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Army and Marine Corps Active Protection System (APS) Efforts

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Summary

Active Protection Systems (APSs) are subsystems integrated into or installed on a combat vehicle to automatically acquire, track, and respond with hard or soft kill capabilities to a variety of threats, including rocket-propelled grenades (RPGs) and anti-tank guided missiles (ATGMs). APS technologies are not new, and a number of nations have already employed APS on the battlefield. The U.S. military is now beginning to include APS as part of its formal combat vehicle modernization plans and, if the initial deployment of APS proves successful, could expand the use of APS to potentially thousands of tactical military vehicles—a complex and potentially costly undertaking.

The proliferation of advanced RPGs and ATGMs is of concern to some defense officials and policymakers, including Congress. These weapons—RPGs in particular—have been particularly popular with insurgents because they are readily available, relatively inexpensive, and require little training. Israel's experiences with RPGs and ATGMs in the 2006 Israel-Lebanon War and the 2014 Gaza Conflict and growing concerns with Russian military capabilities and activities in Eastern Europe have possibly served as catalysts for intensifying U.S. APS efforts. Technical and operational challenges to APS include being able to work under extremely demanding circumstances and compressed timelines, robustness against countermeasures, minimizing the threat to friendly forces and civilians, being compatible with the space and power allocated to it on the vehicle, and affordability.

A number of nations have operationally deployed APS on combat vehicles—Russia and Israel most notably—and some experts characterize U.S. efforts as somewhat lagging. U.S. military officials contend there are still a number of developmental and safety challenges that must be overcome before current APS systems are suitable for battlefield deployment.

According to the U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC), "Active Protection Systems have been in the design and development stages since the early 1950s, but none have successfully made the transition from development to integration on a platform."

The Army's and Marines' current APS efforts are described as technology demonstrations and have not progressed to formal Programs of Record. The Army and Marines are coordinating their respective efforts, although no joint program currently exists. The Army is currently involved in two separate parallel and distinct APS efforts—the Expedited, Non-Developmental Item (NDI) APS effort and the Modular Active Protection System (MAPS) effort. The Marines describe their APS efforts as a "technology demonstration" whereby the Marines would attempt to install a Trophy APS on the M-1A1 tank in coordination with the Army's Expedited NDI effort. The Marines have a number of unique APS requirements—including the ability to be transported by ship and withstand salt water corrosion—which will also factor into their eventual APS plans.

Potential issues for Congress include whether current NDI APSs are effective and safe enough for operational use, the benefits of MAPS relative to non-developmental efforts, MAPS' impacts on NDI APS performance and costs, the Army's and Marines' detailed plans for APS fielding, and APS adaptability to future threats.

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Why This Issue Is Important for Congress

Active Protection Systems (APSs) are subsystems integrated into or installed on a combat vehicle to automatically acquire, track, and respond with hard or soft kill capabilities to a variety of threats, including rocket-propelled grenades (RPGs) and anti-tank guided missiles (ATGMs). APS technologies are not new, and a number of nations have already employed APS on the battlefield. The U.S. military is now beginning to include APS as part of its formal combat vehicle modernization plans and, if the initial deployment of APS proves successful, could expand the use of APS to potentially thousands of tactical military vehicles—a complex and potentially costly undertaking. Congress, in its oversight and authorization and appropriations roles, has expressed interest in past and current U.S. military APS efforts and will likely continue to be actively involved as these technologies mature and possibly integrated onto U.S. combat vehicles.

The Need for APS

A combination of evolving threats, advances in technology, experiences in combat, and the possibility of future conflicts have served to heighten the perceived need to pursue APS for U.S. military use more aggressively. Some of the factors affecting current U.S. APS efforts are discussed in the following sections.

Proliferation of Advanced RPGs and ATGMs

RPGs

The proliferation of advanced RPGs and ATGMs is of concern to some defense officials and policymakers alike. Recently, the conflict in Syria has brought this concern into greater focus. These weapons—RPGs in particular—have been especially popular with insurgents because they are readily available, relatively inexpensive, and require little training.[1] RPGs are basically single man-portable, shoulder-fired, unguided rockets. RPGs have been widely proliferated but can be mitigated to a degree by installing passive nets and bar armor on vehicles and by tactics, techniques, and procedures. The Lexington Institute notes:

> The threats aren't standing still. Both Hezbollah and Hamas have acquired advanced Russian rocket-propelled grenades (RPGs) and anti-tank guided missiles (ATGMs), some with tandem warheads designed to defeat the reactive armor on most Western tanks. In its 2006 operation against Hezbollah, the Israeli Defense Forces lost a number of its top-of-the-line Merkava tanks and the lives of soldiers to these ATGMs. These same weapons have shown up in the hands of Ukrainian separatists.[2]

[1] David Hambling, "Russia Unveils "Abrams Killer" Rocket," *Wired*, November 28, 2008.

[2] Daniel Gouré, "Now Is The Time To Provide U.S. Armored Vehicles With Active Protection Systems," The Lexington Institute, August 3, 2015, http://lexingtoninstitute.org/now-is-the-time-to-provide-u-s-armored-vehicles-with-active-protection-systems/.

Figure 1. Russian RPG-30

Source: David Hambling, "Russia Unveils "Abrams Killer" Rocket," *Wired,* November 28, 2008.

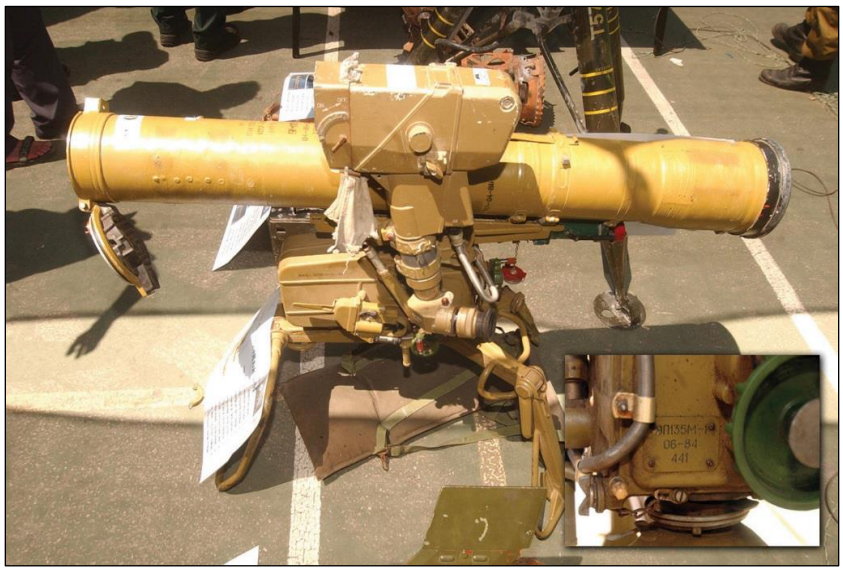
Figure 1 depicts a Russian RPG-30, which reportedly has a 105 mm tandem warhead supposedly capable of penetrating over 650 mm of steel armor, even if it is located behind reactive armor[3]—a central armor protection feature on a number of modern tanks.[4] The RPG-30's special feature is a second tube that fires a smaller-caliber decoy rocket a fraction of a second before the main rocket fires. This design is intended to cause an APS to engage the decoy rocket instead of the main rocket. A wide variety of both traditional, less sophisticated RPGs (such as the RPG-7) and advanced RPGs are being employed on battlefields throughout the world by both armed forces and non-state actors.

[3] Hambling. Introduced in the 1980s, reactive armor consists of explosive tiles mounted on top of traditional steel armor, which detonates when struck by a projectile in order to disrupt the armor-piercing jet produced by RPG, ATGM, and main gun-shaped charges.

[4] Information in this section is taken from David Hambling, "Russia Unveils "Abrams Killer" Rocket," *Wired*, November 28, 2008.

ATGMs

Figure 2. Russian Konkurs ATGM



Source: MAJ Michael J. Trujillo and MAJ Frank Adkinson, "Getting Left of Launch: Guided Missiles and the Threat to Our Force," U.S. Army *Armor* Magazine, January-March 2016.

Notes: This ATGM was reportedly captured in southern Lebanon in 2006 by Israeli Defense Forces.

Figure 2 depicts a Russian Konkurs ATGM. Open-source U.S. military analysis reports there are eight types of ATGM systems currently in use by non-state groups operating in Syria—including the U.S-made Tube-Launched, Optically Wire-Guide (TOW) ATGM.[5] It is estimated by U.S. military sources that 130 countries and various non-state groups—including Jabhat al-Nusrah and the Islamic State in Iraq and Syria—have ATGMs. ATGMs have some tactical advantages over weapons such as Improvised Explosive Devices (IEDs) and RPGs, as ATGM gunners can attack targets from several thousands of meters outside the range of direct fire. They also have some disadvantages. For example, the Konkurs ATGM in **Figure 2** has a 4 kilometer range, which, while providing a great deal of standoff protection, can also reduce the accuracy of the ATGM as the operator could lose track of the intended target at such an extended range. Most ATGMs in use require little operator training—due to the effectiveness of the link between the missile and its launcher—and operators tend to build proficiency with their systems relatively quickly.

