The Army Science Board

Fiscal Year 2020 Study

An Independent Assessment of the 2040 Battlefield and its Implications for the 5th Generation Combat Vehicle (5GCV)

Final Report: Executive Summary

August 2023

Department of the Army
Office of the Assistant Secretary of the Army
(Acquisitions, Logistics and Technology)
Washington, DC 20310-0103

The Army Science Board (ASB), organized under the Federal Advisory Committee Act (FACA) in 1977, provides the Army with independent advice and recommendations on matters relating to the Army's scientific, technological, manufacturing, acquisition, logistics and business management functions, as well as other matters the Secretary of the Army deems important to the Department of the Army.

The ASB's members and consultants are eminent authorities in the disciplines of science, technology, engineering, math, social science, business, and governance. The Board also draws upon the expertise of senior retired military officers from all branches of service. All are dedicated experts who volunteer their time to provide independent assessments to Army senior civilian and military leadership.

The following report is a product of the ASB. The statements, opinions, conclusions, and observations contained in this report are those of the ASB study members and do not necessarily reflect the official position of the United States Army or the Department of Defense.

This document is available in electronic format from the Defense Technical Information Center (DTIC) at http://www.dtic.mil.

TABLE OF CONTENTS

Introduction

Secretaries of the Army Mark Esper and Ryan McCarthy tasked the Army Science Board (ASB) on 4 January 2019 and 6 January 2020, respectively, to study armor/anti-armor warfare circa 2040. Secretary Christine Wormuth reaffirmed the need for such an independent assessment of future armor/anti-armor warfare when the ASB was reestablished on 14 August 2021. Army Futures Command (AFC) sponsored the study. Generals John M. Murray and James E. Rainey, the commanders of AFC during the conduct of the study, directed the effort.

Today's Army finds itself in a geostrategic and military situation similar to the 1970s with telling similarities and important differences from the Cold War era. Then, the Army transitioned from Vietnam and counterinsurgency warfare to confront a modernized Soviet army on a potential Central European battlefield as the third industrial age took hold, driven by the initial applications of the microprocessor. Today's transition is from counterterrorism and counterinsurgency centered in the Middle East to the potential for large scale combat operations against two major adversaries as the fourth industrial age accelerates, driven by networks, autonomy, and artificial intelligence. These adversaries, a comprehensively modernizing Chinese People's Liberation Army (PLA) currently centered on the western Pacific and eastern Asia and Russia's selectively modernized ground force focused on Europe, create complexities that in important ways exceed those faced in the Cold War. Comprehensive modernization programs, the Big Five then and the Big Six today, serve as the vanguard of a necessarily changing Army.

Based on the 1970-80 transition, the ASB examined the acquisition approaches that the Army successfully employed to develop the Cold War Big Five and the Multiple Launch Rocket System. Developing new armor capabilities employing those approaches, conflict insights, concepts, technology testbeds, and competitive prototyping that were central to the M1 development but updated by modern processes would allow a successful balance between development risk, affordability, and improved operational capability. These approaches were critical to the M1 remaining the dominant main battle tank (MBT) capability over the two generations since its fielding in the 1980s.

In addition to a successful acquisition model, in the 1970s the Army employed "Lessons Learned" from two Middle East wars, in particular the 1973 Arab-Israeli War, to inform the development of both Active Defense and AirLand Battle doctrines and necessary supporting material developments. Today the Army is analyzing "Lessons Learned" from conflicts in Syria, Yemen, Nagorno-Karabakh, and Ukraine, and the ASB has also employed this approach.

Without making such an armor technology modernization investment now, estimated in this study at $3-4 billion, the Army puts at risk mission success in close combat on the 2040 battlefield. Regardless of the theater of operations, the lack of an overmatching MBT capability jeopardizes Army mission success. The costs for this program were compared with those experiences during the 1970-80 period and found to be similar in inflation adjusted dollars.

To maintain land warfare overmatch, the Army should immediately initiate a testbed and development program with the creation of requirements for the 5GCV and the creation of an ATGM CFT. The US ability to deter war and win on future land battlefields is at serious risk without development of the 5GCV. The M1 Abrams tank, fielded in 1980, was superbly developed and provided unprecedented capabilities, but will not have the dominant deployability or mobility, lethality, or protection necessary for success on the 2040 battlefield. The M1 Abrams development program, with state of the art analytics, provides an appropriate model for the development of the 5GCV with dominant lethality, protection, mobility, and deployability essential for the 2040 battlefield. And lastly, the Army must partner with industry, other USG agencies, and Allies and partners to acquire the best 2040 technologies for a dominant 5GCV.

Framing Assumptions

The following assumptions were foundational to the performance of the study.

1. Armored combined arms forces remain decisive to land combat, are central to conventional force deterrence and, if deterrence fails, victory.
2. Fielding of the 5GCV requires an understanding and balancing of competing demands, technological, financial, operational, and industrial among many.
3. A US geostrategic reset is underway, transitioning from Middle Eastern counterterrorist and counterinsurgency to great power competition from China and Russia.
4. The Army armored force is required to meet US national security objectives and establishing conflict deterrence even in the face of strategic mobility issues, particularly in the US Indo-Pacific Command (USINDOPACOM) area of responsibility (AOR). However, in response to its Terms of Reference (TOR), the study will address only the deployability and supportability of the MBT.

The 2040 Battlefield

Based on our findings, The M1 Abrams will not dominate the 2040 battlefield. All of the M1's advantages in mobility, firepower and protection are at risk. The M1A2 SEP V3&4 upgrades will improve effectiveness but will not restore dominance. Near transparency in all domains will significantly increase the lethality our forces will experience. China and Russia have studied our forces and doctrine and are fielding countermeasures. We will continue to have to fight outnumbered, exacerbated by a low MBT operational readiness rate and an aging fleet.

Insights from Recent Conflicts and Critical Theaters

Recent Conflict Insights

Figure 1 Merkava mounted Trophy APS defeats Kornet ATGM

Conflict in South Lebanon in 2006 exposed shortcomings that drove changes in the Israeli Defense Force, particularly armored vehicle protection. The Israelis restored survivability overmatch with active protection (APS) against shaped charge ATGMs to retain the ability to close with and destroy the enemy through maneuver and fire with protection. In Operation Protective Edge, the IDF did not lose a single tank to ATGM fire, including in very close terrain.

Figure 2 Aftermath of Zelenopillya Rocket Attack (2014)
Kyiv Post

While the Nagorno-Karabakh and Ukraine wars demonstrated the importance of armored operations, particularly the need for combined arms operations, they also exposed vulnerabilities from ATGMs, armed unmanned aerial vehicles (UAV) and loitering submunitions, antitank mines, and the dangers of increasing battlefield transparency. These conflicts also reinforce the imperative of maneuver enabled by armored combined arms operations to overcome this more transparent and lethal battlefield with massed fires driving unprotected forces back into trenches.

Figure 3 Ukrainian Javelin Strike on a Russian T90 (June 2022)
UAF UAV video footage

The speed and scale of resource consumption and equipment loss far exceed recent experience. This conflict's duration and intensity reinforces the importance of industrial base production capacity, system sustainability, and logistics to maintaining tempo and movement.

Figure 4 Russian tank on tank friendly fire incident (April 2022)
UAF UAV video

In addition to the operational and tactical insights above, strategic considerations emerging from this conflict center on the issue of scale, including the scale of the battlespace, operations, lethality, complexity, contested domains, destruction, casualties, logistics consumption, and reconstitution requirements.

Russia and US European Command (USEUCOM) Insights

During the Cold War and since its end, Russia has been the pacing armor/anti-armor threat. And recent conflicts predominantly feature Russian weapons. Yet, Russia's ability to rebuild militarily after Ukraine remains in question. This adds ambiguity to defining the duration of continued M1 dominance and future requirements. However, this ambiguity creates opportunities to focus development to ensure overmatch, render costly Russian investments ineffective, and create new dimensions of combat to further US battlefield dominance.

China and USINDOPACOM Insights

Since World War II, armor operations have been common in the Indo-Pacific region. Beyond current Western Pacific flashpoints, developments like the Belt and Road Initiative (BRI) and the PLA's mission to protect China's expanding developmental interests suggest that China's future armor capabilities will be shaped to support operations across the Indo-Pacific and beyond, adding complexity to US armor/anti-armor development.

Figure 5 Chinese Type 99A MBT

As part of this modernization effort and in support of China's grand strategy, the People's Liberation Army Army (PLAA) has fielded significant armor/anti-armor capabilities. Its most modern Type-99 main battle tank is reflective of Chinese association with Russia and Chinese innovation. Modernization continues, with approximately half its 5000-tank inventory now Type-99. While not yet an M1 equivalent, its development demonstrates China's intent to field large quantities of modern armor. It is doubtful that the Chinese will depart from Russian design approaches until it gets visibility into US developments beyond the M1. But China will build the research and technology base to support such a development. This base includes significant armor and gun research and development (R&D), continually upgraded systems, and production of new systems while fielding current systems.

Similarly, the Chinese are developing and fielding significant ATGMs. The Chinese military has emphasized technology necessary for ATGM development and continuing fielding of advanced ATGMs is anticipated.

A full understanding of Chinese armor/anti-armor missions and developments remains ambiguous. To improve understanding, this study reviewed armor operations in the Indo-Pacific through several lenses.

The study team conducted a tabletop wargame using a near term Taiwan scenario supported by the Center for Army Analysis. This wargame demonstrated armor's value in Taiwan's defense but struggles with deployment and sustainment precluded US armor's arrival in sufficient numbers before China achieved a fait accompli. A review of classified wargame reports and other analysis suggested similar challenges with deployment and sustainment.

Figure 6 Third Party Intervention
SCMP Map, ASB graphic

Related to the South China sea, the study examined the implications of "third-party intervention" by China in Korea. Northern Theater Command, with the capability and capacity to act without outside support, intervention would prevent unification of the peninsula following regime collapse or escalate horizontally, splitting US forces between Korea and Taiwan. Both scenarios involved potential US and Chinese armor engagements, highlighting the challenges of fighting outnumbered against a fully modernized armor/anti-armor force able to generate combat power at speed, scale, and reach. Horizontal escalation in Korea with Taiwan risks US Army forces operating without the degree of air, maritime, space, and cyber support assumed to be part of any US operation.

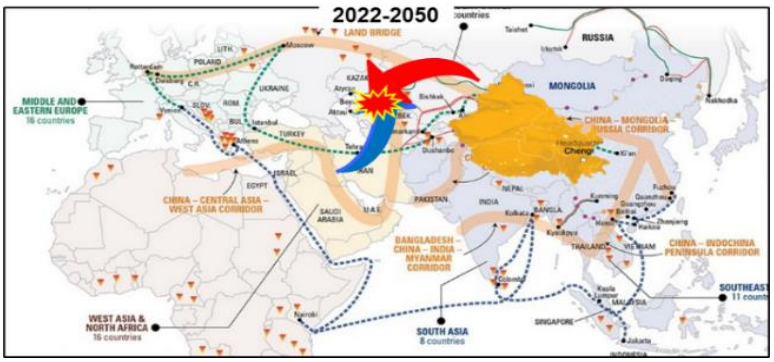


Figure 7 The Belt and Road Initiative and Potential Conflicts.
Heritage Institute map and study graphics

The study also explored the challenge of future conflict along the BRI. With BRI investment exceeding $1 trillion, China seeks to secure key supply chains (energy, minerals, food, trade) and economic advantage in Central Asia and Africa, potentially shifting important levels of trade and Chinese supply chains inland. Significant energy supplies already flow through Central Asia to China. In 2017, Xi Jinping charged his military to "'resolutely safeguard' development interests" which extend along the BRI. As China moves to

protect these investments, conflict along the BRI in Eurasia has the potential for military land operations against a peer land force with the US depending on deployments over significant lines of communication far more challenging than those in Europe or the Western Pacific.

These indications suggest that while China has prioritized air, naval, and rocket force development in support of its first centennial objective, including ending poverty, economic growth, regional hegemony, and assimilation of Taiwan, the Chinese recognize that armored maneuver continues to matter. Moreover, the scope and scale of its military R&D investments suggests China will likely overtake Russia as this century's armor/anti-armor pacing threat.

Character of the 2040 Battlefield

Similarities to Today's Battlefield

While the Indo-Pacific region today is dominated by threats on sea and in the air, a fundamental of warfare among major powers is that dominance on land is essential to determine the outcome of conflict among major combatants. Preparation for eventual land combat is fundamental to defense in the Pacific theater, particularly as China's interests expand beyond the Western Pacific.

What is not likely to change in the foreseeable future are the Army's statutory requirements (Title 10 US Code) to conduct "…prompt and sustained combat incident to operations on land" and assigned responsibilities from Department of Defense Directive 5100.01, that the Army "…organize, train, equip, and provide forces with expeditionary and campaign qualities" in order to…"conduct operations in all environments and types of terrain, including complex urban environments, to defeat enemy ground forces, and seize, occupy, and defend land areas". These tasks have been consistent for several decades and will continue to be critical to the Army's success as part of the Joint Force. Indeed, the Secretary of the Army recently noted that providing "counter-attack forces" was one of five "incredibly important" tasks for the Army in the Indo-Pacific.

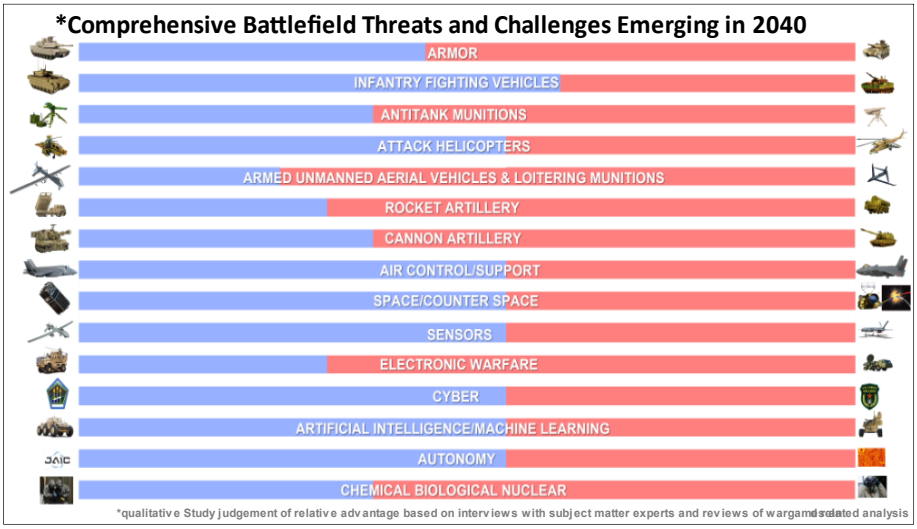


Figure 8 Comprehensive Battlefield Threats in 2040
ASB graphic

Changes Anticipated in the 2040 Battlefield

Insights from recent conflicts, analysis of the PLAA and Chinese R&D, and longer-term technology trends all point to a battlefield that is expanding across multiple dimensions, modes, and domains of warfare and geography and actors, and increasing in complexity. Changes to the character of war in 2040 will involve all domains and warfighting functions, spanning swaths of geography not seen since WWII. While battles will still be fought over localized objectives, battles, campaigns, and conflicts will routinely involve global inputs and consequences. Notably, the battlefield is not expanding in time. The speed of information, events, and weapons systems are accelerating, compressing decision cycles and reaction times. This places a premium on leader and unit agility in executing at the speed of decision – effectively anticipating and acting ahead of the adversary.

