Soldiers assigned to 1st Battalion, 4th Infantry Regiment, are given instruction on the use of the Project Origin robotic combat vehicle in the Hohenfels Training Area, Germany, on 6 June 2022. Project Origin uses autonomous ground vehicles to support Army maneuver by providing a variety of load packages, depending on the situation. Its use was demonstrated during exercise Combined Resolve 17 as part of the Army's modernization and emerging technologies initiatives. (Photo by Spc. Christian Carrillo, U.S. Army)

# Prioritizing Maintenance Restructuring and Resourcing for Autonomous Systems

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*Yesterday I flew in the F-16 for the first time. Last night, as I reflected on that machine, on the M1 tank, the AH64, the Bradley fighting vehicle and the levels of technology they represent compared to the equipment the Army I joined as a private soldier thirty-eight years ago, my judgment switch locked firmly into the "better quality" divot—better quality, almost regardless of how we recruit and what it costs. There's just no way to realize the combat potential of those machines without very smart guys who are very, very well-trained.*

—Gen. Donn Starry

In keeping with national strategic guidance from the Department of Defense (DOD), the Army has devoted a significant amount of time and research into exploring the application of autonomous vehicles on the battlefield. The topic appears in every significant strategy from the national level down to the major Army command level. Approaching a decade after the 2016 publication of a Defense Science Board (DSB) recommendation for a wholistic approach to autonomous capability integration, the U.S. Army has surprisingly avoided spending the energy to analyze, understand, and address the dramatic degree of complexity these technological advances place on maintenance support structures. Institutional trust in the acquisition process as a means of writing off the challenges of maintaining and sustaining autonomous systems seems to have masked the need for senior leader acknowledgment regarding the risk and resourcing. While industry leads the way in this field, the Army cannot afford to forget about all aspects of tactical employment of autonomous systems. Resourcing for correctly trained soldiers within properly designed maintenance structures at echelon must remain a part of the autonomous vehicle conversation because the Army cannot afford to outsource its tactical maintenance capability.

Maintaining an autonomous fleet under challenging tactical conditions requires a fundamental adjustment to how the Army structures and executes maintenance support due to the significant increase in software/hardware requirements on top of the physical act of maintaining a given platform. If maintenance operations remain unchanged, increasingly complex maintenance tasks associated with autonomous ground vehicle platforms will require significant maintenance support from nontactical commercial/contracted services, at a greater cost than deliberately accounting for the increase in challenges along the way. This adjustment, while significant, is evolutionary, not revolutionary. The Army has adapted to seismic changes like this before. While he focused on rebuilding a shattered army after U.S. involvement in Vietnam, Gen. Donn Starry found himself needing "to put doctrinal and organizational muscle on the technological skeleton" of the "Big Five" systems.[1] A deliberate and wholistic approach to the acquisition and implementation of autonomous systems must include senior leader acknowledgment and resourcing with respect to maintenance and sustainment across the lifetime of the platform through the operational support phase. Currently, strategic guidance on maintenance resourcing is thin at best, absent any acknowledgment at worst. Autonomous platforms will require a striking redefinition of the duties and responsibilities of maintainers, tailored and resourced maintenance organizations that blend physical and digital maintenance capability, and trained technicians with broad crossover experience at the forefront of autonomy in industry. Maintaining autonomous platforms also requires either a dramatic investment in resourcing Army structure or the complete transition of these support requirements to a civilian contracting model with an eye-watering price tag. In either case, these requirements demand senior leader acknowledgment and emphasis to ensure that any autonomous system the Army acquires has the associated support, resourced at the strategic level, and employed at the tactical level, to fight and win our nation's wars.