The 2006 Israel-Lebanon War and the 2014 Gaza Conflict

Some experts cite Israeli combat experiences in 2006 and 2014 as demonstrative of the value of APS. In July 2006, after Hezbollah rocket and missile attacks killed and wounded a number of Israeli soldiers, Israel launched a series of air and ground attacks against a number of Lebanese towns and villages. Some analysts believe the war ended inconclusively and later characterized Israeli ground operations as "ineffective." Hezbollah's use of RPGs and ATGMs was considered a major factor in the conflict. One study notes Israel's "armored forces [were] not prepared for

[5] Information in this section is taken from MAJ Michael J. Trujillo and MAJ Frank Adkinson, "Getting Left of Launch: Guided Missiles and the Threat to Our Force," U.S. Army *Armor* Magazine, January-March 2016.

swarming[6] of Hezbollah ATGMs and other anti-tank weapons [RPGs]."[7] Specifically, about 50 Israeli Merkava tanks were reportedly hit by ATGMs and about 20 of these tanks were penetrated, resulting in 23 crew casualties. ATGMs also reportedly produced major casualties among dismounted infantry forces who were occupying buildings. Anti-tank weapons were credited with causing the majority of Israeli casualties during the war.

These lessons and others were apparently not lost on the Israeli Defense Forces (IDF).[8] In late 2010, Israel began to install the Trophy APS on Merkava tanks and Namer armored personnel carriers (APCs).[9] In July 2014, after rocket attacks against Israeli cities and infrastructure targets, Israel undertook military operations in the Gaza Strip designed to stop the rocket attacks. The operation lasted until the end of August 2014. Hamas anti-armor operations were deemed less effective than in 2006. One report suggests:

> Hamas was less effective with these tactics. Not a single IDF tank was confirmed destroyed, nor were any Namer heavy APCs lost in combat. Other armored vehicles appeared more vulnerable, including the aging M113 APC, in which seven Israeli troops were killed in an RPG blast. Armored corps personnel were killed and wounded by sniping and mortar fire, but by and large Hamas anti-tank weapons and tactics were not of great effect. This was due to the Trophy anti-ATGM system employed on Merkava Mk 4 tanks, the protection provided by Merkava tanks and Namer APCs, and probably Israeli tactics that employed heavy firepower against ATGM threats.[10]

Given the contrast between Israel's combat experiences in 2006 and 2014, U.S. defense officials, who might have originally been skeptical about the effectiveness of APS, may have taken a renewed interest in adapting APS for use on U.S. combat vehicles.

Concerns with Russian Military Capabilities and Activities in Eastern Europe

According to one defense expert:

> In the aftermath of the Ukraine invasion, Western military planners no longer think they can predict how Russian leader Vladimir Putin might react to perceived provocations or opportunities. So the possibility of war in Europe is back on the table as a priority concern, and that means land warfare in which the U.S. Army would have to carry most of the burden.[11]

Some senior U.S. military leaders have suggested a "resurgent" Russia is the "nation's top national security threat,"[12] with some claiming the U.S. Army is "outranged and outgunned by

[6] Swarming refers to massing a number of weapons against an individual target hoping to overwhelm its defenses and destroy it with multiple, near-simultaneous, attacks.

[7] Information in this section is taken from Anthony H. Cordesman, "The Lessons of the Israeli-Lebanon War," Center from Strategic & International Studies (CSIS), Washington, DC, March 11, 2008.

[8] From CRS Meeting with Israeli Ministry of Defense officials, June 27, 2016.

[9] Yuval Azulai, "Anti-Tank Missile Defense System Makes Debut," GLOBES – Israel's Business Arena, July 20, 2014.

[10] Jeffrey White, "The Combat Performance of Hamas in the Gaza War of 2014," CTC Sentinel, The Washington Institute, Washington, DC, September 2014.

[11] Loren Thompson, "War in Europe: Why the Army is Worried," *Forbes*, December 11, 2015.

[12] Dan Lamothe, "Russia is Greatest Threat to the U.S. says Joint Chiefs Chairman Nominee Gen. Joseph Dunford," *Washington Post*, July 9, 2015 and David Vergun and Lora Strum, "Russia Greatest Threat to U.S., Milley Tells Lawmakers," U.S. Army News Service, July 21, 2015.

many potential adversaries."[13] Others contend, however, the heavy emphasis placed on the Russian threat is merely a ploy by the Army to gain "a bigger chunk of the budget."[14]

Aside from these competing views, the Army, Marines, and the Department of Defense (DOD) have expressed concerns about the vulnerability of U.S. armored vehicles to evolving anti-tank threats.

Basic APS Considerations and Theory

Proposed Criteria for a Successful APS

It has been suggested that an APS should meet both technical and operational criteria to be effective, including

- be able to work under extremely demanding circumstances and compressed timelines;
- be robust against countermeasures;
- minimize the threat to friendly forces and civilians;
- fit in the space and power allocated to it on the vehicle; and
- be affordable.[15]

Detection and Response

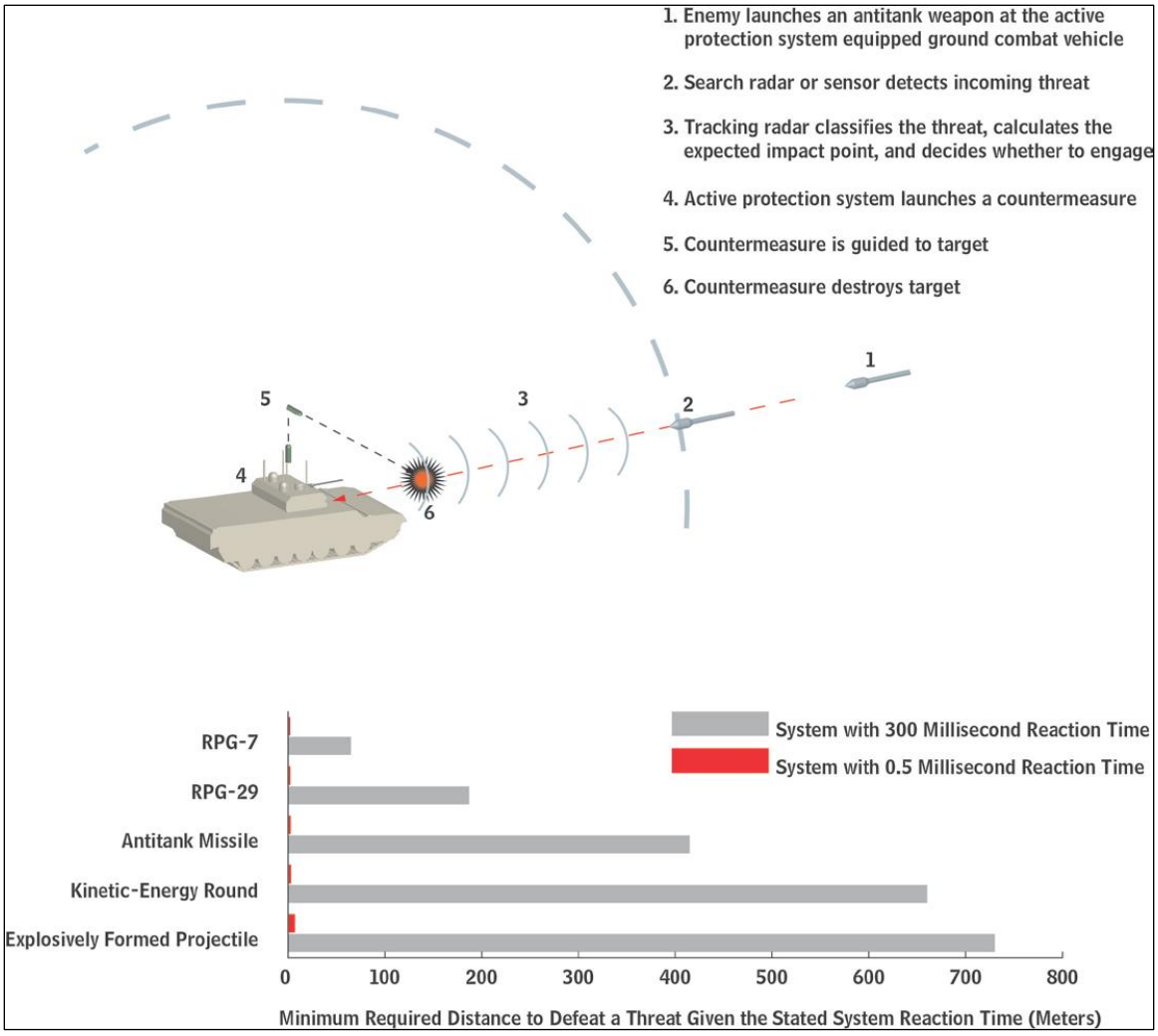
An effective APS requires a capability to detect and classify incoming projectiles. The means by which this is accomplished is small on-board radars and/or sensors such as optical sensors. Once detected and classified in very short order, the system calculates an intercept point away from the vehicle and, if the projectile poses a threat to the vehicle, countermeasures (soft kill and/or hard kill) are employed to defeat the incoming threat. This entire transaction is accomplished almost simultaneously; the closer the point of attack, the more critical this becomes. This sequence of events is depicted in the following figure:

[13] Opening Statement of Senate Armed Services committee Chairman Senator John McCain at Hearing on U.S. Army Posture, April 7, 2016, http://www.mccain.senate.gov/public/index.cfm/2016/4/opening-statement-by-sasc-chairman-john-mccain-at-hearing-on-u-s-army-posture.