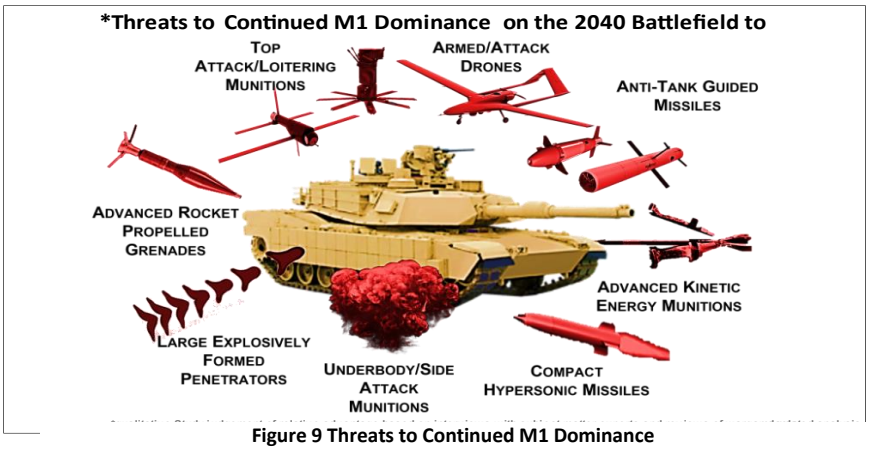


Figure 9 Threats to Continued M1 Dominance
ASB graphic

Tactically, adversaries are increasingly able to routinely integrate land-based combined arms capabilities with effects from air, sea, space, cyber, and electromagnetic spectrum operations. Space targeting, increasingly prolific land and air breathing sensors, and network operations will make long-range fires more prevalent and increasingly more lethal, challenging formations over the breadth and depth of the battlefield. Increasingly autonomous air vehicles including loitering munitions increase lethality at speed to attack the least resilient aspects of battlefield systems and platforms.

The 2040 battlefield will likely see significant increases in the use of robotics for combat, ISR, and logistics functions; AI-aided capabilities to include target location and identification and platform movement; cyber-attacks on command-and-control facilities; longer-range indirect fire systems (both artillery and rockets/missiles) with increasingly capable precision munitions that can defeat anything they can acquire. However, every nation with the capability to develop and employ these capabilities is also working on counters to them. The future battlefield will place a premium on camouflage, cover, concealment, deception, and denial (C3D2) using new technologies that can defeat, disrupt, confuse, and/or spoof enemy sensors and cyber capabilities that can interrupt, confuse, deceive, and even take over enemy command and control systems to desynchronize enemy capabilities.

The development of totally robotic (unmanned) vehicles is being advanced in the belief that such vehicles will be able to do much of what the manned MBT now does. We judge such capability is unlikely to materialize by the 2040s. The recommended 5GCV technology testbeds

will provide necessary knowledge including field data applicable to a robotic vehicle, and these demonstrators should be considered as being part of maturing both manned and unmanned vehicles.

While there are many consistencies between Europe and the Indo-Pacific, logistics and support, difficult in both theaters, are exacerbated by the Indo-Pacific's longer distances and less developed infrastructure, including ports and airfields. Further, long-range fires ability to target logistics infrastructure will make forward support a critical factor and more difficult in the Indo-Pacific theater than in Europe. Emerging analysis of the Indo-Pacific exposes challenges to the ABCT, with arrival extending over longer periods, requiring exploration of force designs, platform capabilities and strategic lift capabilities to mitigate these challenges.

The above challenges do not mean vehicles must be tailored for individual theaters. However, the requirement for an 5GCV common to both theaters will require accounting for Indo-Pacific unique logistics requirements. Decisions on 5GCVs should aim to make the entire 5GCV unit more strategically deployable and sustainable. The 5GCV should be a vanguard for a new, more agile formation, reversing current trends towards the ABCT getting much heavier with AMPV (~40 tons) replacing the M113 (~12 tons) and the XM30 (~40-55 tons) replacing Bradley (~27 tons). All study weight projections of the 5GCV are lighter than M1 series. Other follow-on platforms must follow suit. Additionally, force designs, platform capabilities and strategic lift capabilities must address the ability to responsively deliver a credible force package to both areas of interest. The current strategic lift assets are aging out and require significant reception infrastructure analysis demonstrates will not be accessible in future operations.

Assessment of the M1 on the 2040 Battlefield

Given threat assessments and difficulty of integrating emerging technologies, the M1 is reaching the end of life. Over the time of the study, briefings by the technology community universally held that much of the M1's technology is reaching obsolescence. It is expected that some new and maturing technology can and should be applied to the M1 series. However, it is doubtful that the full benefit of this technology can be gained by retrofitting a 1980s MBT any more than it can be expected that new technology will maximally improve a 1980s commercial vehicle. For example, robotics and automation promise to reduce crew size by at least one person. Crew reduction can improve survivability and yield significant weight reductions in a 5GCV. However these advantages are unlikely to be realized by modifying the M1.

M1 survivability is also in question. Contemporary conflict exposes vulnerabilities and adversary R&D and adversary energetics, ATGM, and main gun R&D investments are robust, exacerbating battlefield risk over time. In particular, the M1 is vulnerable to top attack. Many current and future ATGMs, armed UAVs, loitering munitions, top attack submunitions and long-range fires from both Russia and China have this capability. Modern top attack ATGMs can defeat reactive armor. Chemical energy warhead lethality is outstripping passive and active armor protection.

Modern adversary tank main guns are larger than the M1's 120mm main gun and may be able to penetrate the M1's passive armor. The M1's main gun, the smallest fielded by potential

adversaries, is losing effectiveness against adversary armor. The Russian T-90 and the Chinese T-99 both have 125mm main guns. The German and French are exploring 130mm and 140mm main guns respectively for tanks. As the M1X prototype demonstrates, a 130mm gun severely reduces the onboard magazine, from 40 to 19 rounds, and, without significant improvements in probability of kill (Pk), drops unacceptably stowed kills, from 36 to 17 (with a .90 Pk), reducing sustained lethality and doubling munitions resupply requirements. However, as the Nagorno-Karabakh and the Ukraine conflicts demonstrate, current and emerging lethal systems, while challenging current tank survivability, do not replace maneuver, fire, and shock effect on battlefield.

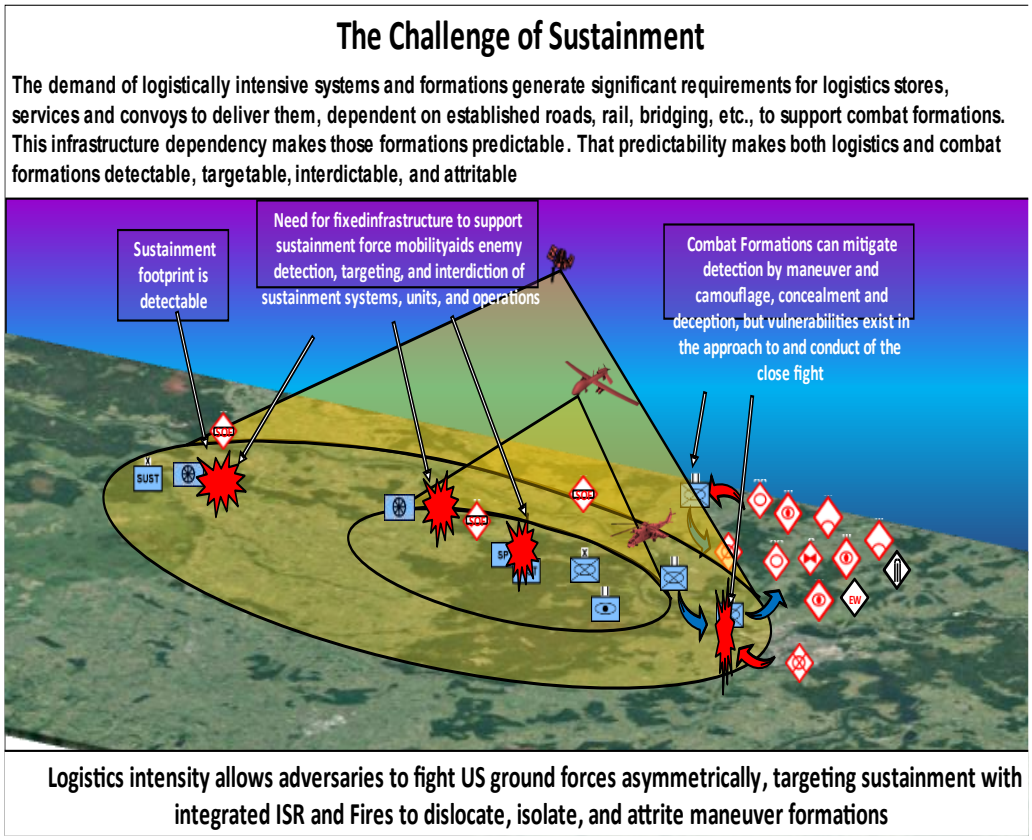


Figure 10. Sustainment Challenges on a Transparent Battlefield
ASB graphic

At 70 to 80 tons in its various models, the M1 has serious strategic, operational, and tactical mobility and sustainment issues. The M1 constrains air, sea, and land transport options and ports of debarkation in key regions. Weight limits the use of many rail cars as well as which bridges and roadbeds can be used. Weight also impacts fuel consumption, power to weight ratios, and increases maintenance demand. Moreover, logistically intensive units, such as the current ABCT, demands multiple refueling and rearming operations, as many as three per day. On an increasingly transparent battlefield, this logistics intensity can create vulnerabilities to the formations employing the M1, as the units that deliver sustainment dependence on fixed infrastructure creates predictability than can be interdicted. The enemy can limit armored operations by fighting the less survivable sustainment system, rather than directly engaging the armored formation.

Our longest serving MBT, the M1's economically useful service life has been extended through multiple rebuilds and refits with no long-term improvements in reliability, availability, maintainability, or operational fleet readiness. In addition to new combat capabilities, a new

platform presents the opportunity to improve size, weight, power, and sustainability resulting in lower total cost of ownership vs continued M1 sustainment and greater assured operational availability. Underlying assumptions that drive reliability, availability and maintainability should be relooked in light of test data, improving system and component reliability, the greater role of software to reduce unnecessary time and costs.

While the M1 is losing its long-standing dominance, the battlefield imperative for mobile, protected, firepower systems that can close with and destroy the enemy through maneuver, fire and shock effect remains indispensable in land combat. That effect is not replaced by high volumes of long-range fires and armed UAVs, and while robotics can enable armored combat, the ASB judges that robotics cannot realistically replace armored forces by 2040. A 5GCV that eliminates contemporary and emerging vulnerabilities and increases its lethality is essential to the Army's ability to conduct "sustained combat incident to operations on land." Such a capability also furthers the Army's contribution to deterrence, as General Starry noted, by reducing "to a minimum whatever incentives enemy leaders might perceive as favoring seeking military solutions to political problems ... A clear war-fighting capability is necessary to effectively reduce [enemy] incentives—as they view them."

Developing an M1 replacement, given the immaturity of overmatching technology and lingering issues of ambiguity will require more than a decade. Therefore, the M1 like its predecessor the M60, will be in the force for decades into the future and must be selectively modernized, even as its utility wanes. To reduce out year risk and deliver a 5GCV as dominant as the M1 was for generations, the ASB recommends the Army begin 5GCV research and development immediately.

The Recommended Program to Develop Next Generation Armor

The Opportunity

"It must be the role of technology to provide weapons systems which render ineffective costly investment by our foes – not simply to try to match something the other fellow has just fielded. With new weapons we should seek new dimensions of combat."

GEN Donn Starry
September 1981

The ASB was charged by several Secretaries of the Army, listed in the introduction, to look at the armor/anti-armor competition in the 2040 timeframe. The above discussion of this charge established several central points which derive from the framing assumptions. Based on the ASB look at the geopolitical, military, and technological uncertainties in the early 2020s, a definition of the requirements for armor/anti-armor capability for 2040 and beyond is premature. The ASB therefore is advancing in this study a technology maturation program based on experimental testbeds that will provide operationally and technologically mature options available for 2040 to hedge against the uncertainty this study encountered regarding the 2040 battlefield. Such a program will sufficiently mature technology beyond what the Army Laboratories, Department of Energy Laboratories, and DARPA will accomplish which will allow

acquisition programs to begin fielding in the 2040s. Our investigation has established that the laboratory relevant programs are generally at Technology Readiness Level (TRL) 4 or below, whereas previous ASB studies have shown that a minimum of TRL 7, the goal of the recommended program, is required to initiate a successful Engineering and Manufacturing Development (EMD) acquisition program. This hedging strategy provides the basis for a range of manned and unmanned systems that can be leveraged to maximize Army overmatch as suggested by GEN Starry when the series of strategic, operational, and tactical threats become increasingly clear. The study recommends that operational concepts for MDO drive the enabling technology programs similar to what was done with AirLand Battle and the Big Five.

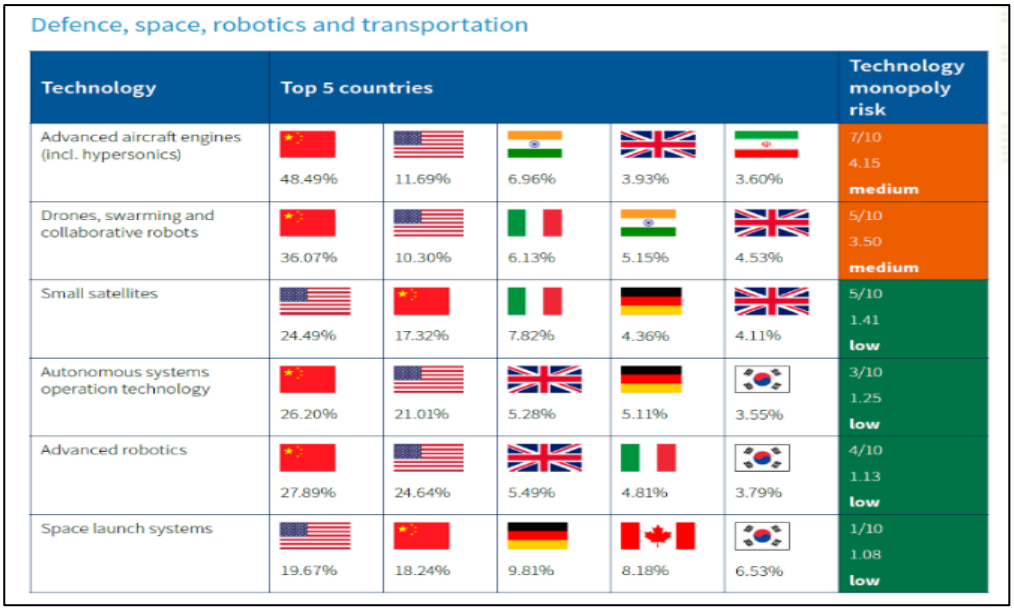


Figure 11 Military Technology Competition

Australian Strategic Policy Institute graphic

A key consideration for the technology program recommended here is the state of adversary science and technology. While the National Intelligence Council's Science and Technology Intelligence Committee and Weapons System Intelligence Committee estimates are at higher classifications, a graphic from a recent Australian Strategic Policy Institute (ASPI) technology report, Figure 11, is representative of the added challenge facing a new start program in this era. China is increasingly a technological peer, and US technological and attendant overmatch superiority is no longer assured. This is particularly the case in key areas related to Chinese investments in armor, tank gun technology and design, unmanned systems, armor defeating shape charges, and energetics. It will be important to track these developments to stay ahead of them and to acquire and exploit Chinese weapons systems as soon as feasible.