The 2017 and 2022 *National Security Strategies* (*NSS*) address the growing national focus on innovation within the artificial intelligence (AI) field, and by extension, the autonomous field. President Donald Trump's *NSS* mentions autonomous vehicles and weapons while

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President Joseph Biden's *NSS* goes one step further and associates a combat-credible military with investments in "trusted artificial intelligence."[2] The U.S. Department of Transportation (DOT) continued this line of thought in the *Strategic Plan for Fiscal Year 2018–2022*, noting that the DOT "must be prepared to respond to challenges posed by emerging technologies, while accelerating their development and deployment to realize potential benefits."[3] As expected, this ability to respond is heavily dependent on the relationship between the DOT and industry, as maintenance of autonomous systems occurs on the industry side conforming to DOT policies. On the military side, the Army published its *2020 Army Artificial Intelligence Strategy*, which acknowledges the guiding assumption that "the Army will transition from an incremental acquisition approach by reforming processes, resourcing, and governance to embrace the continuous development, acquisition, and employment of AI capabilities."[4] This trend of expediting how the Army acquires AI and autonomous technology will have significant second and third order effects if the associated ongoing assessment of the evolution of sustainability and supportability for this technology is not a vibrant and supported process. To this point, the Army's strategic approach involved the creation of the Army Artificial Intelligence Integration Center (A2IC), which operates "across the full AI application lifecycle [*sic*] with an emphasis on near-term execution."[5] Regrettably, the language allows for an easy and understandable slide toward the over prioritization of acquisition now at the expense of deliberate support and resourcing later. Additionally, much of the current consideration blends the training and maintaining tasks across AI and as associated autonomous platform efforts but while these circles overlap, they should receive separate consideration since maintaining AI software involves bringing the physical world to the digital world and maintaining autonomous technology centers on bringing the digital world to the physical world.

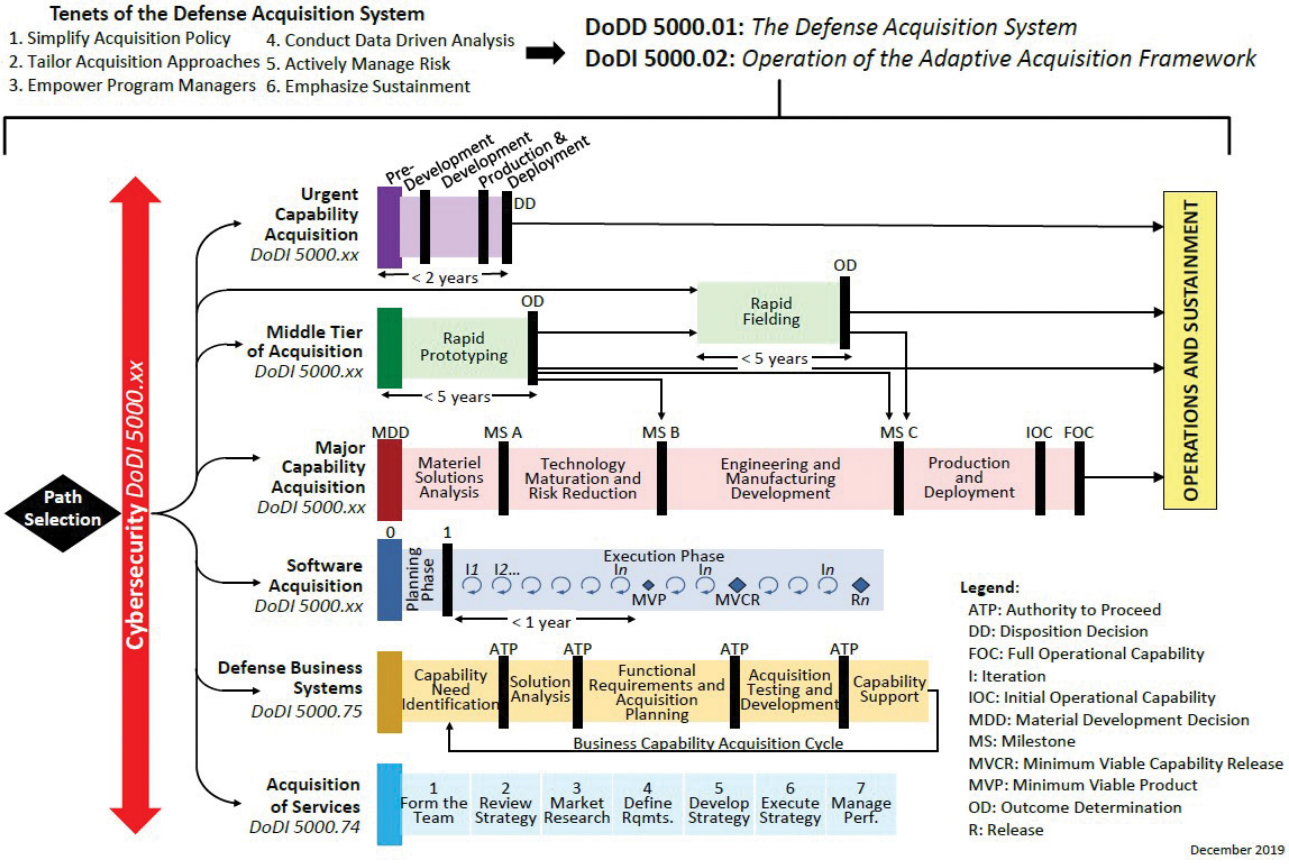
Even national and military strategies have conflated the definitions of AI, autonomy, and machine learning. The scope of this argument defines AI as "a collection of disciplines that enable some autonomous systems to sense, plan, adapt, and act based on their knowledge and understanding of the world, themselves, and the situation."[6] In turn, this argument advances the definition of autonomy proposed by Andrew Ilachinski: "A range of context-dependent capabilities, which may appear at different scales and in varying degrees of sophistication, that collectively enable the coupled human-machine system to perform specific tasks."[7] As technology and capabilities continue to develop, the Army, DOD, and the U.S. government must pay closer attention to these terms and how they interplay with each other. While AI and machine learning have opportunities and challenges intrinsic to their specific fields, autonomous systems carry both a physical and mechanical consideration along with a digital and software-oriented consideration. This places autonomous systems squarely between traditional Army circles that began to overlap at the genesis of the internet of things and now have smashed into one another, erasing former distinctions. To keep pace, maintenance structures and training must account for this blending across the mechanical and digital divide at a scale previously unnecessary to consider.