[14] Mark Perry, "War Room: The U.S. Army's War Over Russia," *Politico,* May 12, 2016.

[15] Bernard Kempinski and Christopher Murphy, "Technical Challenges of the U.S. Army's Ground Combat Vehicle Program," Congressional Budget Office Working Paper 2012-15, November 2012, p. 26.

Figure 3. Example of APS Hard-Kill Sequence of Events and Minimum Required Distances for Engagement



Source: Bernard Kempinski and Christopher Murphy, "Technical Challenges of the U.S. Army's Ground Combat Vehicle Program," Congressional Budget Office (CBO) Working Paper 2012-15, November 2012, p. 25.

Notes: "Quick reaction times are essential for an active protection system to be effective. A system with a reaction time of 300 milliseconds would be able to intercept a typical antitank missile only if it was launched from at least 400 meters away; intercepting an RPG-7 would require that it be launched from at least 30 to 100 meters away. By contrast, a system with a reaction time nearly 100 times faster (0.5 milliseconds) could intercept antitank missiles and RPG-7s launched from within 10 meters of the vehicle," p. 26.

Coverage

Ideally, an APS should provide "hemispheric" coverage to combat vehicles. This is particularly important, as some advanced countries have designed weapons that can use advanced infrared or radar sensors and guidance to attack the tops or engine compartments of vehicles,[16] which are usually less armored than the front, sides, and underside of armored fighting vehicles (AFVs).

[16] Ibid., p. 18.

However, absent hemispheric coverage, APS coverage of certain aspects of a vehicle might still be sufficiently effective to justify its adoption for use. Another important aspect of coverage is the APS's ability to address multiple incoming attacks. Common enemy tactics involve using multiple RPGs and/or ATGMs against a single vehicle, as was seen in Gaza in 2006. The aim of these "swarm" attacks is to overwhelm a vehicle's defenses and improve the chances of disabling or destroying the vehicle with multiple hits. APS's that cannot respond to multiple, incoming threats from different directions are considered by some experts as of limited utility. Also, it is considered an important capability that, after being attacked, an APS can quickly be reloaded or "reconstituted" to respond to further attacks.

"Hard Kill"

CBO's 2012 report on "Technical Challenges of the U.S. Army's Ground Combat Vehicle Program" defines APS "hard kill" as follows:

> A hard-kill active protection system detects, engages, and destroys or neutralizes an incoming threat before it can hit a protected vehicle, actively firing some type of projectile to intercept the threat.[17]

"Soft Kill"

CBO's 2012 report also provides a comprehensive treatment of the "soft kill" features of the APS:

> Soft-kill countermeasures include infrared jammers, laser spot imitators, and radar jammers. They may prevent missile guidance from remaining locked onto the GCV [Ground Combat Vehicle],[18] protecting the vehicle by causing the missile to miss the target or preventing the weapon warhead from fusing. However, countermeasures have proven difficult to implement in practice because they must be tailored to a particular threat; they are not an umbrella defense that would work on a wide range of threats. For example, a millimeter wave radar jammer will not work against an infrared tracker.
>
> Furthermore, when jammers offer umbrella coverage (broadband or barrage jamming), they can also have negative effects on friendly communications and electronic systems. That drawback limits their usefulness in some situations. For example, some barrage jammers used to counter IEDs in Iraq and Afghanistan disrupted normal radio communications for U.S. soldiers.
>
> Employing defensive electronic countermeasures in ground combat can have unexpected consequences: small changes in some parameters, such as radio frequencies, antenna shapes, or orientation, can cause large changes in effectiveness. In recent conflicts, the enemy has proven adaptive and agile in employing new techniques to stymie the Army's countermeasures. As a result, defensive electronic countermeasures cannot be relied on for complete protection.[19]

Although some tend to focus on the "hard kill" aspects of APS, Army officials note that for the majority of ATGMs in use, most of these systems are highly susceptible to "soft kill" APS, which underlies the importance of both soft and hard kill capabilities.[20] In addition, current Army "soft

[17] Ibid., p. 24 and pp. 27-28.

[18] The Army's Ground Combat Vehicle or (GCV) was an Army program to develop a new infantry fighting vehicle (IFV) to replace the M-2 Bradley IFV, which has been in service since the 1980s. The GCV program was cancelled in 2014 by DOD due to budgetary concerns.

[19] Kempinski and Murphy, p. 28.

[20] Information in this section is from a CRS meeting with U.S. Army Tank Automotive Research, Development and (continued...)

kill" efforts focus on defeating electro-optical/infrared (OE/IR) ATGMs.[21] Furthermore, Army officials contend EO/IR jammers that operate in the communications and electronic spectrum widely employed by remotely detonated Improvised Explosive Devices (IEDs) are not effective against ATGMs, and the use of smoke and obscurants can also be effective against ATGMs.[22]

APS Operational and Developmental Challenges

As noted in the previous sections, the basic science and engineering of APS present a number of challenges.[23] These challenges are exacerbated by the possibility that an enemy may employ tactics and techniques, as well as defensive measures, to neutralize the effectiveness of the APS. Those measures may vary "from sophisticated jammers and decoys to simply firing a volley of cheap and widely available rocket-propelled grenades to overwhelm the defense."[24] A general description of armored vehicle survivability challenges, as well as additional developmental challenges (in no particular order of priority), is discussed in the following sections.

Armored Vehicle Survivability

Challenges: When upgrading armored vehicles for survivability, tradeoffs must be considered. To enhance survivability, the traditional approach has been to add additional armor. Adding additional armor, however, increases the vehicle's weight, which can affect both performance and where it can be employed on the battlefield (vehicles can become too heavy to operate on roads and in certain types of terrain). Additional armor also affects a vehicle's power system, fuel consumption, and suspension and can result in excessive wear, shortening a vehicle's useful life. Many defense officials believe that simply adding additional armor to address new threats is no longer practical for these reasons.

Unintended Casualties

Avoidance of unintended casualties—U.S. and allied soldiers and civilians—is a fundamental U.S. military principle. As CBO explains:

> Most of the active protection systems under development use explosive rounds as the intercepting device. The size of the intercepting projectiles varies from 105 mm high-explosive fragmenting warheads similar to artillery shells to smaller shaped charges. The risk of injury that the fragments and blast from those intercepting rounds would present to nearby soldiers, civilians, or other vehicles is a great concern. The fact that the intercepting rounds must be launched automatically without human intervention in order to meet the required timelines increases that concern. The United States and Israel have studied this problem and have tended to select interceptors for their systems that minimize—but do not eliminate—the hazard to people outside the vehicle.[25]

(...continued)

Engineering Center (TARDEC) and Program Executive Office (PEO) Ground Combat Systems (GCS) officials, June 30, 2016.

[21] Information provided to CRS by Army APS officials, August 12, 2016.

[22] Ibid.

[23] Information in this section is from Kempinski and Murphy, pp. 23-24.

[24] Ibid.

[25] Ibid., pp. 27-28.

Army officials further note the long-standing nature of the unintended casualties vs. effectiveness debate and point out that in a similar manner, reactive armor[26] also can pose a hazard to dismounted troops and civilians.[27] It is possible the threat posed to friendly soldiers and civilian non-combatants by the APS can only be reduced and not entirely eliminated, which poses a dilemma for the U.S. military. The desire to avoid unnecessary casualties could result in having to "switch off" the APS when vehicles and dismounted soldiers are operating in close proximity or when operating around civilians, such as in urban environments. Such constraints could limit the usefulness of APS in certain combat scenarios.

Collateral Damage

In a manner similar to unintended casualties, the U.S. military goes to great lengths—even in combat—to avoid collateral damage to private and public property. Provisions addressing collateral damage are frequently included in the Rules of Engagement (ROE) under which U.S. and allied forces routinely operate. Hard-kill APS carries an inherent risk of collateral damage, with the primary hazard being the automatic launch of an explosive counter-munition against an incoming high-velocity explosive threat. In this regard, hard-kill APS may pose a threat to private property—including religious and historically significant property. If the avoidance of collateral damage is of overriding military concern, the employment of APS in and around structures and property could be limited, adding another level of restriction to APS use and potentially further reducing its utility in a growing list of combat scenarios. Army officials contend, however, due to the relatively small size of counter-munitions, that incoming threat projectiles might pose a much more significant collateral damage threat.[28] In addition to limiting effectiveness, operational APS limitations could present tactical opportunities to potential adversaries who could take advantage of self-imposed APS restrictions.