The testbed program recommended here advances several systems level issues that must be explored before a 5GCV acquisition program can be undertaken. The first is that of protection of a combat vehicle when facing the threats shown in Figure 9. This problem is compounded by the necessity of reducing total vehicle weight. Approximately 50% of the weight of the M1 is armor. Future approaches which would increase protection and reduce weight would require approaches that rely less on passive armor and more on active protection. Further, advanced munitions such as hypersonic missiles are so energetic that they cannot be countered by

passive armor further requiring a look at active protective systems. The requirement to look at total protective systems, including active, and passive armor and reduced size vehicles made possible by automation and reduced crew size should be explored. The human factors investigation of such a reduced crew vehicle must be undertaken to assess effectiveness and insure confidence.

A second systems level issue which must be explored is that of lethality. An investigation of energetics applied to current main guns should be explores as well as experimentation of new larger diameter guns being developed by our allies. As one example, US energetics research, critical to tank gun and munitions lethality and size, is baselined against the energetic material Octogen invented in 1941. Chinese research is baselined against the significantly more energetic Hexanitrohexaazaisowurtzitane or CL20 (China Lake Compound #20) invented in 1987 at the US Navy's China Lake Naval Air Weapons Station. Notably, CL20, which provides about 40% more lethality and range, is not widely used in US munitions, but is by both China and Russia. The R&D and product improvement approaches of the last 30 years are insufficient in this current threat and technology environment.

Also, as part of a lethality program, new approaches to ATGMs must be explored. The Army explored several hypersonic missiles, the LOSAT and CKEM missiles which demonstrated the potential of kinetic energy missiles on the armor battlefield. The lethality of these missiles is an order of magnitude than that of a tank main gun. Ukraine illuminates the need to continue to advance the capability of ATGMs.

Possible Concepts to Explore Required Capabilities

The approach employed to construct this hedging strategy is to establish several possible concepts that provide capability believed important to land warfare in the post 2040 timeframe. These concepts, Figure 12, are not advocated as point solutions but rather are conceived as requiring capabilities that the research program should underwrite. As the operational requirements become progressively clearer, the appropriate 2040 vehicles can be defined employing analysis and technology assessments created as part of this research program. The characteristics of the M1A2 SEP VX are provided for comparison.

Vehicle Concept	M1 A2 SEP VX 70+ Tons	5GCV 55-60 Tons	Light Tank 35-40 Tons	Robotic Wingman 20-30 Tons
Firepower	120mm Insufficient	130mm Overmatch	130mm or 120mm with Energetics Overmatch	Hypervelocity Missile Other ATGM Overmatch
Mobility	Strategic: Poor Operational: Poor Tactical: Marginal	Strategic: Poor Operational: Good Tactical: Good	Strategic: Marginal Operational: Good Tactical: Good	Strategic: Good Operational: Good Tactical: Good
Protection	Inadequate	Good	Marginal: Depends on Active Protection	Marginal
C2	Marginal	Good	Good	Good
Crew	4	3	3-2	1-0
Propulsion	Turbine	Hybrid Electric	Hybrid Electric	Hybrid Electric
Engagement Range	2-3 KM	3-5 KM	3-5 KM	Approximately 50 KM
Enabling Technologies	None	Automation New Cannon Autoloader	Active Protection Energetics Signature Management	Robotics Hypervelocity Missiles Off-Board Targeting

Figure 12. Concepts for 2040 Enabled by the Proposed Technologies and Testbeds

5th Generation Combat Vehicle (5GCV)

The baseline vehicle of Figure 12 is the lowest risk concept explored. It is a worthy successor to the M1 and is one of the lead concepts explored in the virtual prototyping conducted by the NGCV CFT and the Ground Vehicle Systems Center. This vehicle was explored in the first phase of this study and was found in this current phase to be significantly more capable than the M1 on the 2040 battlefield. It would have improved lethality and protection however it would be vulnerable to kinetic energy weapons such as CKEM. Further, this vehicle when first fielded is projected to be as heavy as the M1 when it was first fielded and as it matures it would it unable to assist with alleviating the strategic deployment and operational and tactical mobility issue.

Light Tank

Discussions with Army leadership and retired General Officers who exercised joint responsibility in Europe and the Indo-Pacific indicate the necessity of a relook at the weight of the MBT. All agree that the M1 at 70 tons or greater is not tactically, operationally, or strategically mobile. It is therefore important to explore the feasibility of significant weight reduction in a next generation MBT without compromising its protection specifically and operational capability generally. Further, this program should explore technology which is relevant to reducing the weight of all tactical vehicles in the ABCT. The goal for this program is to explore the potential to at least halve the weight of the MBT without compromising operational capabilities outlined above. While there are many technologies that could contribute to this objective, three will be explicitly listed here. First an exploration of the potential of active protection against both kinetic energy penetrators and shaped charge weapons must be undertaken to provide a basis for tradeoff between active and passive protection. Second, robotics to provide reduction in the number of crew members must be explored. The number of crewmembers is a major determinant of the armored volume and as a result, armor weight. And finally, can energetics chemistry allow use of lethal smaller main guns and failing such progress, is there a possibility for a missile firing MBT? While such lethality investigations will certainly yield progress, experimental data is required to assess whether these approaches provide sufficient weight reduction to justify any operational compromise.

Such lightweight options could require revisions to the current Europe based O&O concept to accommodate Pacific operations.

Robotic Wingman

The investigation of the 2040 battlefield also indicated that this battlefield would present to the 5GCV based armor/anti-armor formation new opportunities and challenges. The robotic wingman concept allows exploration of MDO enabled long-range fires extending the armor battlefield and allowing attrition of enemy armor before approaching friendly positions. These smaller, lighter, reduced-crew options would allow different deployment and new operational approaches to armor/anti-armor warfare and to urban warfare. Long-range fires, manned-unmanned teaming, robotics, and masking (or land stealth) are capabilities that must be explored as compliments to friendly armor formations or counters to these or similar capabilities employed by an enemy. The robotic wingman is not advanced as a replacement for an MBT or a competitor to it. Rather the wingman is a concept which employs advancing technology which when employing MDO capabilities would complement the MBT by extending the battlespace. When the M1 was conceived, geographic intervisibility and technology limited the battlespace to approximately five kilometers forward of the leading elements. MDO and advanced missile technology might extend this range to tens of kilometers to engage and attrite an enemy before it can close, possibly uncontested, to lethal distances from friendly manned formations. Land stealth might counter space or battlefield-based surveillance and targeting capabilities necessary to employ long-range engagement. Finally, the threat discussion indicated that potential adversaries are exploring and in several instances fielding main battle tanks with the ability to fire missiles in addition to conventional tank ammunition. The US has

not explored missiles developed to be employed by armor vehicles since the 1960s and the Shillelagh. Missile technology has significantly advanced since that time and the wingman concept allows an exploration of new and advancing longer-range ATGMs.

Important to this concept is the ability to explore manned-unmanned teaming approaches. We do not believe that robotics concepts will be sufficiently mature for fielding in the 2040s. Should robotics approaches mature more quickly than anticipated, the wingman concept allows exploitation of this important technology.

These concepts are being advanced to create objectives for a technology testbed-based research program which is discussed below.

The Recommended Program

Figure 13 outlines a total program to develop a 5GCV based on the M1 template. The prototyping and EMD programs are proceeded by a technology testbed program shown in Figure 14. This program recommends undertaking a technology testbed program similar to that undertaken in the development of the M1. Such a technology testbed program would require approximately eight years to complete. After completing this technology testbed program, prototyping and EMD based on the M1 template would take ten years to complete the total development program. Such a total program would result in a new MBT first unit equipped in the early 2040s. The study team reviewed the cost of the M1 technology testbed activity and determined that the $3-4 billion cost for the recommended program for the 5GCV program is consistent with the cost, in inflated dollars, of the similar program for the M1.

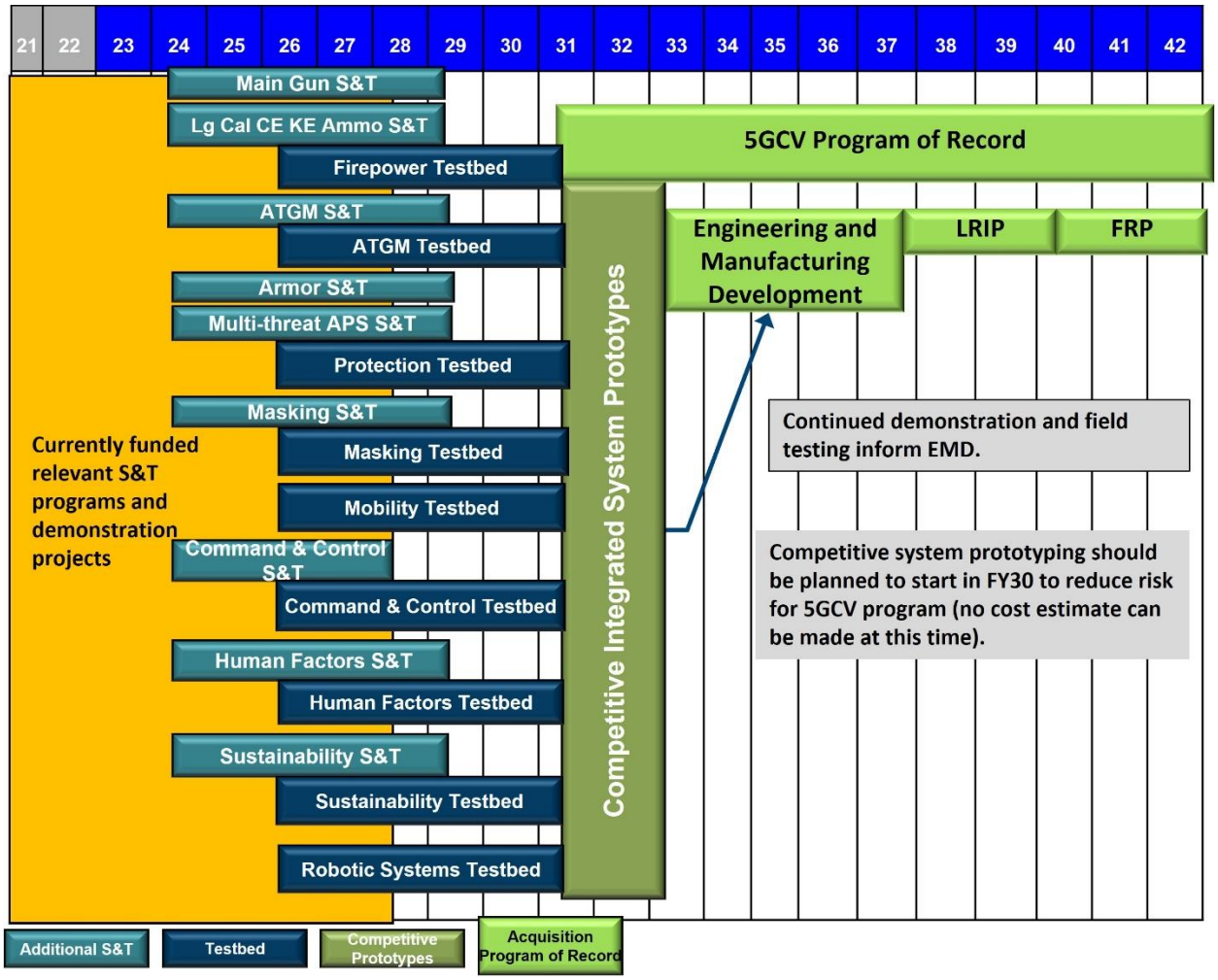


Figure13 Recommended 5GCV Acquisition Program

Technology Development

The study team assessed approximately 60 relevant technologies, and as with the M1 program, recommended nine testbeds, shown in Figure 14, to assure both mature technology (TRL 7 and beyond) and understanding the capabilities that these technologies make available to the Army to meet operational requirements. Such a program is necessary to provide an analytical basis for the new technologies proposed for this vehicle. The technology testbeds, their schedules, and the estimated cost is shown in Figure 14.

The 60 technologies contribute to critical future capabilities. Discussions with requirements and R&D organizations identified several critical technology related capability chokepoints in addition to those discussed above for weight reduction and lethality: 1) Aided Target Recognition (AiTR) to reduce crew load, improve mission performance and realize MUMT; 2) Artificial Intelligence (AI) to increase efficiency, speed mission execution, and enable control of autonomous vehicles; 3) the network to ensure envisioned and required network capabilities and provide improved mission execution and lethality without crushing realistically available

bandwidth; 4) Reliability, Availability and Maintainability (RAM) to increase assured operational availability and reduce sustainment demand and manpower requirements; 5) Camouflage, cover, concealment, denial, and deception (C3D2) to reduce the probability of detection, targeting, and engagement and improve survivability on a transparent battlefield; 6) Light weight, ballistically resilient armor to improve survivability and reducing system weight to improve tactical and operational mobility and strategic deployability, and reduce sustainment requirements; 7) Energetics to improve lethality (range and Pk) at 120mm or smaller caliber; 8) Power and energy solutions, engine and battery technologies, to improve mobility (speed, horsepower per ton) and reduce sustainment requirements.