In 2016, the DSB made several recommendations that portended the fundamental shift in how industry and the military had to define the role and scope of a mechanic. The DSB argues that the U.S. military, "formerly equipped with largely electro-mechanical platforms," had already begun the transition to platforms and systems with integrated software essential to the operation of those systems.[8] By adding a digital component to the electrical and mechanical components, the requirement for supporting these systems changes how the U.S. military must train technicians and importantly, will only grow as the complexity of the digital/electric/mechanic nature of the platforms grows.[9] The DSB observed that acquiring these systems would be "data-heavy in all phases, from design, through modeling, simulation, validation, verification, tech insertion, and operational concepts and tactics, techniques, and procedures."[10] In accordance with the U.S. military's acquisition process, the support requirements including maintenance through the life cycle of these platforms should, logically, be as intensive across all described areas because these data-driven, digitally integrated tactical platforms must function on contested and multidomain battlefields.[11] The mechanic of today's U.S. Army does train across the categories of "maintenance, repairs, electrical systems familiarity, and electronic trouble shooting," which addresses to some degree the mechanical, electrical, and digital maintenance support for a platform.[12] When compared

Soldiers from Detachment E, Army Applications Group, 75th U.S. Army Reserve Innovation Command (USARIC), learn about the design and components of a V-BAT unmanned aircraft system after evaluating a demonstration of its autonomous capabilities on 17 September 2024 at Yuma Proving Ground, Arizona. Through direct collaboration with industry experts at Yuma Proving Ground, the soldiers provided frontline insights to refine these cutting-edge technologies, bridging the gap between concept and real-world application. (Photo by Sgt. 1st Class John Carkeet, 75th USARIC)

to industry, the divide between approaches to future maintenance becomes apparent. Tesla aspires to create autonomous vehicles "paired with remote diagnostics and over-the-air software updates" that require no services thanks to fewer moving parts.[13] Tesla's "mobile technicians" conduct mobile service from anywhere, maximizing remote diagnostics.[14] While industry, including Tesla, has not fully realized these lofty goals, the differences in how the Army describes the mechanic versus how Tesla describes the mobile technician are striking. To add to the challenge, Tesla does not have to consider battle damage, cyberattacks, restricted terrain, or any other host of military issues in anywhere near the fidelity that the Army must acknowledge due to the nature of multidomain, large-scale combat operations.