Battlefield Considerations Affecting APS Operations

Although technologies under development might show promise in the laboratory or the testing range, how APS functions on the battlefield is the final determinant of effectiveness. CBO's 2012 report raises a number of battlefield-related considerations related to APS effectiveness:

> The available time [for the APS to activate] may be shortened further if the control system has trouble detecting the incoming rounds. Battlefield clutter (man-made objects or natural features that create false signal echoes) can reduce the detection range of the system and create false targets. Enemy radar jammers may have the same effect. As a result, the active protection system may be delayed in detecting, or not ever detect, the less time it has to react.
>
> Once the active protection system detects an incoming round, it must track the round for a period of time to determine if the trajectory poses a danger to the vehicle. Most systems do this by calculating whether the round will pass through a zone it deems a protected area. The system will attempt to intercept any incoming round that it predicts will enter this area. Demonstrations by contractors suggest that the systems may be capable of doing this in simple one-on-one situations, **but how the systems will work in a situation where many active protection systems are operating side by side, with overlapping sectors of coverage and with multiple incoming threats, remains to be seen** [emphasis

[26] See footnote 3 for a description of reactive armor.

[27] Information provided to CRS by Army APS officials, August 12, 2016.

[28] Information provided to CRS by Army APS officials, August 12, 2016.

> added by CRS]. What will happen when multiple vehicles classify an incoming round as a threat? How do they coordinate a response? Those questions remain largely unanswered.
>
> Coordinating the defensive fire among vehicles implies that the systems communicate with each other. Can the communications networks handle that traffic in the very short time required? Furthermore, there is the potential for mutual interference from having many radar systems transmitting in close proximity. Will the systems end up jamming each other? How to address mutual interference and how to allot defensive fire from multiple systems that might be in the protected area are technical issues whose solutions have not yet been determined.[29]

APS might also have an impact on a combat vehicle's overall electro-magnetic "signature." Based on the number of APS sensors employed in a given area, the Army might need to limit the number of systems in that area to avoid mutual interference.[30] These considerations are illustrative of the challenges of integrating APS for use on the battlefield. It is not just enough that the system functions as the scientists and engineers envision, but it must successfully operate in a complex physical and electronic combat environment as well, where, all too often, the "fog of war" greatly affects the actual performance of weapon systems.

Size and Power Requirements

The components of an APS include some form of threat detection, a tracking system, signal processing systems, and the actual countermeasures systems. These components are mounted both outside and inside of the protected vehicle. In addition, these components require power—either from batteries or power generated from the vehicle. Because U.S. APS systems could initially be retrofitted to existing combat vehicles, there could be difficulties in installing APS components inside already space-constrained vehicles. How to power the APS, particularly if it relies on power generated from the vehicle, is another question for retrofits. It is possible that size, weight, and power constraints (referred to as SWAP) could dictate what type of APS is adopted for use, which could result in a less than optimal design and a decreased level of protection. The Army notes legacy combat vehicles, such as the M-1 Abrams tank, were not designed to support the additional size, weight, and power that APS would require.[31] In the case of vehicles under development, it is likely APS size and power requirements will be incorporated into the vehicle's design so SWAP requirements should be less of a factor when selecting an APS system. In this regard, Army officials point out that the Israeli Merkava Mark 4 tank was designed around the Trophy APS.[32] The Army's Modular Active Protection System (MAPS) effort, described below, is intended to address these issues.

Closed vs. Open Architecture[33]

Whether the Army and Marines adopt a non-developmental APS for use and/or develop an APS, the decision to employ closed or open architecture systems will likely be a key issue for defense officials and policymakers. Closed APS systems are described as being "hard-wired" together,

[29] Ibid., pp. 26-27.

[30] Information provided to CRS by Army APS officials, August 12, 2016.

[31] Ibid.

[32] Ibid.

[33] Unless otherwise noted, information in this section is taken from Sydney J. Freedberg, Jr., "Army Pushes Missile Defense for Tanks: MAPS," *Breaking Defense,* April 25, 2016.

which, while having certain attributes such as lower initial development costs and high levels of performance,[34] are not considered by some officials as adaptable as open or "modular" systems. For example, in an open architecture APS, if the enemy figures out how to jam radars or defeat countermeasures, theoretically affected sensors and countermeasures can be removed and new sensors and/or countermeasures can be "plugged" in their place; in a closed system, the entire system might have to be redesigned or upgraded. U.S. defense officials are said to favor an open architecture for any new APS development so that "new features can be fielded quickly as new anti-vehicle threats emerge."[35] The Army notes their emphasis on open architecture is derived from broad DOD guidance issued in the Defense Acquisition Guidebook and DOD Instruction 5000.02, *Operation of the Defense Acquisition System*.[36] The Army also has contracts and is working with industry to develop standards for implementing an open systems approach for APS.[37] Furthermore, the Army warns there would likely be significant costs to bring what they refer to as "vendor locked" APSs (APSs fielded or nearly fielded) into full compliance with U.S. safety boards and testing organizations requirements.[38]

Some in industry contend their systems are not truly "closed" systems as DOD suggests and incorporate modular design features, and that they are not "vendor locked" and are more safety compliant than has been suggested.[39] With some commercially developed APSs already in use (or close to being operational), policymakers will likely debate the merits of these systems in relation to the time and cost required to develop an open architecture APS that could be more adaptable, effective, and affordable over its extended lifecycle, as the Army claims.

Affordability

Aside from the procurement or developmental costs associated with closed and open APS, affordability issues will likely influence the Army and Marines' APS programs. The service's initial plans for APS is to install them on M-1 Abrams tanks and, if this proves successful, to expand use to other armored fighting vehicles and possibly to other tactical vehicles. The Army, however, notes it is the vehicle's base armor requirements that drive the selection of an APS, and APS efforts associated with Abrams, Bradleys, and Strykers might not prove feasible.[40] Should the Army opt to adopt a NDI APS, there could be several hundreds of vehicles in active and reserve forces receiving a NDI APS. Fielding a NDI APS capability could prove to be a highly expensive undertaking for the Army and Marines, particularly if the APS adopted for use has a high per-unit cost. Other associated costs that could affect the overall affordability of APS include associated training, installation, and maintenance costs—including the cost of repair parts and components, as well as who does the repairs and maintenance (contractors or servicemembers). The frequency of required APS software and hardware updates will also contribute to overall costs.

[34] Michael Hanratty, Robert H. Lightsey, and Arvid G. Larson, "Open Systems and the Systems Engineering Process," Acquisition Review Quarterly, Winter, 1999, pp. 47-60.

[35] Sebastian Sprenger, "Renewed Interest Brewing in Piloting Field-Grade Vehicle Protection Systems," *Inside Defense*, January 15, 2016.

[36] Information provided to CRS by Army APS officials, August 12, 2016.

[37] Ibid.

[38] Ibid.

[39] From CRS discussions with industry officials.

[40] Information provided to CRS by Army APS officials, August 12, 2016.

A Brief History of Selected U.S. APS Efforts

According to the U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC), "Active Protection Systems have been in the design and development stages since the early 1950s, but none have successfully made the transition from development to integration on a [U.S.] platform."[41] In the late 1990s, for example, the Defense Advanced Research Projects Agency (DARPA) led efforts to develop "a small, low-cost, fully self-contained active defense system for military vehicles and high value assets."[42] The system, designated SLID for "Small, Low-cost, Interceptor Device," was intended to protect from missile and artillery threats.[43] In 1998, the Army was involved in a program designated the Counter Active Protective Systems (CAPS), which was intended to develop a suite of capabilities—including electronic countermeasures, advanced, long stand-off warheads, decoys, and ballistic hardening countermeasures—that could be mounted on tanks.[44]

APS development figured prominently in the Army's Future Combat System (FCS) program,[45] which began in 1999. According to the Government Accountability Office (GAO), in 2005 the lead systems integrator for the FCS program sought proposals from industry for a developer who could design and deliver an APS prototype that could be mounted on current combat vehicles by 2009 and tested on FCS vehicles in 2011.[46] The FCS program was cancelled in 2009. It was decided, however, to continue work on both developing an APS for use on combat vehicles as well testing existing APS systems that could be mounted on combat vehicles to meet urgent operational needs until an APS could be developed and fielded.