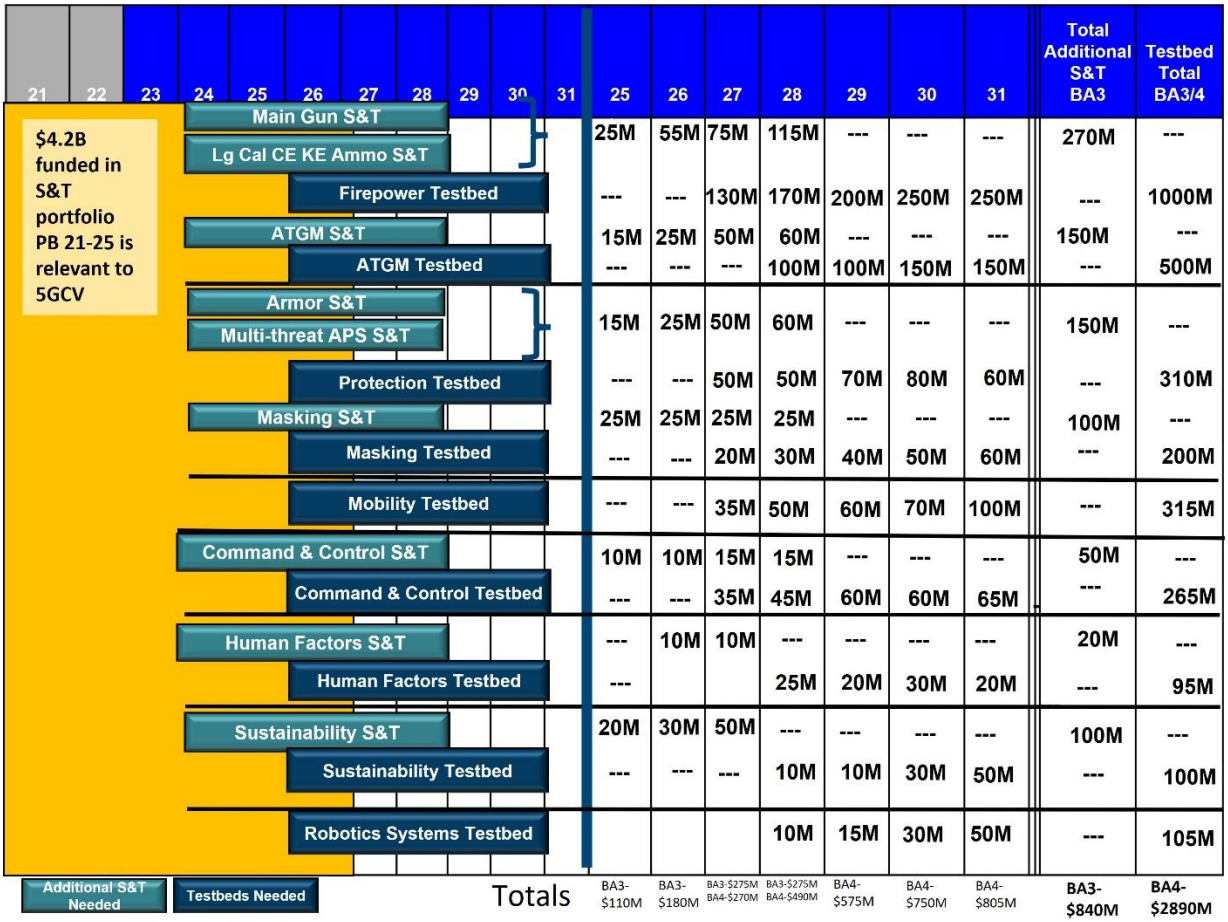


Figure 14 Recommended 5GCV Testbed Program

The recommended testbed program for the 5GCV program is similar to the program for the M1. However, unlike the M1 program, no analytical framework exists today to design and evaluate a concept 5GCV. Such a framework is necessary to provide an analytical basis for modern digital engineering and operational evaluation of the various concepts for the 5GCV.The field test data obtained from the testbeds would allow verification and validation of the systems analytical tools necessary to design and evaluate a new MBT. Further these analytical tools will be useful for assessing any new systems developments employing this technology. However, such an

analytical framework will result from the testbed program only if the requirements for analysis are planned for and funded.

To support a modern analytic framework, the acquisition and exploitation of Chinese and Russian weapons systems would provide threat data which can be integrated into models and simulations and which can be used to produce representative test samples for actual testing.

Findings Summary

Intelligence Assessment
The current assessment of the Intelligence Community concerning lessons learned in Ukraine and the Indo-Pacific and China is summarized below.

The insights from current and recent conflicts and intelligence assessments of the 2040 battlefield indicate the importance of a properly led trained and equipped armor combined arms team. Deterrence, and if deterrence fails, victory require such a capability.

The threat spectrum against the MBT has significantly increased. Ukraine demonstrates that long-range fires and ATGMs are an important threat to the MBT. In Ukraine, these fires and losses to mines exceed tank-on-tank losses.

The challenge of delivering a credible force to important theaters in a timely manner must be addressed in parallel with a new MBT development to assure that the Army armored force can get to the fight. The Indo-Pacific is a more difficult theater to deploy and support than Europe**.** Further fewer predeployment opportunities and fewer ports to support sealift of an armored force are available in the Indo-Pacific than in Europe. The Indo-Pacific theater has the potential to fundamentally change the requirements for combat vehicles.

A significantly reduced weight MBT by itself does not assure ABCT deployability. Other elements of the ABCT are also increasing in weight. Our current ABCT with AMPV and MX30 only make this problem worse. However, reducing the weight of the MBT is a significant first step as the technology employed to reduce the weight of the MBT will also apply to other combat vehicles. The Department of Energy and DARPA assisted with the development of protection means during the development of the M1 and can assist with a new combat vehicle. The Army should be open to developments of other technical agencies in the government. Addressing the weight issue of the entire ABCT was beyond the purview of this study. However, such a study should be undertaken.

Assessments of adversary developments indicates that lethality will be a problem unless development of new cannon technology is undertaken. Our Allies have begun such a program and should be considered for any new development.

The US is losing its lead in ATGM development to China. Hypervelocity ATGM development can restore this lead. Department of Energy has helped the Army in hypervelocity missile development for long range fires. DARPA and DOE helped with ATGM development.

Testbeds and experimentation addressing these problems is not now being undertaken. Testbeds were employed extensively to test advanced capabilities during the development of the M1.

The 2040 Battlefield and Its Implications to the Next Generation MBT

When compared to today's conflicts, the assessment of the 2040 battlefield indicates important similarities and differences. The mission of the combined arms formation is fundamental to deterrence and victory and will remain the same in the 2040's. Battlefield transparency and lethality will increase requiring significantly better protection and new and innovative solutions to the lethality capability of a new vehicle. Such a vehicle must be capable of operating on the world-wide Multidomain Operations battlefield.

The M1 will not be effective on the 2040 battlefield. Its design for protection, lethality mobility and C2 are not sufficient to dominate the 2040 battlefield. Innovation will be required to solve the protection issue while simultaneously reducing weight to assure strategic, operational, and tactical mobility. This study believes that investments in new materials, passive armor, active protection particularly for kinetic weapons and signature suppression will be required. Issues include the choice of the main armament and whether the 5GCV is a heavy MBT or a lighter vehicle.

The current Army ability to perform analysis is significantly less capable than that available during the development of the M1. Previous studies conducted by the Army Science Board and the Defense Science Board during the development of the M1 relied heavily on analysis to substantiate their findings and recommendations. Little or no such capability exists today. The development of the M1 relied on significant technical and operational analysis to determine its requirement and such a capability will be required for the development of the successor to the M1. Any application of modern Digital Engineering for the development of the next generation MBT will require modern computational tools and analytic models which are not now in evidence.

Recommendations Summary

SECARMY and CSA: The Army should immediately initiate a 5GCV development and testbed program with the corresponding activities.

- Make a conscious decision NLT February 2024 that a 5GCV will be fielded by 2040-2042.
- Direct ASA(ALT) to create a PEO- managed program consisting of 9 testbeds IAW ASB Study following February 2024 decision.
- Direct ASA(ALT) to create a S&T/R&D and preliminary future acquisition strategy based on the M1 development model reflected in slide #16.
- Direct timely determination by the Uniformed Military of the answers to the 5 questions in slide #16.

- Direct ASA(FM&C) and DCS G-8 to create POM funding wedge for 5GCV activities in the next POM cycle.

ASA(ALT) and AFC: ASA(ALT) and AFC address preliminary requirements generations issues, early S&T/R&D investments, and initial acquisition strategies.

- ASA(ALT): Report on PEO and PEO organizational structure to manage testbed program NLT February 2024.
- AFC: Report on 5GCV requirements generation structure NLT February 2024, i.e., NGCV CFT management or new management/organizational approach.
    - Brief SECARMY and CSA on preliminary answers to 5GCV development questions in slide #16 NLT February 2025.
- ASA(ALT) and AFC:
    - Prioritize new cannon requirements; work with Governments of Germany (Rheinmetall) and France.
    - Prioritize top attack and underbelly defenses; in coordination with (ICW) DARPA and DOE seek innovative vehicle and formation protection solutions, especially against kinetic energy weapons to determine if significant 5GCV passive armor weight reductions can be made.
    - Prioritize combat vehicle weight "bogey"; ICW DOE seek innovative passive armor solutions.
    - Prioritize vehicle designs to reduce width and length of 5GCV.
    - Prioritize determination of crew size ICW TRADOC and based on proven experimentation and analytics.
    - AFC ICW TRADOC begin preliminary determination of 2040 operational concepts, derivative 2040 doctrinal concerns, to include crew-level TTPs and related combat formation structures.
    - AFC ICW AMC identify ways to reduce logistics and sustainment burdens.
    - AFC ICW USARPAC, USAREUR-AF, TRANSCOM/DOT and USN identify strategic mobility issues and solutions, especially with Indo-Pacific. If necessary, HQDA ICW Joint Staff and OSD address national military strategy issues associated with constrained strategic mobility resources.

HQDA DCS G-2, NGIC, and AFC: ICW national agencies prioritize intelligence understanding of Chinese armor and anti-armor R&D investments and fielding developments. China likely to replace Russia in armor developments. Critical Intelligence Items of Interest include

- Materials
- Energetics
- Use of AI for Automatic Target Recognition (ATR) and Counter-ATR
- Cannon Technologies and Munitions
- Advanced ATGMs
- Hypervelocity Munitions

SECARMY and USA: Re-establish the DUSA(OR) as Army lead agency for Army-wide investments in state of the Army analytics, modeling, and simulation for modern digital engineering and

design, evaluation of kinetic and non-kinetic applications, and assessments of 2040 combat effectiveness force-on-force scenarios.

SECARMY and CSA: Direct AFC to establish an ATGM CFT to assess Chinese and Russian ATGM investments and to develop a 2040 Battlefield ATGM strategy.

Conclusion: Future US Success in Land Warfare Is at Risk

The inability to get to the fight in a timely manner with a dominant force would compromise the ability of the future Army to fulfill its role as an important instrument of US foreign policy. An innovative program to investigate the ability to reduce weight and ease supportability requirements without compromising combat capability is a program that would fulfill GEN Starry's guidance to explore fundamentally new and generational solutions to Armor and Anti-Armor capability.

Chinese and Russian developments in lethality, survivability, and mobility are eroding US conventional deterrence in land warfare in both the Pacific and Europe. A program to restore lost margins of US technological superiority in armor and anti-armor capability must become a national priority.

The development of more sophisticated modeling and simulation and experimentation tools has become a pacing factor in proving 5GCV concepts and must be achieved before Engineering and Manufacturing Development can begin. A critical priority for analysis is to determine the added value of convergence and cooperative weapons systems relative to individually enhancing the capabilities of 5GCVs and other weapons systems.

20 July 2023

The Army Science Board

An Independent Assessment of the 2040 Battlefield and Its Implications for the 5th Generation Combat Vehicle (5GCV)

Dr Jim Tegnelia, Study Chair
Christopher Yuknis, Briefer

An Independent Assessment of the 2040 Battlefield and Its Implications for the 5th Generation Combat Vehicle (5GCV) Outline

- Introduction
- Bottom Line Up Front
- Framing Assumptions
- The 2040 Battlefield
- Obsolescence of the M1
- The Recommended M1 Program for the 5GCV
- Supporting Study Findings
- Study Recommendations

The 2040 Battlefield and the 5GCV Technologies Terms of Reference

- Assess the 2040 battlefield
  - Assess anticipated actions from adversaries
- Examine US doctrine
- Assess available 2040 technologies
  - Allies
  - US industry
  - Other government agencies
- Assess technology testbed and acquisition programs for a 2040 fielded 5GCV
  - Based on M1 acquisition methodology
- Defense Economics: Is the recommended program affordable?

This study was tasked to only address materiel issues associated with the M1 Abrams and the 5GCV.

Study Team Membership

ASB Members
- James A. Tegnelia, Ph.D. – Study Chair
- Mark N. Glauser, Ph.D. – Study Co-Chair
- COL(Ret) William S. Crowder – Sustainment and Deployability
- Robert E. Douglas, Ph.D. - Analytics
- William J. Neal, Ph.D. – Networks
- William E. Snowden, Ph.D. – Protection and Lethality
- Albert Buck Tanner, Ph.D. – Vehicle Design and Development
- Anthony J. Tether, Ph.D. – Concepts and Programmatics

ASB Senior Advisors
- Joseph V. Braddock, Ph.D. (deceased)
- Leonard W. Braverman, Ph.D.

Government Advisors
- Jeffrey P. Carie - Ground Vehicle Systems Center
- Robert A. Hay - Army Futures Command
- John W. Miller III - Maneuver Center of Excellence
- Robert W. Sadowski, Ph.D. - Ground Vehicle Systems Center
- James W. Schirmer - PEO Ground Combat Systems

ASB Consultants
- Terrence F. Alger II, Ph.D. – Engineering
- COL(Ret) Clinton J. Ancker III – Doctrine and Concepts
- COL(Ret) John F. Antal – Concepts
- COL(Ret) C. Forrest Burke – Logistics
- COL(Ret) Christopher G. Cross, Ph.D. – Technology
- Marilyn M. Freeman, Ph.D. – Technology
- COL(Ret) Herbert J. Gallagher – Protection
- COL(Ret) William W. Hansen –Doctrine and Programmatics
- MG(Ret) William C. Hix – Concepts and Threat
- BG(Ret) Peter L. Jones – Threat and Intelligence
- COL(Ret) Robert J. Kmiecik – M1 Program and Operations
- LTC(Ret) Richard B. Ladd (deceased)– Sustainment
- LTG(Ret) Michael E. Williamson, Ph.D. – Programmatics
- MG(Ret) Walter Wojdakowski – Doctrine and Operations
- COL(Ret) Christopher A. Yuknis – Senior Government Advisor and Concepts

Study Managers
- LTC Charles G. Bies – Study Manager and Armor Operations and Tactics
- COL(Ret) Harry K. Lesser, Jr. – Study Manager and Threat and Intelligence

Balance of Experienced Technical and Operational People

Research, Data Gathering, and Analysis

Army Organizations

- Deputy Assistant Secretary of the Army (RT)
- Army Futures Command
  - Futures and Concept Center
  - Combat Capabilities Development Command
    - Ground Vehicle Systems Center
    - C5ISR Center
      - Night Vision and Electronic Sensors Directorate
    - Aviation and Missiles Center
    - Armaments Center
    - Army Research Laboratory
    - Data and Analysis Center
    - Next Generation Combat Vehicle CFT
- PEO Ground Combat Systems
- Center for Army Analysis
- National Training Center
- Engineer Research and Development Center
- Maneuver Center of Excellence
- Sustainment Center of Excellence/Combined Arms Support Command
- Space and Missile Defense Command

Other Government Organizations

- DARPA
- US Marine Corps
- US Air Force
- US Transportation Command
- Department of Energy
  - Sandia National Laboratories
  - Idaho National Laboratory
- Department of Transportation
- Johns Hopkins Applied Physics Laboratory
- RAND Corporation

Intelligence Community

- National Intelligence Council
- Central Intelligence Agency
- Office of the Deputy Chief of Staff, G-2
- National Ground Intelligence Center
- Missile and Space Intelligence Center

US Industry

- Optimal Outcomes
- Potomac Foundation
- BAE Systems
- General Dynamics Land Systems
- Northrop Grumman
- Lockheed Martin

Allied Industry

- Israeli Aerospace Industries
- Rafael
- Rheinmetall
- SAAB
- Soucy Group

Research/Literary Review – The study team reviewed over 300 documents, reports, previous studies, briefings, doctrine, armor/anti-armor concepts, related technologies, threat capabilities, etc. , over 5 years.

Scenario Planning and Analysis - The study team created a structured scenario planning process to investigate potential M1SEPvX and 5GCV platforms and formations in European and Indo-Pacific theaters. Analysis of these efforts produced a list of critical capabilities and enabling technologies.

The 2040 Battlefield and the 5GCV Opportunity

The Opportunity

"It must be the role of technology to provide weapons systems which render ineffective costly investment by our foes – not simply to try to match something the other fellow has just fielded. With new weapons we should seek new dimensions of combat."

