Insertion - application of common technology solutions across multiple systems to improve the war-fighting capability of the total force.

hybrid threat
The diverse and dynamic combination of regular forces, irregular forces, terrorist forces, and/or criminal elements unified to achieve mutually benefitting effects.

indirect fire
Aiming and firing a projectile without relying on a direct line of sight between the gun and its target, as in the case of direct fire.

initiative
Using resourcefulness to get something done without the normal material or methods being available.

integration
The arrangement of military forces and their actions to create a force that operates by engaging as a whole.

interoperability
The ability to operate in synergy in the execution of assigned tasks.

joint combined maneuver
The synchronized application of two or more arms or elements of one service, along with the application of joint, inter-organizational, and multinational capabilities to place the adversary in positions of disadvantage.

leadership
The process of influencing people by providing purpose, direction, and motivation to accomplish the mission and improve the organization.

lethality
The ability to kill or cause physical destruction.

line of effort
A line that links multiple tasks using the logic of purpose rather than geographic reference to focus efforts toward establishing operational and strategic conditions.

lodgment

A designated area in a hostile or potentially hostile territory that, when seized and help, makes the continuous landing of troops and material possible and promotes and provides maneuver space for subsequent operations.

maneuver
Employment of forces in the operational area through movement in combination with fires to achieve a position of advantage in respect to the enemy.

manned, unmanned teaming
The synchronized employment of Soldiers, manned and unmanned air, and ground vehicles, robotics, and sensors to achieve enhanced situational understanding, greater lethality, mobility, and improved survivability.

means
An action or system by which a result is brought about; a method.

mission
The task, together with the purpose, that clearly indicates the action to be taken and the reason therefore.

mission command system
The arrangement of personnel, networks, information systems, processes and procedures, and facilities and equipment that enable commander to conduct operations (ADP 6-0).

mobility
The ability to move Soldiers and their weapons and equipment to positions of advantage over their adversaries.

modernization
Adapt (something) to modern needs or habits, typically by installing modern equipment or adopting modern ideas or methods.

near-term
Expresses planning efforts out to 25 years.

network
A single, secure, standards-based, versatile infrastructure linked by networked, redundant transport systems, sensors, warfighting and business applications, and services that provide Soldiers and civilian's timely and accurate information in any environment, to manage the Army enterprise and enable unified land operations with joint, allied, and inter-organizational partners.

objective
The clearly defined, decisive, and attainable goal toward which every operation is directed. A location on the ground used to orient operations, phase operations, facilitate changes in direction, and provide unity of effort.

obsolete
No longer produced or used; out of date.

Operation
A military action or the carrying out of a strategic, tactical, Service, training, or administrative military mission.

operational environment –
A composite of the conditions, circumstances, and influences that affect the employment of capabilities and bear on the decisions of the commander.

operational risk
The risk of a change in value caused by the fact that actual losses, incurred for inadequate or failed internal processes, people and systems, or from external events.

overmatch
Application of capabilities or unique tactics either directly or indirectly, with the intent to prevent or mitigate opposing forces from using their current or projected equipment or tactics.

planning
The art and science of understanding a situation, envisioning a desired end future, and laying out effective ways of bringing that future about.

protection
The ability to avoid, deflect, or absorb enemy attacks without the vehicle or Soldiers sustaining damage or injuries.

range of military operations
Military activities, tasks, missions, and operations along the continuum of conflict from peace to war that vary in purpose, scale, risk, and combat intensity and which can be grouped into three areas: military engagement, security cooperation, and deterrence; crisis response and limited contingency operations; and major operations and campaigns.

reconnaissance
A mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or adversary, or to secure data concerning the meteorological, hydrographical, or geographical characteristics and the indigenous population of a particular area.

risk
Probability and severity of loss linked to hazards.