Although the United States has been exploring APS technologies since the 1950s, other nations have developed and successfully fielded APS to their forces. The first operational APS—the Drozd—was developed by the Soviet Union between 1977 and 1982.[47] Designed to protect against RPGs and ATGMs, it used primitive millimeter-wave radar sensors mounted on each side of the tank's turret to detect incoming rounds. The Drozd covered only the forward 60 degrees of the turret, but the tank crew could rotate the turret to change the tank's protective profile. The Drozd was reported 80% successful against RPGs in Afghanistan. In the late 1990s, France mounted the Galix countermeasures system on its Leclerc main battle tanks.[48] The turret-mounted Galix provided 360-degree coverage and could automatically fire 80 mm smoke rounds, anti-

[41] S. Durbin, N. Fountain, and W. Norton, *TARDEC Active Protection System Compliance Plan*, U.S. Army Tank-Automotive Research, Development, and Engineering Center, Warren, MI, August 17, 2010, p. 1.

[42] CPT Tom J. Meyer, "Active Protective Systems: Impregnable Armor or Simply Enhanced Survivability?," U.S. Army *Armor* Magazine, May-June 1998, p. 11.

[43] Ibid.

[44] Ibid.

[45] The Future Combat System (FCS) was a multiyear, multibillion-dollar program at the heart of the Army's transformation efforts. It was to be the Army's major research, development, and acquisition program and was to consist of 14 manned and unmanned systems tied together by an extensive communications and information network. FCS was intended to replace current systems such as the M-1 Abrams tank and the M-2 Bradley infantry fighting vehicle. The FCS program was cancelled in 2009 by the Secretary of Defense, primarily due to budgetary considerations.

[46] U.S. Government Accountability Office, Report to the Chairman, Subcommittee on Air and Land Forces, Committee on Armed Services, House of Representatives, Defense Acquisitions: Analysis of Procedures Used to Evaluate Active Protection Systems, GAO-07-759, June 2007.

[47] Information in this section is taken from Meyer, p. 8.

[48] Ibid., p. 10.

personnel rounds, or decoy rounds.[49] Israel has employed APS operationally on selected vehicles since the late 1990s and, as previously discussed, has recently employed its Trophy APS extensively in combat in 2014, with plans underway to expand its use with Israeli forces. Currently, Russia's newest tank, the T-14 Armata, has separate hard kill and soft kill APSs.[50] Although these systems reportedly have multiple sensors and launch tubes, the Armata's APS supposedly covers only against threats lateral to the turret, meaning that there is no protection against guided missiles that are air-launched or have a top-attack mode.[51]

Contemporary U.S. Army Experience with APS

In March 2006, a contract potentially worth $70 million was awarded to Raytheon to develop an APS for FCS-manned ground vehicles as well as the Army's fleet of combat vehicles. The APS program came under public criticism in September 2006 when a press report alleged that the Army rejected the Israeli-developed Trophy APS for use in the FCS program, despite the system being successfully tested on U.S. combat vehicles.[52] The report further contended the Army was favoring the APS system in development by Raytheon over the Trophy system because of "money and politics" and that U.S. forces in the field were suffering casualties because of this decision.[53] A GAO report, however, maintains there was no conflict of interest, concluding:

> No officials from the offering companies participated in the evaluation and all offers were evaluated based on the same criteria. Four proposals were evaluated and three were determined to be comparable in terms of cost and schedule. The winner—Raytheon—was chosen on technical merit, as being more likely to meet APS requirements although its design had less mature technology.[54]

Among the Army's concerns was that the Trophy system had a single-shot capability.[55] The Army also believed the Raytheon system would result in less collateral damage than the Trophy system. The Army suggested that adopting the Trophy system could provide soldiers with a "false sense of security" and also suggested that the Raytheon-developed system was progressing favorably, noting it had intercepted live warheads during testing.

Section 216 of the Fiscal Year 2008 National Defense Authorization Act (P.L. 110-181) required the Secretary of Defense to conduct live fires tests of foreign and U.S. APSs suitable to protect wheeled tactical vehicles—especially light wheeled tactical vehicles—to determine their effectiveness and develop information that could be useful for defense acquisitions.[56] The Army notes the major findings of these tests were as follows:

- none of the systems tested were mature enough for fielding;
- further development and testing and evaluation standards were needed;

[49] Ibid.

[50] Nick de Larrinaga, "Return of the Bear, J*ane's Defence Weekly,* March 16, 2016. p. 27.

[51] Ibid.

[52] Adam Ciralsky and Lisa Meyers, "Army Shuns System to Combat RPGs," MSNBC.com, September 5, 2006.

[53] Ibid.

[54] U.S. Government Accountability Office (GAO), Report to the Chairman, Subcommittee on Air and Land Forces, Committee on Armed Services, House of Representatives, Defense Acquisitions: Analysis of Processes Used to Evaluate Active Protection Systems, GAO-07-759, June 2007, Executive Summary.

[55] Information from this section is from an Army FCS Briefing given to CRS on September 7, 2006.

[56] P.L. 110-181, National Defense Authorization Act for Fiscal Year 2008, January 28, 2008, p. 37.

- industry claims were not successfully demonstrated;
- systems were not fully deployable or tested under operationally realistic conditions; and
- there was no U.S. military concept of operations, or tactics, techniques, or procedures for APS use.[57]

In 2013, U.S., British, and Canadian evaluations of commercially available APS revealed that "APS was deemed too high risk" and "APS was not currently ready to field."[58] Presently, Army officials suggest that the fielding challenges and risks associated with non-developmental APS systems have not changed since 2013 but instead battlefield threats and the operational environment have changed—thereby emphasizing the need for an APS-like capability.[59]

Selected APSs in Use or Under Development

A survey of international industry suggests there are a number of systems either in use or under development that could qualify as "active protection" systems. The following systems have been featured in press articles and have been associated with DOD APS efforts. According to the Marines, it should be noted that these systems are hard kill systems and not illustrative of what industry has previously developed.[60] According to defense officials, the systems listed here will require additional funding and investment to further test, validate vendor claims, and integrate into selected vehicles.

Israel's Trophy System[61]

Rafael, the developers of Trophy, considers it "the world's only fully operational combat-proven APS." In terms of system performance, Rafael contends that Trophy

- "Provides protection against all known chemical energy threats, including chemical energy tank rounds;
- Proven high kill probability;
- Offers 360 degree protection in azimuth, as well as extensive elevation coverage;
- Operates in challenging combat scenarios: short range, on the move, multiple/simultaneous shots from one or different directions;
- Proven built-in Hostile Fire Detection(HFD) capability;
- Safety certification process (Fuze Board)[62] completed;

[57] Information provided to CRS by Army APS officials, August 12, 2016.

[58] Information in this section is from a CRS meeting with U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and Program Executive Office (PEO) Ground Combat Systems (GCS) officials, June 30, 2016.

[59] Ibid.

[60] Information in this section was provided to CRS by Marine Corps APS officials, August 11, 2016.

[61] Information in this section is taken from a CRS meeting on June 27, 2016 with representatives from Rafael Advanced Defense Systems, DRS Technologies, and the Israeli Ministry of Defense.

[62] Refers to the Army Fuze Safety Review Board which has been in existence since the 1960s and is charged with determining if an adequate level of safety exists in the designs of fuzes and safety and arming devices (S&As) developed and fielded by the US Army for all non-nuclear munitions. Items reviewed by the Board include all initiating systems for Army non-nuclear projectiles, warheads, payloads, hand emplaced munitions (or ordnance), Pyrotechnic (continued...)

- Independent tests prove minimal risk to civilians, dismounted troops and nearby vehicles;
- Pre-defined safety zone for friendly troops on the ground can be defined; and
- Proven capability to fully operate with other radio frequency (RF) systems (radars, electronic warfare, radio, data, etc.) in a close proximity."[63]

Trophy was introduced operationally in 2009 and is an integral part of Israel's Merkava MK4 main battle tank. U.S. Army officials, however, have expressed reservations about some of Trophy's advertised capabilities, noting that Trophy is compliant only with Israeli Fuze and Safety boards and that RF operational and other performance capabilities claims are based solely on Israeli testing and experiences.[64]

Israel Military Industries (IMI) Iron Fist[65]

From IMI's Iron Fist web page:

> Iron Fist provides a combined Soft-and Hard-Kill Active protection System, adaptable to various platforms from light vehicles to heavy AFVs.
>
> Iron Fist employs a sophisticated, multi-sensor early warning system, utilizing both infrared and radar sensors, providing the crew with enhanced situational awareness and early warning from potential threats. Upon a threat warning, the modular system employs the multi-layered defenses, comprising electro-optical jammers, Instantaneous smoke screens and, if necessary, an interceptor-based hard kill Active Protection System (APS). The Iron Fist effectively protects against the full spectrum of Anti-Tank (AT) threats including AT Rockets fired at short range, in open area or urban environment, AT Guided Missiles, High Explosive AT and Kinetic Energy rounds.
>
> The Iron Fist is currently in advanced development at IMI. The company has installed the system for demonstrations in light and heavy armored vehicles, where Iron Fist capability demonstrators underwent full end-to-end interception tests, against all threat types, operating on the move and in urban scenarios. In these installations, Iron Fist proved highly effective, with its wide angle protection, minimal weight penalty and modest integration requirements.
>
> Iron Fist APS was selected by the Israel Defense Forces (IDF) as the Active Protection System designed to protect the Namer heavy infantry fighting vehicle.[66]

IMI further notes that Iron Fist is an open architecture system and can be integrated with other sensors and countermeasures. U.S. Army officials point out IMI is currently under contract to develop MAPS-compliant technologies to satisfy U.S. safety requirements.[67]

(...continued)

Initiated Explosive (PIE) ammunition, pyrotechnics, grenades, mines, dispensing systems, mine clearing devices, non-lethal weapons and other ordnance devices; http://www.ardec.army.mil/organizations/esic/AFMO/afsrb/index.aspx, accessed July 7, 2016.