GEN Donn Starry
September 1981

Bottom Line Up Front

- To maintain land warfare overmatch, the Army should immediately initiate a testbed and development program with the creation of requirements for the 5GCV and the creation of an ATGM CFT.
  - US ability to deter war and win on future land battlefields is at serious risk without development of the 5GCV.
  - The M1 Abrams tank, fielded in 1980, was superbly developed and provided unprecedented capabilities, but will not have the dominant deployability or mobility, lethality, or protection necessary for success on the 2040 battlefield.
  - The unprecedented M1 Abrams development program, with state of the art analytics, provides an appropriate model for the development of the 5GCV.
  - A 5GCV with dominant lethality, protection, mobility, and deployability will be essential for the 2040 battlefield.
  - The Army must partner with industry, other USG agencies, and Allies and partners to acquire the best 2040 technologies for a dominant 5GCV.

Framing Assumptions

Warfighting Assumptions

- Armored combined arms forces remain decisive to land combat, are central to conventional force deterrence and, if deterrence fails, victory.
  - Ultimate capability to close with and destroy all adversary tanks on the battlefield and to restore maneuver.
  - Tanks needed for offensive maneuver and force protection; and other purposes; tank-on-tank engagements.
  - No other platform provides necessary shock effect.
- To field the 5GCV requires an understanding and balancing of competing demands.
  - Technical threats to combat vehicles.
  - Robotic tanks not ready for 2040.
  - Revised combat formations and organizations.
  - Manpower constraints.
  - Fiscal constraints.
  - Sustainability imperatives.
  - Industrial constraints: manufacturing ability, among others.

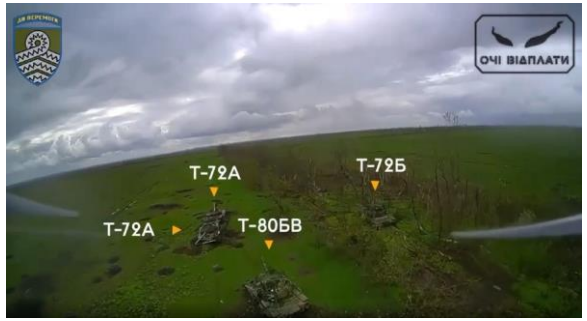
Geopolitical and Strategic Assumptions

- Major US geostrategic reset underway.
  - Then, post-Viet Nam War counterinsurgency, followed by great power threats from the Soviet Union in Europe.
  - Today, transition from Middle Eastern counterterrorist and counterinsurgency to great power competition from China and Russia.
- Contemporary and future conflict reinforces the imperative to close with and destroy the enemy with shock effect, an effect unique to armored forces in all theaters of operations.
- The Army armored force is a major contributor to meeting US national security objectives and establishing conflict deterrence. Must be accomplished in the face of
  - Strategic mobility issues, especially Indo-Pacific.
  - Contested logistics, to include Homeland threat.
- 5GCV will be a single platform, capable of worldwide deployment.

Summary Elements of the 2040 Battlefield

- 2040 Battlefield unchanging elements (FM 3-0 Multidomain Operations).
  - Take and hold critical terrain.
  - Defeat enemy in close combat; conduct pursuit and exploitation.
  - Lethality, mobility, and protection remain key aspects of armor operations.
- 2040 Battlefield changes the character of warfare.
  - Profoundly transparent battlefield; surveillance in all domains.
  - Comprehensively lethal, integrated, multidomain, and destructive battlefield.
  - Ability to strike all elements of the battlefield at any time - there is no sanctuary. Likely attack from homeports to frontlines.
    - Devastating long-range fires
    - Increased use of armed UAVs, swarms, and UGVs
    - Increasing engagements beyond line of sight
- 2040 Battlefield imperatives.
  - Strategically Joint and multinational operations; tactically combined arms operations.
  - Use latest technologies and deny enemy's use of their technologies.
  - Lethality, mobility, and protection remain key aspects of armor operations.

US must continue to fight outnumbered and win.

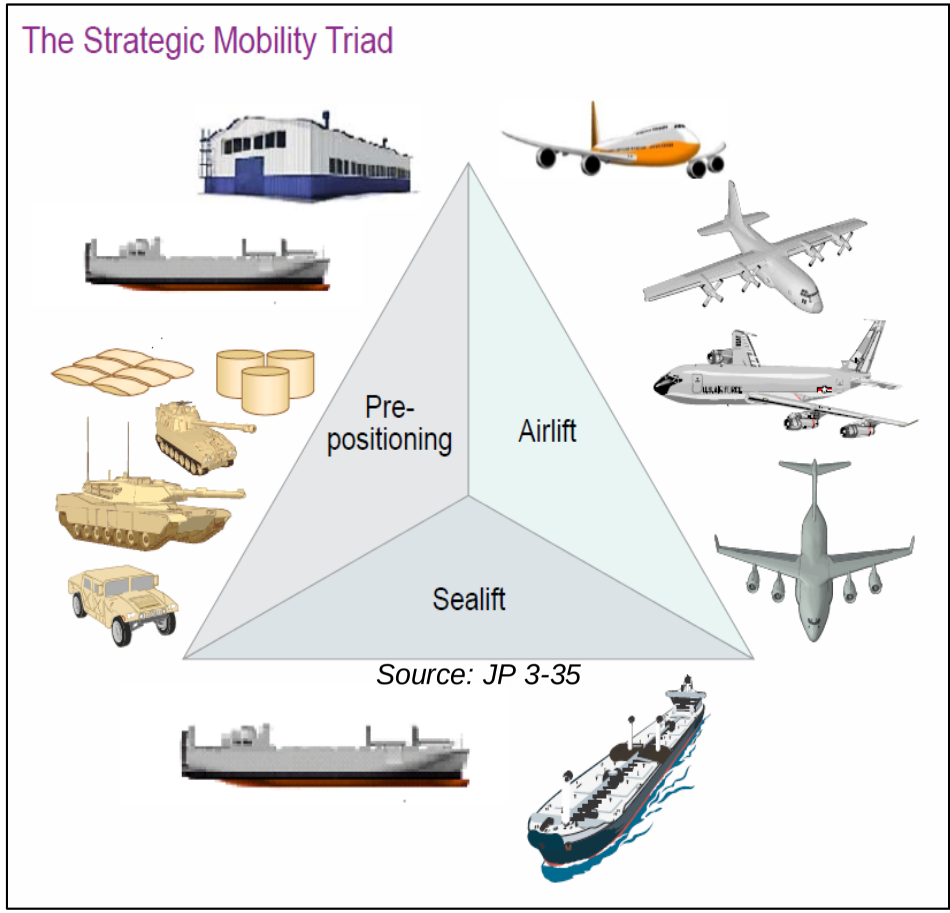


Summary Elements of the 2040 Battlefield (continued)

- 2040 Battlefield Environment
  - The role of US Army to close with and destroy the enemy and to seize and hold ground will not change.
  - The totality of the battlefield will be near transparency in all domains and will be subject to significantly greater lethality.
  - Overwhelming artillery fires, UAVs, drones, ATGMs in top attack mode, and mines can and will degrade maneuver and potentially create the most deadly and dangerous battlefield we have ever faced.
  - An inability to generate overwhelming combat power to enable operational and tactical maneuver will likely result in a stalemated front and extended battlefield resulting war of attrition.
- Adversaries
  - China: Growing threat both strategically and operationally; may not fight China but will fight Chinese equipment.
    - Will strengthen all military functions, fueled by aggressive, well-funded and technically sophisticated R&D.
    - Type 99 tank assessed to exceed Russian T-90 and match German Leopard 2.
    - PLAA rapidly supplanting Russia as US pacing threat, modernizing in all military functions.
    - Will not move beyond Type 99 until US decides on 5GCV replacement program.
    - Understanding Chinese R&D investment critical - significant intelligence requirement.
  - Russia: Remains a strategic threat; conventional capability greatly diminished by Ukraine.
    - Will recover likely over 5-10 years.
    - Recovery less sophisticated level due to Western sanctions; decreased domestic R&D.
    - Ukraine war not over; many more lessons to be learned and understood.

Profound Change to the 2040 Environment: Strategic Mobility

- Three methods exist to deploy an operationally significant force.
  1. Army Pre-Positioned Stocks (APS)
     - ➢ Costs in addition to fielded ABCTs
     - ➢ Requires airlift for personnel, organic enabling equipment
       - 10+ C-5 equivalents for personnel
       - 14-24 days to generate combat ready ABCT
  2. Sealift: Only way to move ABCTs from CONUS; sealift is inadequate
     - ➢ Needs significant sealift assets and SPOE
     - ➢ Many Ro/Ro ships are ageing out; replacement an issue
     - ➢ Longest time to move equipment (90 days representative of deploying a corps from CONUS to forward staging areas)
     - ➢ Requires airlift for personnel
  3. Force Airlift: Not Feasible
     - ➢ The Air Force has 222 C-17s
     - ➢ 575 C-17 sorties to move an ABCT
     - ➢ 752 sorties for a sustainment brigade
     - ➢ 412 sorties for a combat aviation brigade
- Forward deployment will most likely be required.



Reducing weight and improving reliability for the entire force reduces sustainment tail and lift requirements.

*RAND report: 01-RR-2259-A, Preparing for Near-Peer Conflict on the Ground

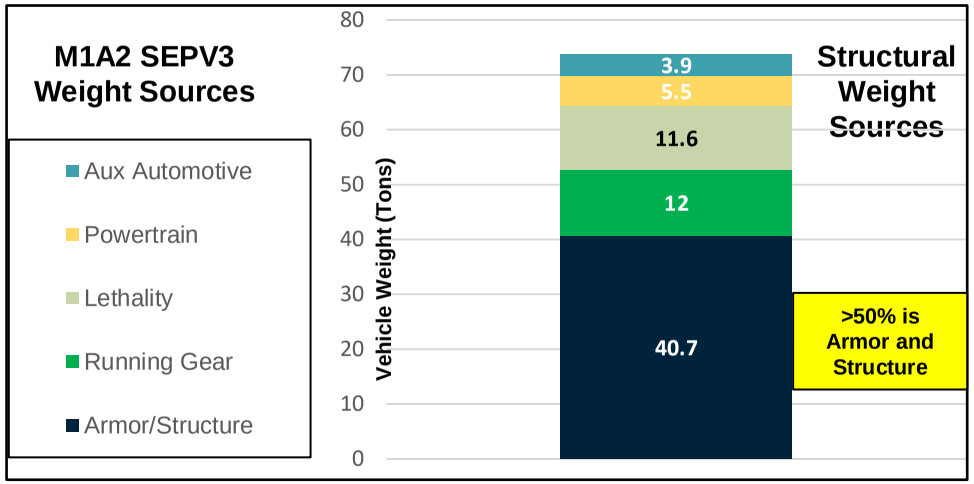
The M1 Will Not Remain the Dominant MBT on the 2040 Battlefield

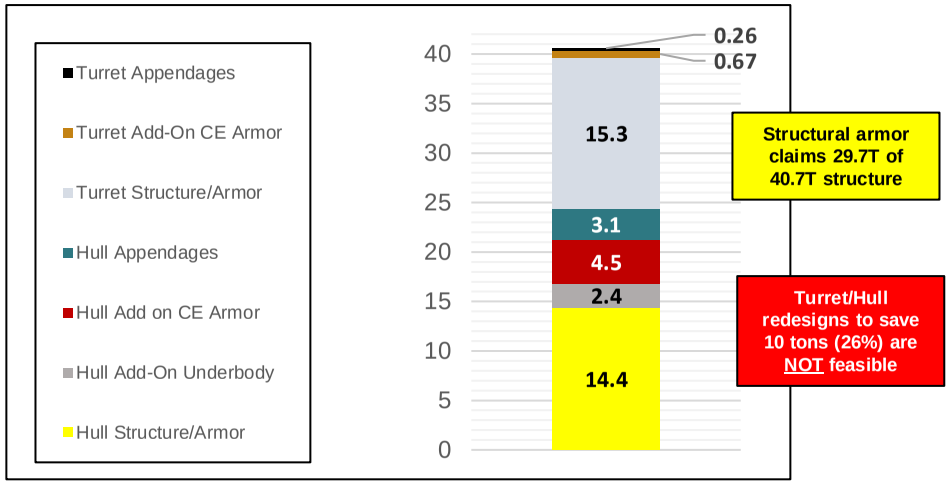
- Protection margins lost.
  - Threat weapons have significantly greater accuracy and penetration power.
  - Vulnerable to long-range artillery fires including smart DPICM, top attack, and under-body attack.
  - Limited passive armor upgrades at acceptable weight penalties.
  - Active protection systems can be overwhelmed by volume of fire.
  - 2040 threats including hypervelocity missiles, non-kinetic threats such as EW, laser dazzling, chemical-biological, cyber, and EMP will proliferate.
- Firepower margins lost.
  - 120mm cannon has reduced effectiveness against Russian and Chinese armor.
  - No advanced cannon or energetics programs in the US program.
  - Allied, Russian, and Chinese modern gun programs continue.
    - German 130mm cannon and French 140mm cannon developments.
    - Larger, more lethal rounds cut stowed rounds by 50% or more, increasing logistics demand.
    - Smaller caliber gun solutions require new energetics.
- Aging M1 reliability, availability, and maintainability significantly degrades combat capability and increases costs.
- All forms of mobility degraded - strategic, operational and tactical.
  - Initial M1 weight 62.3T; M1A2 SEP V3/4 w/APS 77.9T; mine roller 88.7T.
  - No clear path for significant weight reduction without major redesign.
  - Conscious decision to drastically reduce weight will result in compromised protection.