SIDRA
Acronym used to describe the modernization process for the CVMS.

situational understanding

The product of applying analysis and judgment to relevant information to determine the relationships among the operational and mission variables to facilitate decision-making.

small arms
Man portable, individual, and crew served weapon systems used mainly against personnel and lightly armored or unarmored equipment.

strategy movement
Act of changing physical location or position to achieve important objectives, goals, or interests.

survivability
A quality or capability of military forces, which permits them to avoid or withstand hostile actions or environmental conditions while retaining the ability to fulfill their primary mission.

task organization
The act of designing an operating force, support staff, or logistic package of specific size and composition to meet a unique task or mission.

tempo
Is a measure of the pace of an operation or operations in terms of equipment usage.

threat
Any combination of actors, entities, or forces that have the capability and intent to harm United States forces, United States national interests, or the homeland.

unity of effort
The coordination and cooperation toward common objectives, even if the participants are not necessarily part of the same command or organization—the product of successful unified action.

ways
Explain "how" the ends are to be accomplished by the employment of resources

Section III
Special terms

No entries

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[1] A combat vehicle is a vehicle, with or without armor, designed for a specific fighting function. Armor or armament mounted as supplemental equipment on noncombat vehicles will not change the classification of such to combat vehicles. Joint Pub 1-02.
[2] Overmatch is the combination of capabilities that prevent enemy organizations from successfully using their equipment or employing their tactics.
[3] Tactical mobility is the ability to traverse a variety of terrain. Global responsiveness is the ability to deploy combat vehicles from the U.S. or bases in allied states.
[4] Appendix C explains the relationships between protection, lethality, and mobility, and cost and weight.
[5] Synchronized, simultaneous, or sequential application of two or more arms or elements of one service, along with joint, interorganizational, and multinational capabilities combined with leadership and education across services to ensure unity of effort and create multiple dilemmas for the enemy to seize, retain, and exploit the initiative. AOC, p 45.
[6] For further discussion of potential enemy threats and A2 and AD capabilities, see SECRET appendix B. Contact the document proponent.

[7] AOC, p31.
[8] Army under Force 2025 Maneuvers will evaluate the ideas contained in this strategy and the assumptions on which they are based to ensure that the Army's preparation for the demands of future armed conflict rest on a solid conceptual foundation.
[9] Scalable here means capable of deployment and employment in larger or smaller customized unit sets. Tailorable here means able to organize with varying rations of mounted, dismounted, and enabling capabilities for specific missions.
[10] Depth: the extension of operations in time and space to prevent enemy forces recovering from simultaneous efforts. To achieve depth, commanders think ahead in time and determine how to connect tactical and operational objectives to strategic goals. Commanders and staffs anticipate future opportunities and dangers and make decisions that allow their forces to retain and exploit the initiative. AOC, p19.
[11] U.S. Army forces require the ability to detect, recognize, and identify enemy targets at the maximum range of U.S. weapon systems. To ensure the Army reduces the risk of accidentally engaging friendly forces, Soldiers train never to engage targets until they are identified positively as enemy. U.S. potential enemies, however, may assume more risk and engage at the first range they detect U.S. vehicles, thereby challenging or negating U.S. overmatch.
[12] Robotics and Autonomous Systems Strategy, currently in advanced draft form from ARCIC MAS-D. Copy available upon request through proponent..
[13] Above 20-gross horsepower per ton of weight is a typical power to weight ratio goal for a maneuverable combat system
[14] Most commercial-grade electronics are not designed to operate in the high temperature confined spaces of a combat vehicle without access to cooling.
[15] In weight terms, under 20-tons for C-130, in the 30-40 ton range for two vehicles per C-17 (depending on required aircraft range), with over 40-tons limiting to one per C-17.
[16] Note that there are more detailed and precise definitions of cost with more categories; for example, total system life cycle cost includes the cost of the personnel who operate and maintain the system, training aids and support systems, training and wartime ammunition, and so on. As this discussion is focused on vehicle design, it will not explore those other cost factors.
[17] Note: though it is not within the scope of this design discussion, budgetary and decision stability are as important to successful vehicle design as system requirements stability.
[18] VICTORY stands for the U.S. Army's Vehicular Integration for C4ISR/EW Interoperability (VICTORY) initiative. The initiative is to develop standards for interoperability between line replaceable units on combat vehicles.
[19] Harold A. Littledale. *With the Tanks*, pg 81-88.
[20] Ronan Doare. In Robots on the Battlefield. pg. 73-88.
[21] AOC, appendix C-2.
[22] Ibid.
[23] Ibid.

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