[63] Ibid.

[64] Information provided to CRS by Army APS officials, August 12, 2016.

[65] Information in this section is taken from IMI website, http://www.imi-israel.com/home/doc.aspx?mCatID=68194, accessed July 8, 2016.

[66] Ibid.

[67] Information provided to CRS by Army APS officials, August 12, 2016.

Raytheon's Quick Kill System[68]

Raytheon has spent a decade developing its Quick Kill APS since its 2006 contract award to develop APS for the Army's FCS program. After FCS was cancelled in 2009, the Army awarded Raytheon another APS contract for the Ground Combat Vehicle (GCV) in 2012, but GCV (and APS) was defunded by the Army in 2014. Quick Kill APS, as it has evolved over the years, employs a maneuverable countermeasure approach whereby when a threat is detected, rounds are ejected from the top of the vehicle, and then maneuver to defeat the threat. Raytheon contends this approach is both simpler and safer than other APS systems, places a lower power burden on the defended vehicle, and involves much less software than current APS models. Quick Kill is a "hard kill" system exclusively. Raytheon also notes that their Quick Kill 2.0 version will be compliant with the Army's Modular Active Protection System (MAPS) program, which is described in later sections.

ARTIS's Iron Curtain System[69]

Virginia-based ARTIS produces the Iron Curtain APS. Iron Curtain is designed to protect against RPGs and other shoulder-launched threats and, theoretically, ATGMs by utilizing high-speed sensing and parallel processing to intercept and destroy threats inches from their intended targets. The Army notes that it could take from $5 million to $24 million to upgrade Iron Curtain so that it can address ATGM threats.[70] ARTIS contends that its near-vehicle defeat feature significantly reduces collateral damage, as well as threats to dismounted military personnel and civilians.

ARTIS claims that Iron Curtain is highly adaptable and can be mounted on a wide variety of ground vehicles, as well as rotary-winged aircraft, watercraft, and fixed sites such as buildings. Iron Curtain can be configured to protect fronts, sides, and the tops of vehicles and has the ability to classify targets and can address new and emerging threats, usually with just a software upgrade.

ARTIS began its Iron Curtain work in 2004 as a Defense Advanced Research Projects Agency (DARPA) project, culminating with a successful live-fire test in August 2013 and again in 2014 as part of the Army's GCV program.

Rheinmetall Defence's Active Defense System (ADS)[71]

Germany-based Rheinmetall Defence Systems (RDS) produces its Active Defence System (ADS), which employs both soft and hard kill defenses. It employs two independent sets of electro-optical sensors, which reportedly can detect, recognize, and neutralize threats in less than one millisecond and can defeat threats fired from less than 10 meters. Because of overlapping sensors and countermeasure redundancy, the ADS can respond to multiple incoming threats, and because threats are defeated in the immediately proximity of the protected vehicle, collateral damage is reduced. RDS claims that ADS can be modified to fit onto a range of vehicles, from tactical wheeled vehicles to tanks. U.S. Army officials note ADS is a fairly mature system and has undergone significant RPG and ATGM testing by U.S. NATO allies and has performed well.[72]

[68] Information in this section is taken from a CRS meeting on June 24, 2016, with representatives from Raytheon.

[69] Information in this section is taken from a CRS meeting with ARTIS on July 15, 2016.

[70] Information provided to CRS by Army APS officials, August 12, 2016.

[71] Information in this section was provided to CRS by Rheinmetall Defence Systems.

[72] Information provided to CRS by Army APS officials, August 12, 2016.

While ADS is considered a mature and capable system by the Army, it may require additional design work to address U.S. safety requirements.[73]

Current U.S. Army and Marine Corps APS Efforts

General[74]

Both Army and Marine officials emphasized to CRS that their respective APS efforts are not in any sense either acquisition programs or Programs of Record[75] by DOD definition. Although there is not a Joint Program Office (JPO) for APS, both services are working in concert on their respective APS programs, which they currently characterize as "vehicle capability assessments" and "technology demonstrations," respectively, as opposed to formal acquisition programs.

The Army's APS Effort[76]

The Army is currently involved in two separate parallel and distinct APS efforts—the Expedited, Non-Developmental Item (NDI) APS effort and the Modular Active Protection System (MAPS) effort.

Expedited, Non-Developmental Item (NDI) APS Effort[77]

The Army's Expedited NDI APS Program is focused on fielding an existing "hard kill" APS capability in the near term for the Army's M-1 Abrams tanks, M-2/3 Bradley fighting vehicles, and the M-1126 Stryker combat vehicle.[78] The requirement for the NDI APS is based on the previously discussed evolution of threats and the operational environment and the Army's anticipation of an operational need request from commanders in the field.

The Army's current NDI APS plans call for installing and evaluating commercially available APS systems on the M-1 Abrams and on the M-2 Bradley and M-1126 Stryker in FY2017 and FY2018. Testing and evaluation during this period will be limited to basically how the APS performs on the selected platforms and will not involve integration in current vehicle battle management systems or extensive live-fire testing. The Army's desired outcome for these activities is the development of a baseline APS system installation kit for NDI APS hardware, as well as evaluation data that will be used to inform future Army decisions. In FY2018, the Army

[73] Ibid.

[74] Information in this section is taken from CRS meetings with U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and Program Executive Office (PEO) Ground Combat Systems (GCS) officials, June 30, 2016, and Marine Corps Systems Command officials on June 28, 2016.

[75] A Program of Record describes a program that is funded (approved) across the Future Years Defense Plan (FYDP), through the Service's Program Objective Memorandum (POM). When designated a program of record, a program becomes a "line item record" in the budget. This is typically occurs with Milestone B approval, where a program is given "official" status as a development program. See Defense Acquisitions University "Ask a Professor," https://dap.dau.mil/aap/pages/qdetails.aspx?cgiSubjectAreaID=38&cgiQuestionID=106517, accessed July 7, 2016.

[76] Information in this section is taken from CRS meetings with U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and Program Executive Office (PEO) Ground Combat Systems (GCS) officials, June 30, 2016.

[77] Ibid.

[78] For additional information on these vehicles, see CRS Report R44229, *The Army's M-1 Abrams, M-2/M-3 Bradley, and M-1126 Stryker: Background and Issues for Congress*, by Andrew Feickert.

plans to decide how to proceed with the NDI APS effort, with options including beginning the process to acquire limited NDI APS for use or "shelving" it for future fielding should the situation warrant. A recent press report suggests the Army's NDI APS integration efforts plan to focus on integrating the Trophy system with the M-1 Abrams, the Iron Fist system with the M-2 Bradley, and the Iron Curtain system with the M-1126 Stryker.[79]

Modular Active Protection System (MAPS) Effort[80]

In parallel with the Expedited NDI APS effort, the Army is involved with the Modular Active Protection System (MAPS) effort. MAPS is—in and of itself—not an APS, but instead a modular framework and controller intended to enable the integration of commercial or government-provided APS subsystems (sensors and hard and soft kill countermeasures) for current and future combat vehicles. The Army describes MAPS as a sort of a "house hold electrical system" that can accommodate a variety of appliances and technologies—both current and future—without having to be rewired or upgraded every time a new component is installed. The Army contends MAPS should permit the rapid introduction of new technologies to respond to evolving threats while preventing "locking into" a single vendor and thereby promoting innovation in the commercial sector.

The Army's current MAPS plans call for continued development of a MAPS safety-compliant controller through the end of FY2019, as well as developing MAPS-compliant soft kill and hard kill countermeasures. As part of this effort, the Army is also examining how current NDI APS can be integrated into MAPS, thereby taking advantage of subsystems already in existence as opposed to developing new APS "from scratch." If successful and funds are available, the Army envisions transitioning MAPS to a Program of Record at some point in the future.

The Marine Corps APS Effort[81]

The Marines describe their APS efforts as a "technology demonstration" whereby the Marines would attempt to install an existing Trophy on the M-1A1 tank in coordination with the Army Expedited NDI effort. The Marines plan to conduct limited testing, leveraging whenever possible similar Army efforts, and do not plan to integrate the installed Trophy with any of the M-1A1's battle management and communications systems. The Marines would also examine the need to "harden" the current Trophy system so that it would meet survivability requirements.