Elaborating on the increasing need for digital skill, even eclipsing the electrical or mechanical skills already inherent in Army maintenance, autonomous systems have only grown more complex. In late 2017, Ilachinski noted that "as autonomous systems increase in complexity, we can expect a commensurate decrease in our ability to both predict and control such systems: i.e., the 'spectre of complacency in complexity.'"[15] While Ilachinski meant this as an observation universally applicable to how humans interact with autonomous systems, the comment specifically applies to the maintenance of autonomous systems. Due to the lack of senior leader resourcing for maintenance structures and the associated training, the Army has turned its eyes away from the hard reality of creating a "common language" between human maintainers and autonomous systems



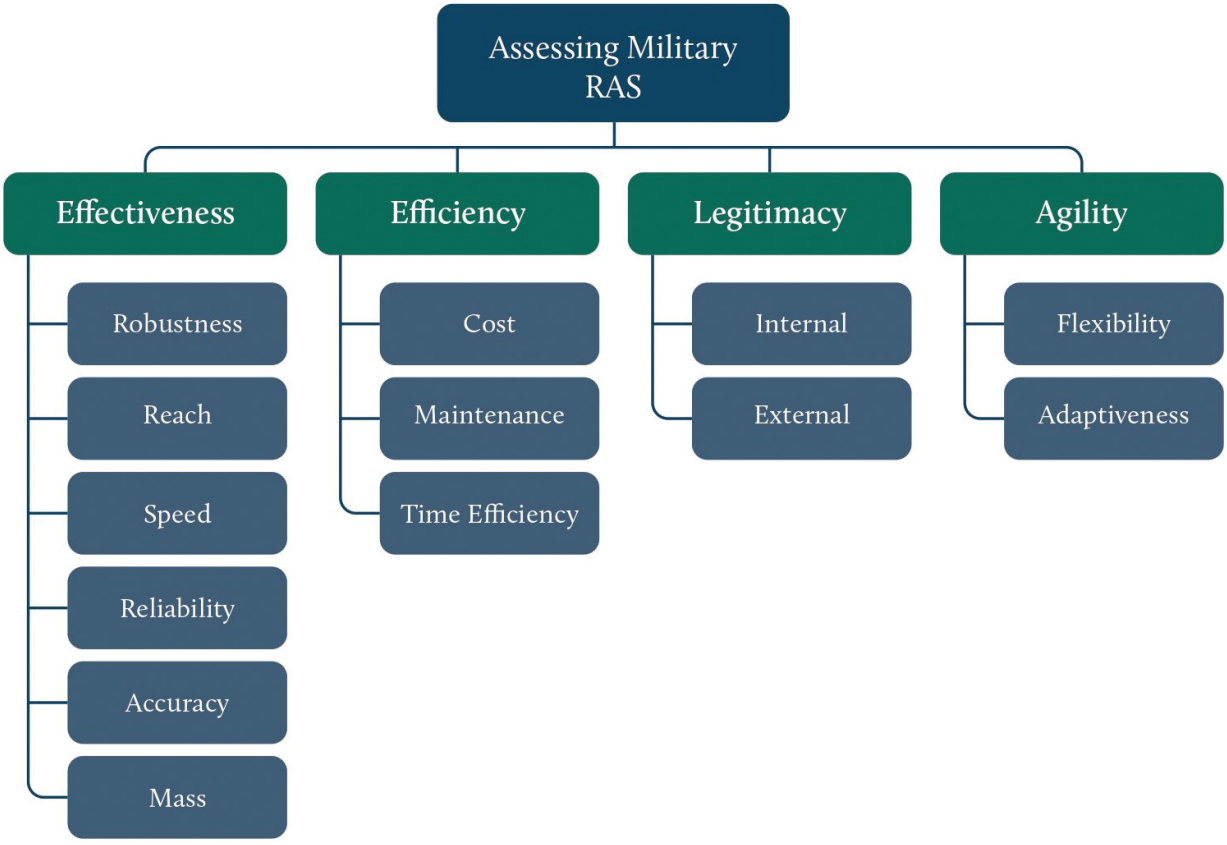

(Figure from Defense Acquisition University)