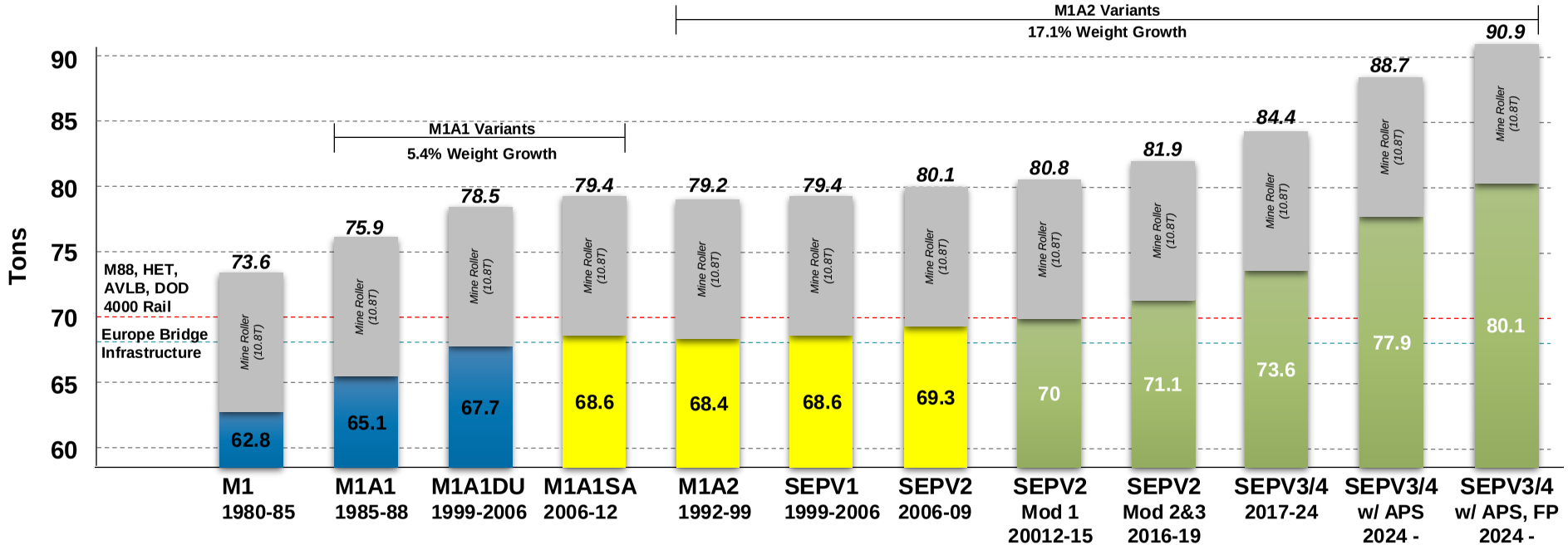
Russian T-90M MBT

Chinese Type 99A MBT

Abrams Weight Growth







Increasingly Lethal 2040 Threats to the M1

Ukrainian Observations

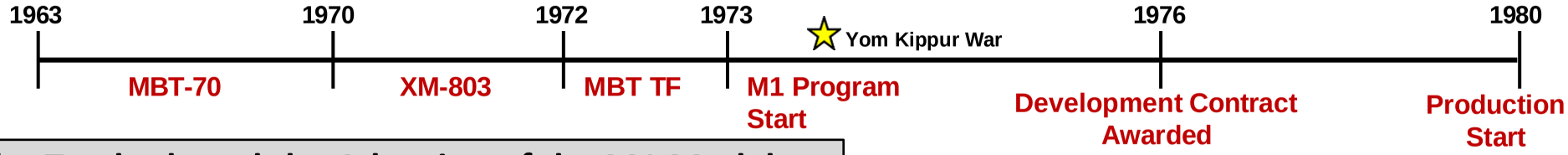
- Biggest killers have been
  - Mines
  - Artillery
  - UAVs
  - ATGMs
  - Other tanks
- Emerging threats include hypervelocity munitions

The M1 can and will be attacked from every direction.

Critical Findings for Abrams on the 2040 Battlefield

- Abrams will not dominate the 2040 Battlefield.
  - Today all of the M1's combat advantages in mobility, firepower, and protection are at risk.
  - By 2040 today's combat advantages are likely to be fundamentally compromised and no longer dominant.
  - M1A2 SEP V3&4 upgrades will improve Abrams effectiveness but will not restore Abrams dominance.
  - The battlefield will feature near transparency in all domains and significantly greater lethality.
  - China and Russia have studied the American way of war and are fielding countermeasures – anti-access/anti-denial strategies, among others.
  - Abrams equipped units will be at a numerical disadvantage, exacerbated by low operational ready rates of an aging fleet.
  - The Army must fight outnumbered and win.

Bottomline from M1 Development for the 5GCV



Rationale for Testbeds and the Adoption of the M1 Model

- All subsystems and components were proven to work before Systems Engineering and Preliminary Design Review were completed - only testbeds can provide the answers.
- No technological breakthrough was required to successfully field the M1 Abrams.
  - No "Gold-Plated Bells and Whistles"
  - Soldiers' trust and confidence in platform
- Operational Testing simultaneous with Development Testing.
- Developed the best system possible with limited money.
- Built political and Army Senior Leadership support.

5 Critical Questions for the 5GCV

- What should the crew size be?
- How much should it weigh?
- What weapons should it have?
- How can 5GCVs be protected from top and underbelly attacks?
- How can 5GCVs reduce logistics and sustainment burdens?

M1 Capability Priorities

1) Crew Survivability
2) Surveillance and Target Acquisition Performance
3) First and Subsequent Round Hit Probability
4) Time to Acquire and Hit
5) Cross Country Mobility
6) Complementary Armament Integration
7) Equipment Survivability
8) Environmental Impact
9) Silhouette
10) Acceleration and Deceleration
11) Ammunition Stowage
12) Human Factors
13) Produceability
14) Range
15) Speed
16) Diagnostic Aids
17) Growth Potential
18) Support Equipment
19) Transportability

Introduction to the Recommended Program

- The 2040 Battlefield requires a 5GCV.
  - New lighter 5GCV offering a “clean sheet design” with superior combat potential.
  - Major shift in design paradigm, including manufacturability.
- Time now for innovative solutions for risk reduction and cost restraints.
  - M1 development experience indicates need for testbeds and experimentation.
    - Reduce technical risk.
    - Understand needed technical and crew performance standards.
    - Need for examination of Human Factors for automation enabled reduced crew.
    - Vehicle concepts are helpful to guide testbed activity.
  - Maturing technology for the 5GCV will help the heavy force and possibly the entire force.

Must start testbeds soon to make a 2040 fielding of a vehicle that dominates the 2040 Battlefield.

Concepts: Introduction to the Recommended Program

Vehicle Concept	M1 A2 SEP VX 70+ Tons	5GCV 55-60 Tons	Light Tank 35-40 Tons	Wingman 20-30 Tons
Firepower	120mm Insufficient	130mm Overmatch	130mm or 120mm with Energetics Overmatch	Hypervelocity Missile Other ATGM Overmatch
Mobility	Strategic: Poor Operational: Poor Tactical: Marginal	Strategic: Poor Operational: Good Tactical: Good	Strategic: Marginal Operational: Good Tactical: Good	Strategic: Good Operational: Good Tactical: Good
Protection	Inadequate	Good	Marginal: Depends on Active Protection	Marginal
C2	Marginal	Good	Good	Good
Crew	4	3	3-2	1-0
Propulsion	Turbine	Hybrid Electric	Hybrid Electric	Hybrid Electric
Engagement Range	2-3 KM	3-5 KM	3-5 KM	Approximately 50 KM
Enabling Technologies	None	Automation New Cannon Autoloader	Active Protection Energetics Signature Management	Robotics Hypervelocity Missiles Off-Board Targeting

5GCV Testbed Opportunities for Generational Change

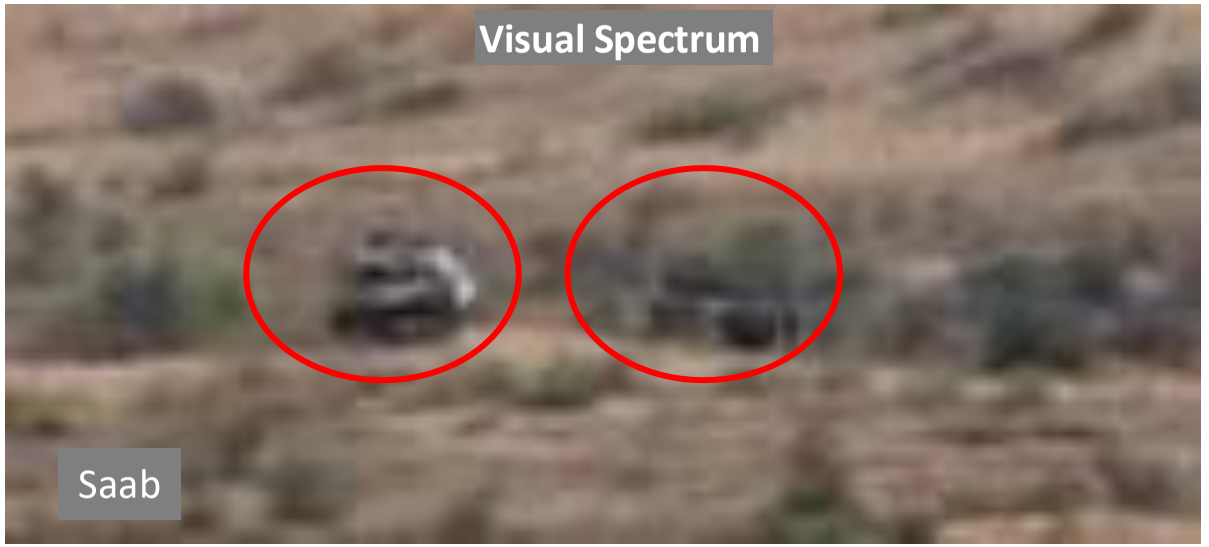
Technology Driven Opportunities (ordered by investment required)

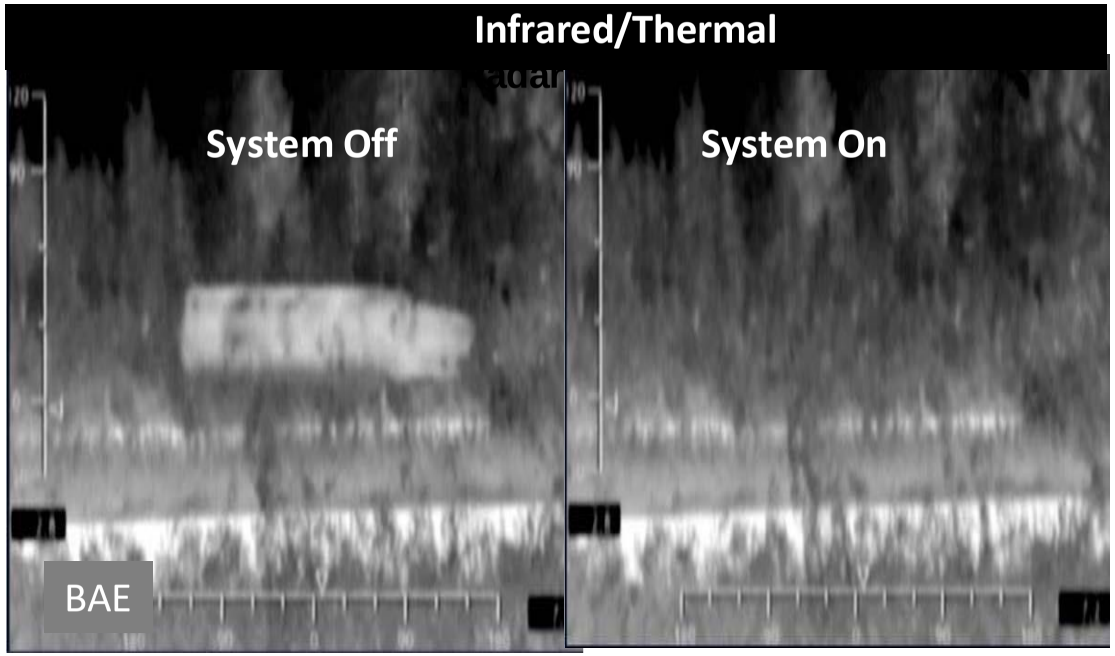
- Materials Design
- Energetics Development
- Active Vehicle and Formation Protection
- Computational Power
  - Artificial Intelligence
  - Aided Target Recognition
  - Autonomy
  - Networks
- Masking and Signature Management
- Power and Energy
- Greater Reliability, Availability, and Maintainability

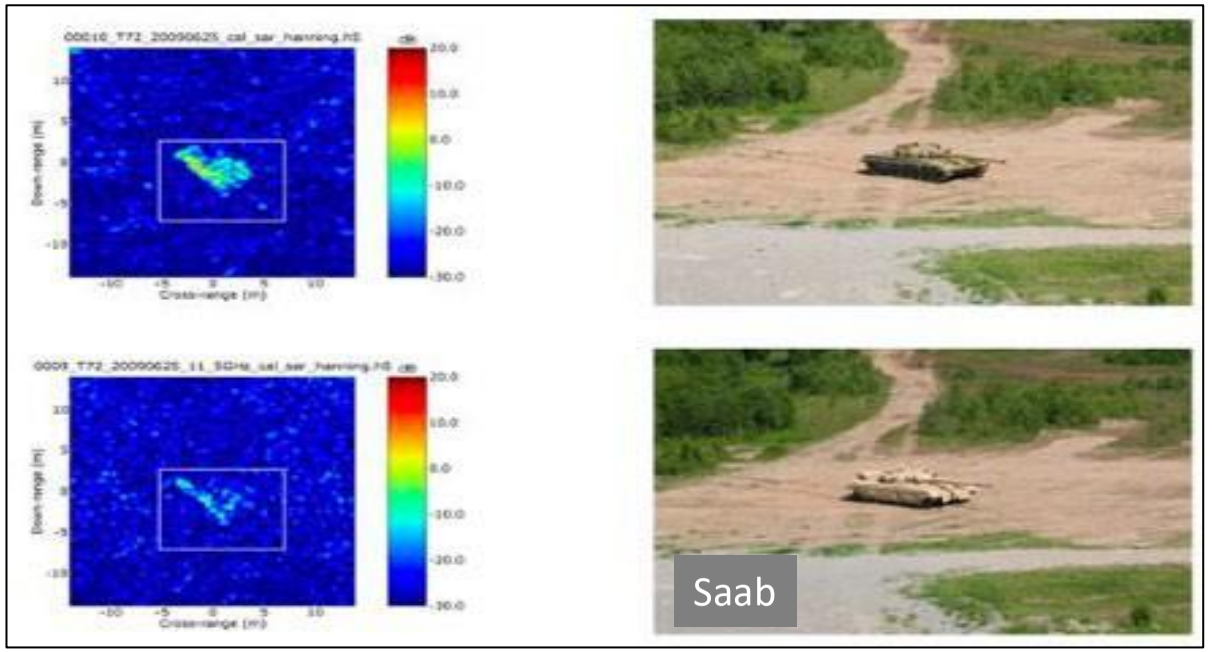
5GCV Result

- Greater Mobility
- Improved Protection and Survivability
- Devastating Firepower and Lethality
- Sustainable
- Upgradable by Design

Allied Masking Efforts Lead Those in the US







Anti-Tank Guided Missiles

Challenges

- While the Army has product improved current ATGM systems (TOW 2B, Hellfire, Javelin), it has not invested in new ATGM approaches since the end of the Cold War.
- The Chinese and Russians have made significant investments in ATGM technology and are developing more advanced systems, e.g., Chinese Red Arrow-12, Russian Sokol.
- The Russians have invested in countermeasures to the current US generation of ATGMs.
- No Cross Functional Team proponent within the Army Modernization Strategy.

Opportunities

- Hypervelocity KE missiles can restore these margins. It is unlikely that current protection approaches can counter hypervelocity technology.
- Sandia National Laboratories has demonstrated with UAS the ability to hit moving point targets beyond line of sight and at extended ranges.

Anti-Tank Guided Missiles

- US ATGM capability is losing it overmatch dominance to China and possibly our Allies.
- Current investment going into upgrading existing missiles.
- New investments required for new missiles with expanded capabilities to include beyond line-of-sight engagements.

KE Missile from a Lightweight Platform

MBT Target Destroyed by KE Missile

Missile	Year	Range (km)	Energy on Target (MJ)
CKEM	2000	5	**10**
LOSAT	1990	5	**40**
HVM I	Concept	10	**24-40**
HVM II	Concept	50	**17-20**

Supporting Study Findings

- Other Technologies – USG Agencies, Industry, and Allies
  - DARPA and DOE instrumental in M1 development; 5GCV must take advantage of these agencies.
  - US has only one credible industrial house for tank design and development.
  - Detailed USG supervision and management of testbed program and acquisition activities required.
  - US does not have a competitive national advantage in main gun development; must take advantage of technological expertise from Allies, especially Germany and Rheinmetall.
- Defense Economics
  - Study found $3-4 Billion testbed program comparable to Abrams program.
  - Technological complexity of computers and software development will be major developmental constraint.
  - Significantly more research into cost parameters required.