Marine-Unique APS Requirements[82]

Marine officials emphasized that Marine-unique requirements, based on their amphibious assault mission, could have a significant impact on their decision to adopt the Trophy or some other APS.

[79] Jen Judson, "Army Testing Foreign Active Protection Systems for U.S. Combat Vehicles," *Defense News*, June 29, 2016.

[80] Information in this section is taken from CRS meetings with U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and Program Executive Office (PEO) Ground Combat Systems (GCS) officials, June 30, 2016.

[81] Information in this section is taken from a CRS meeting with Marine Corps Systems Command officials on June 28, 2016.

[82] Ibid.

"Hardening" the APS

Based on the Marines' M-1A1 concept of employment and its anticipated operational environment, it is likely that the Trophy APS will need to be "hardened" to protect it from small arms and artillery fire. In addition, it is likely additional armor protection will be needed to protect exposed tank crewmen from the Trophy's blast effects. These hardening efforts will add additional weight, bulk, and cost to the Marines' M-1A1s.

Additional Weight

Adding an APS capability to any combat vehicle—Army or Marine—will add weight to that vehicle and could affect performance as well as maintainability. In the Marines case, additional weight could affect the vehicle's ability to be accommodated aboard naval and commercial shipping. The Marines estimate adding Trophy to their M-1A1s could result in an overall vehicle weight increase of 2.5 to 3 tons, which could have a significant impact on its ability to be transported by ship.

In addition to shipping, the added weight of an APS could also affect the M-1A1's ability to be transported to shore by ship-to-shore "connectors" such as the Marines' Landing Craft, Air Cushioned (LCAC). It is unknown what impact—if any—this would have on operations. Part of the Marine Corps APS effort is intended to examine these potential issues.

Additional Bulk

Adding the Trophy or some other APS to M-1A1s could also affect the tank's ability to "fit" inside of commercial or naval vessels. The Marines have noted that embarked vehicles are often tightly packed onboard ships and the addition of APS components could affect the ship's overall load plan. One solution, should this prove to be the case, would be to dismount the APS before loading the M-1A1s aboard ship. This could have significant maintenance ramifications as well as operational considerations if the operating environment requires the APS to be reinstalled before the M-1A1 comes ashore.

Protection from Corrosion

Because M-1A1s would be embarked on ships for potentially lengthy periods, it is also necessary that APS components are protected from the corrosive effects of salt water. Protection from corrosion, as well as related maintenance requirements, could also affect the Marines' decision on adopting APS for use.

Recent Congressional Actions

The House Armed Services Committee and the Senate Committee on the Armed Services, as well as the House and Senate Appropriations Committees, included the following APS-related provisions in their respective FY2017 authorization and appropriations acts.

FY2017 National Defense Authorization Act (NDAA)

H.R. 4909 National Defense Authorization Act for Fiscal Year 2017[83]

Vehicle Active Protection Systems

> The committee is encouraged by the Army's current strategy for vehicle active protection system (APS) tests and integration. The committee believes this strategy will allow the Army to better address the threats posed by the growing proliferation of anti-tank guided missiles and rocket-propelled grenades. The committee is aware of the importance of vehicle APS capabilities for forward-deployed units, specifically those units in the U.S. European Command area of operations. The committee supports this effort and encourages the Army to expedite deployment and fielding of vehicle APS technology on ground combat vehicles that will form an essential element of the European Reassurance Initiative.
>
> The committee notes that the Army plans to conduct demonstration testing of mature vehicle APS capabilities on the Abrams main battle tank, the Bradley fighting vehicle, and Stryker combat vehicle. The committee encourages the Army to analyze options for incorporating vehicle APS solutions on additional vehicles, including the Joint Light Tactical Vehicle, and to identify the APS solutions that are best suited for deployment on lighter-weight combat and tactical vehicles.
>
> The committee directs the Secretary of the Army to provide a briefing to the Committee on Armed Services of the House of Representatives by March 1, 2017, on the status of plans to deploy and integrate mature vehicle APS technology on deployed ground combat vehicles.[84]

Subtitle E—Defense-Wide, Joint, and Multiservice Matters

M1 Abrams Tank (Modification)

> The budget request included $480.2 million in line item GA0700 of Procurement of Wheeled and Tracked Combat Vehicles, Army (W&TCV) for M1 Abrams Tank (Modification). The committee recommends an increase of $82.0 million in W&TCV for the procurement and integration of active protection systems (APS). Additional funding for APS was included in the Chief of Staff of the Army's unfunded priority list.[85]

TITLE II—RESEARCH, DEVELOPMENT, TEST, AND EVALUATION

Combat Vehicle Improvement Programs

> The budget request included $316.8 million in PE 0203735A for combat vehicle improvement programs. The committee recommends an increase of $12.0 million in PE 0203735A for the integration of active protection systems (APS) on Army armored

[83] Information in this section is taken from H.R. 4909 National Defense Authorization Act for Fiscal Year 2017, May 26, 2016.

[84] Ibid., pp. 56-57.

[85] Ibid., p. 20.

fighting vehicles. Additional funding for APS was included on the Chief of Staff of the Army's unfunded priority list.[86]

Items of Special Interest

Active Protection Systems

The committee encourages the Army, in cooperation with the United States Marine Corps, to rapidly acquire effective active protection systems (APS) to protect ground combat forces and weapon systems from projectiles including rocket propelled grenades and anti-tank, wire guided missiles. Key armored fighting vehicles such as M1 main battle tanks, Bradley fighting vehicles, Stryker vehicles, and armored assault vehicles should be given first priority for APS due to their mission profiles. The committee understands that APS technology is mature and fielded by some of our allies. The committee encourages the Army to acquire non-developmental, mature designs for integration and testing with our vehicles. The committee believes that such an effort will increase both force protection and combat power of our close combat maneuver forces.[87]

S. 2943 National Defense Authorization Act for Fiscal Year 2017[88]

Senate report contains identical language.

FY2017 Department of Defense Appropriations Bill

H.Rept. 114-577, Department of Defense Appropriations Bill, 2017[89]

Multi-Role Armament Systems

The Committee notes that the Army's combat vehicle modernization strategy has identified requirements for greater lethality for existing combat vehicles, in developing new platforms, and in maintaining technical superiority. The Army's modification of combat vehicles over the years has resulted in additional protection at the expense of mobility, and lagging increases in lethality. The Committee urges the Secretary of the Army to develop new armament systems for both current and future combat vehicles that will provide lethality overmatch as well as the ability to defeat multiple target sets, active protection systems, and lethal and non-lethal capability within the same weapon system.[90]

Active Protection Systems for Marine Corps Vehicles

The Committee is concerned with the growing threat to the warfighter from inexpensive shoulder-launched munitions such as rocket-propelled grenades and commends the Secretary of the Army for initiating the acquisition and testing of active protection systems that provide a higher level of survivability against these threats for Army ground

[86] Ibid., p. 52.

[87] Ibid., p. 63.

[88] Information in this section is taken from S.Rept. 114-255, National Defense Authorization Act for Fiscal Year 2017, May 18, 2016.

[89] Information in this section is taken from H.Rept. 114-577, Department of Defense Appropriations Bill, 2017, May 19, 2016.

[90] Ibid., p. 216.

vehicles. The Committee recommendation includes an additional $10,000,000 in overseas contingency operations/global war on terrorism funding to advance the development and testing of active protection systems. In addition, the Committee notes that the Marine Corps is currently leveraging Army investments on the Abrams tanks, and directs the Secretary of the Navy to consider conducting similar demonstrations on other Marine Corps ground vehicles.[91]

S.Rept. 114-263, Department of Defense Appropriations Bill, 2017[92]

The Senate Report contained no specific language addressing Army or Marine Corps APS issues.

FY2016 and FY2017 Army Budget Reprogramming Request

On August 12, 2016, DOD released a response from the four congressional defense committees to a budget reprogramming request submitted in April 2016 that included the following Army APS reprograming approvals:

- "Added $16.8 million is to support an expedited Non-Developmental Item (NDI) Active Protection System (APS) effort on the Stryker vehicle to assess the "Iron Curtain" APS system's reliability and the ability to mitigate the threat of Rocket Propelled Grenades (RPG's). The "Iron Curtain" is a downward firing APS designed to defeat only RPGs. The funding supports procurement of two prototype hardware "Iron Curtain" APS solutions for the installation and characterization that is required to assess its suitability and for integration onto the Stryker vehicle platform. Iron Curtain is a downward firing APS designed to defeat only RPGs. This is a new start. The estimated total cost of this effort is $31.2 million (FY2016, $16.8 million and FY2017, $14.4 million). The FY2017 funding is included in the FY2017 President's Budget request. This is a base budget requirement."
- "Added $11.0 million is to support an expedited Non-Developmental Item (NDI) Active Protection System (APS) effort on the Bradley vehicle to assess the "Iron Fist" APS system's reliability to mitigate the threat from Anti-Tank Guided Missiles (ATGMs) and Rocket Propelled Grenades (RPGs). The Iron Fist countermeasure uses a gimbaled launcher with a hard kill interceptor. Funding supports the procurement of 4 prototypes APS along with A-kit installation hardware and B-kit system hardware. This effort is required to assess its suitability for potential future integration onto the Bradley platform. This is a new start. The estimated total cost of this effort is $26.3 million (FY2016, $11.0 million; FY2017, $15.3 million). The FY2017 funding is included in the FY2017 President's Budget request. This is a base budget requirement."[93]

[91] Ibid., pp. 235-236.

[92] Information in this section is taken from S.Rept. 114-263, Department of Defense Appropriations Bill, 2017, May 26, 2016.

[93] DD-1415, April 2016 Prior Approval May 6, 2016, p. 6 and Courtney McBride, "Congress OKs Reprogramming for APS, ISR," *InsideDefense*, August 12, 2016.

Potential Issues for Congress

Are Current NDI APSs Effective and Safe Enough for Operational Use?

As previously noted, Army officials in 2016 suggested the fielding challenges and risks associated with non-developmental APS systems have not changed since 2013 but, instead, battlefield threats and the operational environment have changed, thereby perhaps "driving" the need for an APS-like capability.[94] In 2013, the Army noted APS was deemed too high-risk and not currently ready to field.[95] This statement seemingly suggests not much has changed from 2013 to present in terms of NDI APS improvements and raises the possibility that less-than-effective or safe NDI APSs could be adopted for operational use based on the perceived urgency of battlefield threats. However, it is also possible the services are overemphasizing their NDI APS concerns in hopes a "less-risky/more effective" APS can be developed in the future. In 2010, then Secretary of Defense Robert Gates admonished the services for "gold plating" systems, suggesting that a "70 to 80 percent solution in five years is better than a perfect outcome that could take decades, or worse, never materialize."[96] Given the Army's reservations about NDI APS and past DOD practices that some analysts have noted of seeking "perfect" technological solutions, Congress might examine the Army's and Marines' operational and safety requirements for NDI APS in relation to current APS offerings. Such an examination could help to determine if the Army and Marines are potentially "rushing" to the field a less-than-capable, risky APS based on pressure of a perceived threat or are, instead, waiting for a "perfect" solution in the future when the "70 to 80 percent" solution might be at hand. In this regard, it could be useful to characterize what a "70 to 80 percent" solution means in terms of vehicle and soldier survivability and what tradeoffs would be involved in adopting a NDI APS versus pursuing a longer-term effort.

What are the Benefits of MAPS Relative to Non-Developmental Efforts?

The Army's current APS efforts—NDI APS and MAPS—are being conducted in a resource-constrained environment where two somewhat parallel efforts might not be financially viable over the long term. Some have questioned if, under these budgetary constraints, the Army can afford both NDI APs and MAPS.[97] Dr. Daniel Gouré of the Lexington Institute suggests:

> While the Army continues to work within the science and technology community on MAPS, ... if the Army likes a system that works through the interim effort [NDI APS] it might want to "just call it a day and buy a bunch and then use the extra research and development money to go figure out the answer to another big problem it's got."[98]

[94] Information in this section is taken from CRS meetings with U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and Program Executive Office (PEO) Ground Combat Systems (GCS) officials, June 30, 2016.

[95] Ibid.

[96] Sandra I. Erwin, "Cutting Edge Weapons No Longer the Holy Grail," *National Defense*, November 2010.

[97] Sydney J. Freedberg, Jr., "Army Pushes Missile Defense for Tanks: MAPS," *Breaking Defense*, April 25, 2016.

[98] Jen Judson, "Army Testing Foreign Active Protection Systems for U.S. Combat Vehicles," *Defense News*, June 29, 2016.

As previously noted, the Army contends MAPS will permit the rapid introduction of new technologies to respond to evolving threats while preventing "locking into" a single vendor and thereby promoting innovation in the commercial sector. The Army noted a similar MAPS-like approach has been adopted for modernizing its AH-64 attack helicopters and has been highly effective.[99] While these assertions regarding MAPS appear to be reasonable, Congress might examine them in greater detail with Army officials to determine their analytical basis. Potential areas for further examination could include the following:

- Given the Army's current and total planned investment in MAPS, how much does the Army project in total savings over the option of simply integrating an APS directly into a combat vehicle's existing protective and battle management systems?
- What are the safety-associated costs associated with installing an NDI APS components directly on a vehicle versus installing these components on an existing MAPS architecture?
- What are the short- and long-term impacts on vehicle survivability if NDI APS is seen as a "good enough" solution at the expense of MAPS development?
- How will MAPS permit the rapid introduction of new technologies to respond to evolving threats any more effectively than APS vendors upgrading their systems which—in some cases—involves little more than software updates?
- Given current and projected budgetary limitations and the potential of NDI APS costs increasing if the Army decides to outfit an appreciable number of its combat vehicles with these systems in the near future, how might such a cost increase affect longer term MAPS efforts?

How MAPS Affects NDI APS Performance and Costs?

There are also MAPS-related technological and engineering considerations that Congress might further examine in terms of effectiveness and cost. There could be concerns from a basic systems engineering perspective that by requiring NDI APS to operate through the MAPS interfaces, architecture, and controller it could degrade the responsiveness and effectiveness of vendor-developed NDI APS sensors and countermeasures. In a similar manner, some in industry are worried about the possible technical "mismatch" between commercially developed APS and MAPS requirements set by DOD and the Army.[100] As the Center for Strategic and International Studies (CSIS) notes:

> The growing commercial role in military-relevant technology and the speed at which that technology is advancing challenges DOD's capacity to keep up with the flood of technologies both for its own adoption, and to counter the technologies adopted by adversaries.[101]

[99] Information in this section is taken from CRS meetings with U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and Program Executive Office (PEO) Ground Combat Systems (GCS) officials, June 30, 2016.

[100] Information in this section is taken from CRS discussions with industry management and technical personnel and is informed by the author's professional knowledge of systems engineering principles.

[101] "Leveraging Innovation, Center for Strategic and International Studies (CSIS)," https://www.csis.org/programs/international-security-program/defense-industrial-initiatives-group/leveraging-innovation, accessed July 26, 2016.

This statement illustrates commercial sector concerns that DOD and the Army might not be technologically at the same level as industry and current APS systems might need to be modified in order to be integrated into MAPS, potentially resulting in a less-than-optimal APS capability. Finally, some industry representatives have expressed concerns that by adopting MAPS, per unit cost of their APS sensors and countermeasures might actually increase based on the addition of MAPS integration requirements.[102]

What Are the Army's and Marines' Detailed Plans for APS Fielding?

Both the Army and Marines emphasized that their respective APS efforts were in the very early phases of technology demonstration and, as such, there is not a great deal of specific detailed information available. While this is understandable at this phase, additional details will be required over time as these efforts mature in order to inform congressional oversight. Such details include but are not limited to the following:

- What types of Army and Marine vehicles—other than M-1 Abrams from both services and Army M-2 Bradleys and M-1126 Strykers—are being considered for NDI APS and/or MAPS installation? For example, what are the Marines doing to assess APS suitability for their assault amphibian mission profiles and the unique operational and environmental challenges of ship-to-objective transport and maneuver?
- How many vehicles by class (armored fighting vehicles, heavy, medium, and light tactical wheeled vehicles, for example) would receive APS or would only selected vehicles in a unit receive APS in order to provide collective coverage of non-APS capable vehicles?
- Will both Active and Reserve component vehicles receive NDI APS and/or MAPS?
- Will vehicles in the service's pre-positioned stocks—both afloat and ashore—be outfitted with NDI APS and/or MAPS and what is the priority given to these "war stocks"?
- What are the Army and Marines fielding priorities and how long will it take to field APS and/or MAPS to designated vehicles?
- What are the total projected program costs for outfitting potentially tens of thousands of vehicles with APS-related capabilities?

How Adaptable Is APS to Other and Future Threats?

As previously noted "threats are not standing still." In addition to APS's advertised ability to defeat RPGs, ATGMs, and certain tank main gun rounds, there are other types of potential threats to U.S. combat vehicles that merit consideration. In this regard, Congress might wish to examine with the services and industry the adaptability of APS and MAPS in detecting and defeating threats such as

- precision artillery and mortar rounds;

[102] Information is taken from CRS discussions with industry management and technical personnel and is informed by the author's professional knowledge of systems engineering principles.

- main tank gun penetrator, or "sabot," rounds;
- aerial ATGMs from attack helicopters and unmanned aerial systems (UAS);
- hypersonic missiles; and
- advanced electronic defeat technologies.

A greater understanding of APS and MAPS capabilities, as well as their ability to adapt to a variety of threats—both current and emerging—could prove valuable as Congress evaluates the viability and efficacy of Army and Marine APS efforts.

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