Funding Calibration

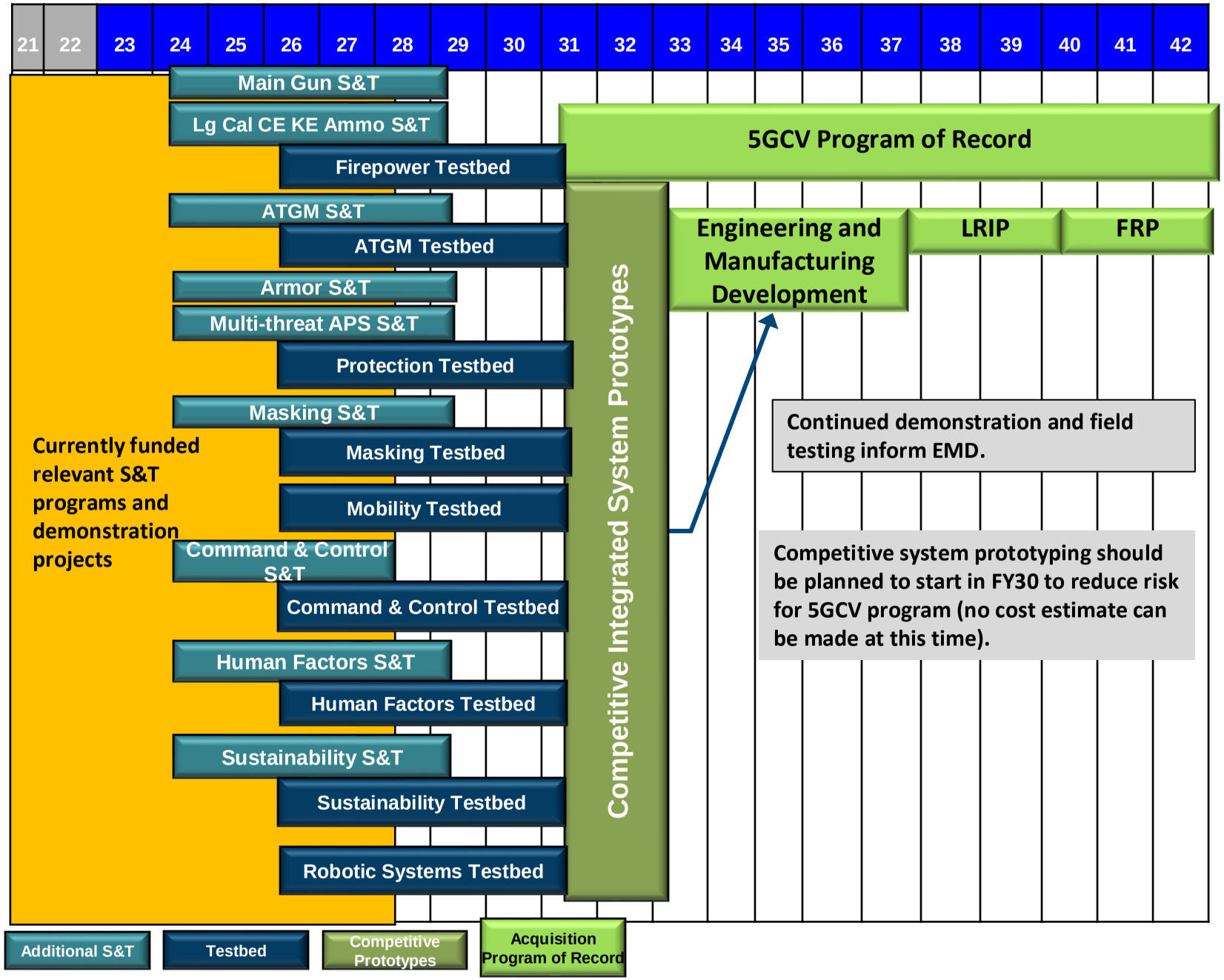
- Test Beds
  - MBT70 technology program conducted from 1963-1970 cost $300M then or $2.1B in current year dollars.
  - This program recommends $2.9B and eight years.
- Competitive Prototyping
  - XM1 prototyping conducted from 1973-1976 and cost $200M then or $1.2B in current year dollars.
  - GCV prototyping: 2 contractors and took 4 years; it included ATR, turret test stand, and cost $1B in 2012.
- More RDT&E funding available in 2021 than in 1975.

1975 Defense Budget	$86.509 B	($428.64 B in 2021 Dollars)
Army Budget	$23.718 B	($113.14 B in 2021 Dollars)
Army RDT&E	**$1.77 B**	**($7.57 B in 2021 Dollars)**
2021 Defense Budget	$696.0 B	
Defense RDT&E	**$106.56 B**	
Army Budget (Base + OCO)	$177.93 B	
Army RDT&E	**$12.81 B**	

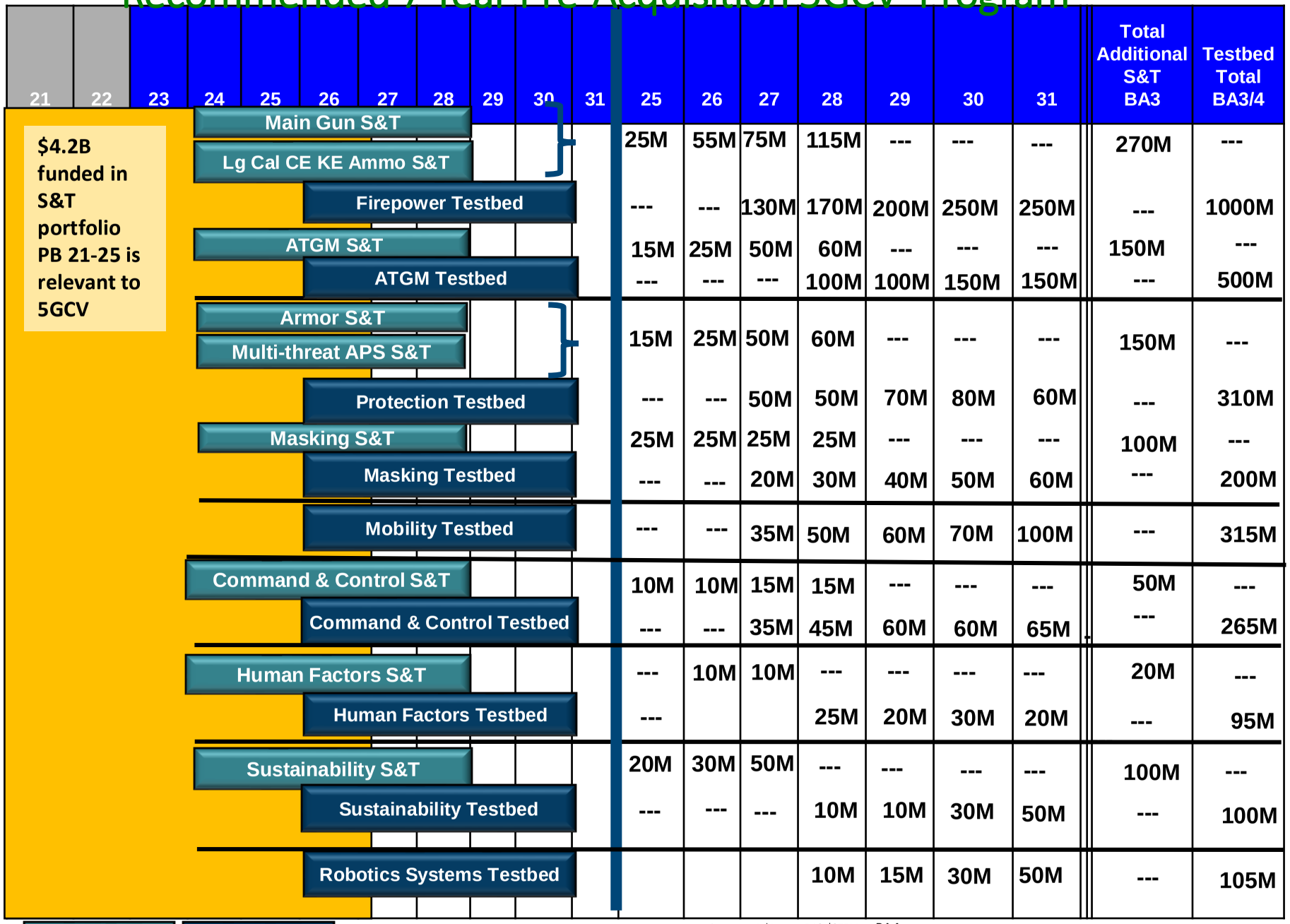
$3-4 Billion for a technology maturation program has historical precedent.

Source: p.190 “Green Book” https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/FY21_Green_Book.pdf
FY21 Defense Budget as found in FY21 Appropriations Act

Recommended 5GCV Program



Recommended 7 Year Pre-Acquisition 5GCV Program



	25	26	27	28	29	30	31	Total Additional S&T BA3	Testbed Total BA3/4
Main Gun S&T	25M	55M	75M	115M	---	---	---	270M	---
Lg Cal CE KE Ammo S&T									
Firepower Testbed	---	---	130M	170M	200M	250M	250M	---	1000M
ATGM S&T	15M	25M	50M	60M	---	---	---	150M	---
ATGM Testbed	---	---	---	100M	100M	150M	150M	---	500M
Armor S&T	15M	25M	50M	60M	---	---	---	150M	---
Multi-threat APS S&T									
Protection Testbed	---	---	50M	50M	70M	80M	60M	---	310M
Masking S&T	25M	25M	25M	25M	---	---	---	100M	---
Masking Testbed	---	---	20M	30M	40M	50M	60M	---	200M
Mobility Testbed	---	---	35M	50M	60M	70M	100M	---	315M
Command & Control S&T	10M	10M	15M	15M	---	---	---	50M	---
Command & Control Testbed	---	---	35M	45M	60M	60M	65M	---	265M
Human Factors S&T	---	10M	10M	---	---	---	---	20M	---
Human Factors Testbed	---			25M	20M	30M	20M	---	95M
Sustainability S&T	20M	30M	50M	---	---	---	---	100M	---
Sustainability Testbed	---	---	---	10M	10M	30M	50M	---	100M
Robotics Systems Testbed				10M	15M	30M	50M	---	105M
Totals	BA3-$110M	BA3-$180M	BA3-$275M BA4-$270M	BA3-$275M BA4-$490M	BA4-$575M	BA4-$750M	BA4-$805M	BA3-$840M	BA4-$2890M

Supporting Study Findings

- US Doctrine and Warfighting Considerations
  - Mission of armored combined arms formations is fundamental and will remain the same in 2040.
  - 2040 Battlefield will require properly trained, lead, and equipped armored combined arms teams for deterrence and warfighting. If deterrence fails, victory requires such capabilities and competencies.
  - Threat lethality will significantly increase requiring better vehicle protection and mobility.
  - 5GCV will require on-board active and passive protection and off-board formation protection solutions.
  - Strategic mobility issues must be addressed.
    - Weight reduction of 5GCV is critical issue for improved strategic mobility.
    - ABCTs are increasing in weight; 5GCV weight reductions important first step, but alone does not solve the ABCT strategic mobility issue for either Europe or the Indo-Pacific.
    - US Navy, US Air Force, TRANSCOM, and DOT must be part of the 5GCV strategic mobility solution.
    - Inability to solve strategic mobility issues may require a change in national defense and national military strategy policies, i.e., possibility of forward deployments or pre-positioning.
    - DARPA and DOE can potentially help with weight solutions.
- Modeling, Simulation, and Analytical Capabilities
  - Modeling, simulation, and other analytical capabilities successfully employed in the M1 development not in evidence for the development of the 5GCV.
  - Analytical upgrade requires significant investment to restore capability available to M1 development.

Conclusion - 2040 Battlefield Success at Serious Risk without Development of 5GCV

- M1 Abrams, while still effective today and maybe to 2030, will not dominate the 2040 Battlefield.
  - Chinese and Russian developments create losses of warfighting margins in lethality and survivability.
  - Abrams weight profoundly degrades tactical, operational, and strategic mobility, subjecting it to 360° attack and formation vulnerability.
  - Aging M1 reliability, availability, and maintainability significantly degrades combat capability and increases costs.
  - The 5GCV Program must become a national priority to restore combined arms dominance.
- The M1 Abrams program of the 1970-1980s delivered unprecedented success.
  - Decision that all sub-systems and components must be proven to work before Systems Engineering and Preliminary Design Review, coupled with no technological breakthrough required for success and growth margins built into its design, resulted in 40 years of Abrams dominance.
  - 5GCV program must follow Abrams development model.
  - If it does, the US will render costly investment by our foes ineffective, will add new dimensions to combat, and allow us to win on the 2040 Battlefield – achieving the Starry Challenge.
- Outstanding technological and warfighting opportunities exist.
  - Advanced US computational power, economic strength, and warfighting prowess.
  - Sophisticated modeling and simulation, emerging digital design and engineering, AI, and robotics.
  - US defense industrial base and Uniformed Military are second to none.
  - The Army must partner with industry, other USG Departments, Allies and partners for the best 2040 technologies.
  - Despite the Russian performance in Ukraine, Chinese and Russian advances demand major adaptations for how the US military will operate on the 2040 Battlefield.

The 2040 Battlefield and the 5GCV Recommendations

- SECARMY and CSA: The Army should immediately initiate a 5GCV development and testbed program with the corresponding activities.
  - Make a conscious decision NLT February 2024 that a 5GCV will be fielded by 2040-2042.
  - Direct ASA(ALT) to create a PEO- managed program consisting of 9 testbeds IAW ASB Study following February 2024 decision.
  - Direct ASA(ALT) to create a S&T/R&D and preliminary future acquisition strategy based on the M1 development model reflected in slide #16.
  - Direct timely determination by the Uniformed Military of the answers to the 5 questions in slide #16.
  - Direct ASA(FM&C) and DCS G-8 to create POM funding wedge for 5GCV activities in the next POM cycle.
- ASA(ALT) and AFC: ASA(ALT) and AFC address preliminary requirements generations issues, early S&T/R&D investments, and initial acquisition strategies.
  - ASA(ALT): Report on PEO and PEO organizational structure to manage testbed program NLT February 2024.
  - AFC: Report on 5GCV requirements generation structure NLT February 2024, i.e., NGCV CFT management or new management/organizational approach.
  - Brief SECARMY and CSA on preliminary answers to 5GCV development questions in slide #16 NLT February 2025.

The 2040 Battlefield and the 5GCV Recommendations (Continued)

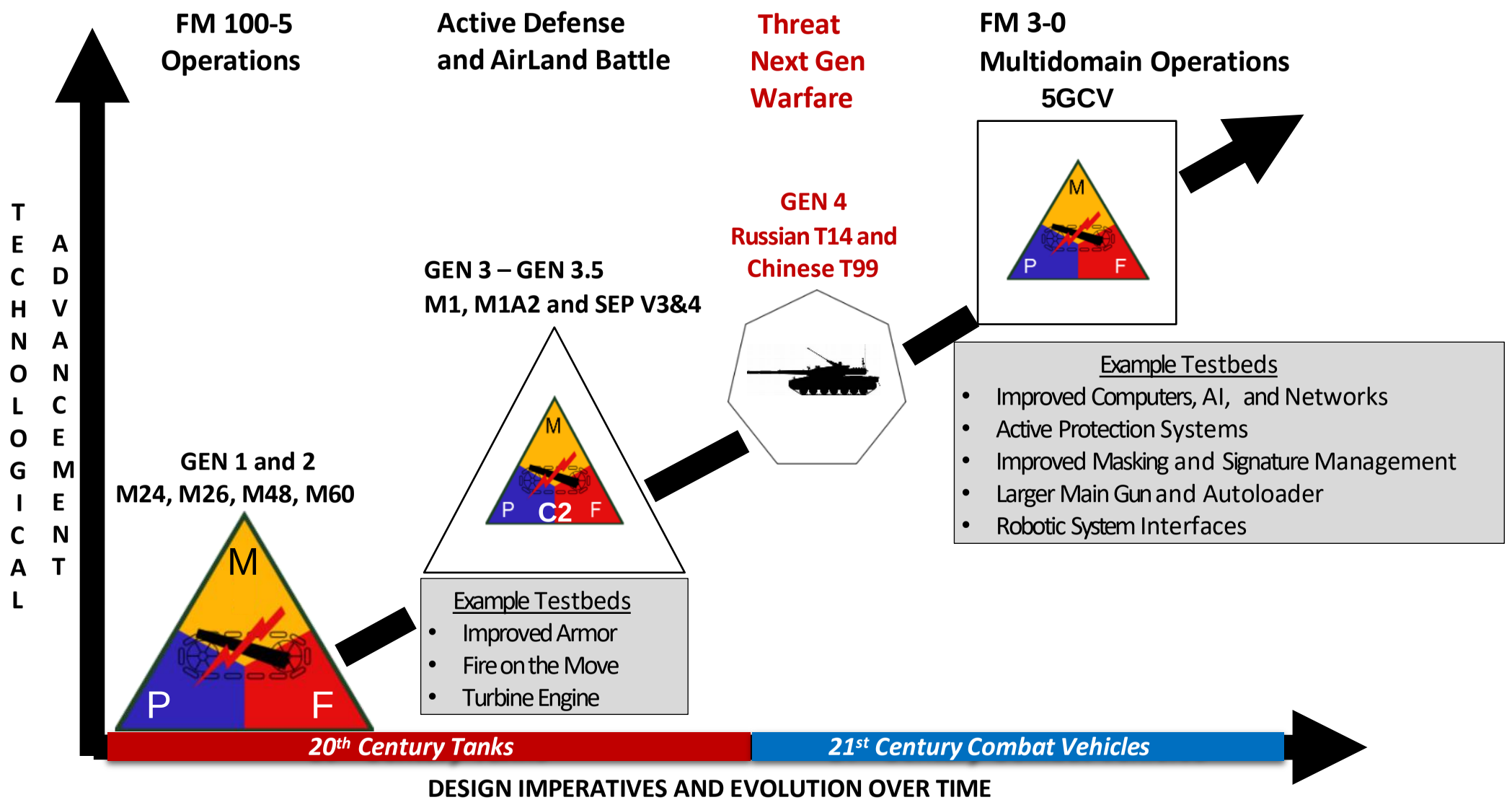
- ASA(ALT) and AFC (Continued):
  - Prioritize new cannon requirements; work with Governments of Germany (Rheinmetall) and France.
    - No US National Institution has cannon design competitive advantages.
  - Prioritize top attack and underbelly defenses; ICW DARPA and DOE seek innovative vehicle and formation protection solutions, especially against kinetic energy weapons to determine if significant 5GCV passive armor weight reductions can be made.
  - Prioritize combat vehicle weight "bogey"; ICW DOE seek innovative passive armor solutions.
  - Prioritize vehicle designs to reduce width and length of 5GCV.
  - Prioritize determination of crew size ICW TRADOC and based on proven experimentation and analytics.
  - AFC ICW TRADOC begin preliminary determination of 2040 operational concepts, derivative 2040 doctrinal concerns, to include crew-level TTPs and related combat formation structures.
  - AFC ICW AMC identify ways to reduce logistics and sustainment burdens.
  - AFC ICW USARPAC, USAREUR-AF, TRANSCOM/DOT and USN identify strategic mobility issues and solutions, especially with Indo-Pacific. If necessary, HQDA ICW Joint Staff and OSD address national military strategy issues associated with constrained strategic mobility resources.

The 2040 Battlefield and the 5GCV Supplemental Recommendations

- HQDA DCS G-2, NGIC, and AFC: ICW national agencies prioritize intelligence understanding of Chinese armor and anti-armor R&D investments and fielding developments. China likely to replace Russia in armor developments. Critical Intelligence Items of Interest include
  - Materials
  - Energetics
  - Use of AI for Automatic Target Recognition and Counter ATR
  - Cannon Technologies and Munitions
  - Advanced ATGMs
  - Hypervelocity Munitions
- SECARMY and USA: Re-establish the DUSA(OR) as Army lead agency for Army-wide investments in state of the Army analytics, modeling, and simulation for modern digital engineering and design, evaluation of kinetic and non-kinetic applications, and assessments of 2040 combat effectiveness force-on-force scenarios.
- SECARMY and CSA: Direct AFC to establish an ATGM CFT to assess Chinese and Russian ATGM investments and to develop a 2040 Battlefield ATGM strategy.

Back-Up Charts

Direct Fire Combat Vehicle Evolution



The Modern Battlefield, Recent Wars, and PLAA Modernization

Observations from Ukraine 2014 – 2022, Nagorno-Karabakh 2020

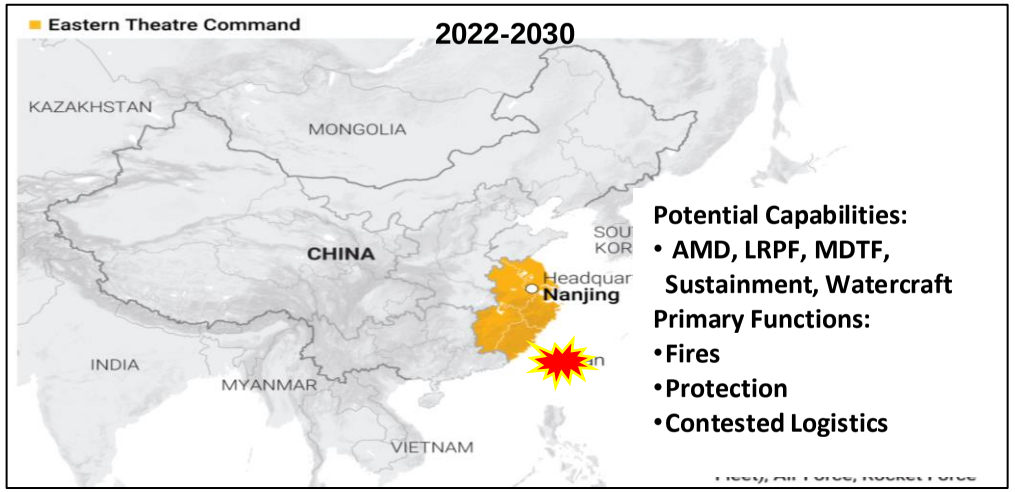
- **Changing Lethality Paradigms** Observations indicate top attack from beyond line-of-sight engagement by indirect fires, UAVs, ATGMs, have killed/damaged the most combat vehicles. Bottom attack from mines resulted in the second most kills.
- **Transparency** Space, EW and UAV fueled transparency and stand off fires intensify lethality, challenging armor survivability.
- **Armor's Role** Armored forces remain vital to maneuver and closing with the enemy on a lethal battlefield; the effect of massed fires has limited unarmored maneuver, driving unprotected forces into trenches.
- **Logistics** The speed/scale of fuel, munition, and equipment consumption exceed contemporary US experience; demand is critical to maintaining combat momentum.
- **Russia Fading** Losses in Ukraine are militarily diminishing Russia, and it is no longer the US pacing armor/anti-armor threat.

China and PLAA Modernization

- **30 Year Effort** Galvanized by Desert Storm, PLAA modernization focuses on overmatching the US, prioritizing information dominance, lethality, and mobility to out-detect, out-decide, and out-range US.
- **Modernization Focus: Two Centennial Objectives**
  - Western Pacific hegemony in this decade.
  - Global hegemony by 2050 with the PLAA protecting China's expanding interests.
  - PLA tasked to be a world class (peer) by 2035 and a first-class military (superior) by 2050.
- **Robust Combined Arms** The PLAA has modernized ~half its 5k tanks to Type 99 (better than T-90) organized in combined arms brigades with long-range fires, EW, air defense, etc., potentially better integrated than Russia, and complemented ~5km Javelin-like ATGMs.
- **Robust R&D** PLAA R&D is improving armor, lethality, unmanned/autonomous systems, hybrid/electric power, and artificial intelligence to evolve the PLAA from mechanization, to informationization, to intelligentization, becoming the armor/anti-armor pacing threat.

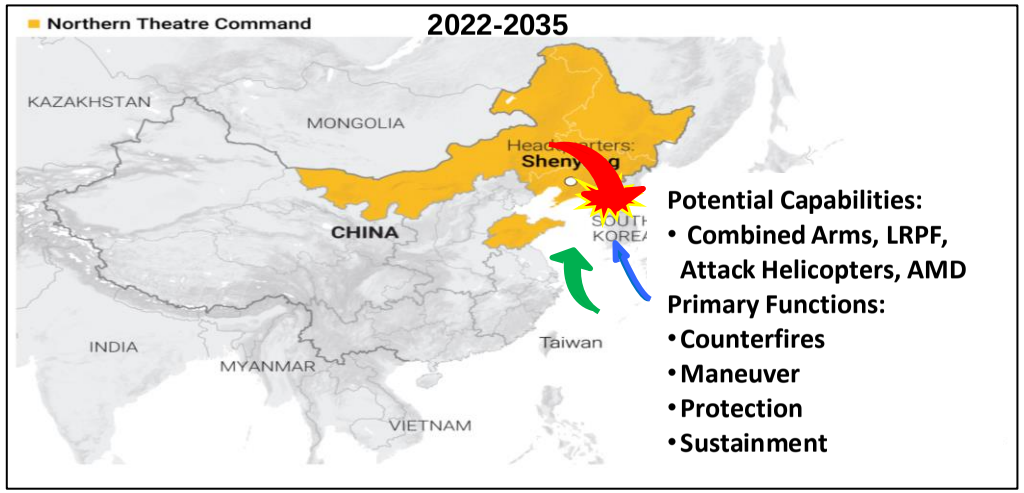
The Modern Battlefield - Potential Current and Future PLAA-US Army Flashpoints

Given China's two centennial objectives, the US Army, as part of the Joint Force, and the PLAA may clash across Eurasia. Should Taiwan be invaded, US Army operations can expand the fight to prevent China from focusing solely on the Taiwan invasion. Further, as the PLA and expand into Eurasia along the BRI, the US must prepare to prevent expanding hegemony circa 2040-2050.



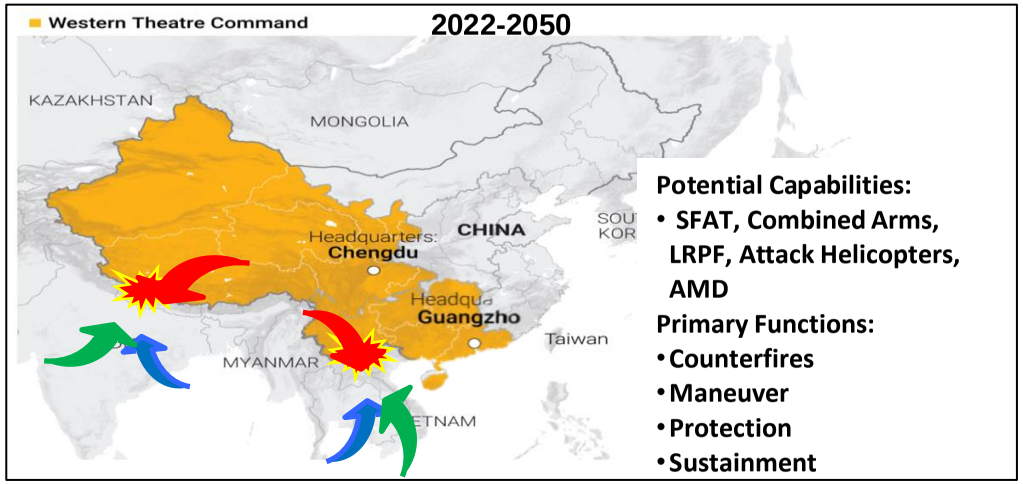
Potential Capabilities:
- AMD, LRPF, MDTF, Sustainment, Watercraft

Primary Functions:
- Fires
- Protection
- Contested Logistics



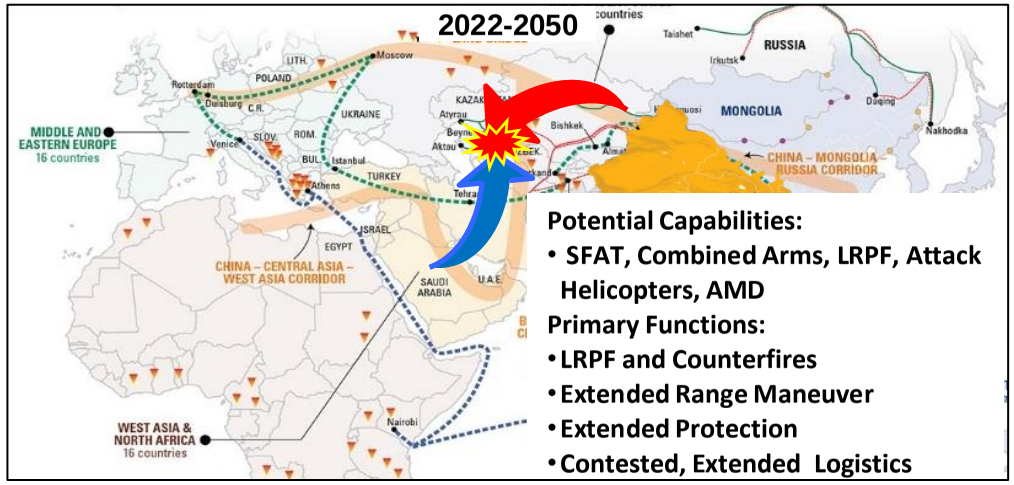
Potential Capabilities:
- Combined Arms, LRPF, Attack Helicopters, AMD

Primary Functions:
- Counterfires
- Maneuver
- Protection
- Sustainment



Potential Capabilities:
- SFAT, Combined Arms, LRPF, Attack Helicopters, AMD

Primary Functions:
- Counterfires
- Maneuver
- Protection
- Sustainment



Potential Capabilities:
- SFAT, Combined Arms, LRPF, Attack Helicopters, AMD

Primary Functions:
- LRPF and Counterfires
- Extended Range Maneuver
- Extended Protection
- Contested, Extended Logistics

Fighting the PLAA will challenge the US Armed Forces' ability to deploy responsively over great distances, rapidly dominate, and sustain operations over long and contested lines of communication for the duration. The US Army's ability to seize and hold terrain and close with and destroy the enemy remains critical to success.