**Figure 1. Army Adaptive Acquisition Framework**

requiring digital, mechanical, or electrical maintenance. Constructing a common maintenance language for autonomous platforms requires acknowledgment of the value in understanding not only how autonomous platforms "achieve a given performance" but in understanding the support required to enable an autonomous platform to "achieve a given performance."[16] The second step in creating a common maintenance language for autonomous platforms requires acting on this understanding in the form of resourcing organizations and maintainers or technicians so that support for these platforms remains at the forefront of the acquisition process. Based on the significant drop off in mentions of maintenance and sustainability of autonomous platforms in strategic guidance between 2016 and 2024, this understanding of the need for a common maintenance language is at risk of relegation to a future, significantly more costly, military problem set.

The Hague Centre for Strategic Studies provides a simple, four-pronged assessment of "the military value of RAS," which covers robotics and autonomous systems.[17] Under this model, the Army continues to make great strides studying the effectiveness of autonomous systems, pushing for legitimacy in the form of ethics and safety, and through strategic guidance, has directed the overhaul of systems and processes to support an agile and adaptive acquisition framework (see figure 1).[18] The final category, efficiency, recommends the consistent assessment of resourcing that includes maintenance costs. This is an area the Army acquisitions system traditionally struggles with, especially for the "urgent operational needs" acquisitions pathway, which prioritizes agility over deliberate and wholistic considerations.[19]

Using this evaluation metric framework, the Army can prevent natural decay in priority for sustainment. This decay is even more pronounced with respect to autonomous systems because the Hague Centre for Strategic Studies clearly points out that maintenance "is especially difficult to evaluate for RAS [robotics and autonomous systems] in general," but it remains "an




(Figure from The Hague Centre for Strategic Studies, *The Military Applicability of Robotic and Autonomous Systems*)

**Figure 2. Evaluation Metrics Used to Assess RAS**

important factor to consider when developing, purchasing, or introducing RAS [robotics and autonomous systems] into a context."[20] Regarding this context, the Hague Centre for Strategic Studies assesses the service and support sector as the second largest domain for investment in autonomous or AI systems, after information and intelligence (see figure 2).[21] The primary risk underlies the fact that as the Army increases agility in the acquisitions process, "experimentation and rapid innovation do not align with a culture of meticulous planning and linear requirements assessment, development and acquisition process."[22] This disconnect between acquisition and development "can lead to difficulty in keeping up with the speed of technical advancements," especially relevant for technological innovation spurred by industry innovation as is the case with autonomous systems.[23] Supportability in the form of maintenance cannot slip out of the Army's field of vision.

The recently shuttered "Expedient Leader Follower" (ExLF) effort provides a functional case study on the importance of maintenance in autonomous innovation. The ExLF program aimed to reduce operator risk by pairing human operated platforms (leader) with autonomous platforms (follower), putting less crews on high-risk roads while still accomplishing the same throughput. After six years, the Army officially canceled the ExLF program, choosing instead to seek a "commercial solution offering," due to the allure of "matured technologies" in the uncrewed vehicle field.[24] Importantly, before the ExLF system officially ceased, the risk assessment of the ExFL program conducted by Booz Allen Hamilton provided several interesting insights into risk that could broadly function as considerations for all developing efforts in the field of autonomous vehicles. Outside of noting the importance of funding for the developer to ensure maintenance for ExLF systems during testing, the risk assessment explicitly stated the obvious but critically important observation that "due to the nature of unmanned vehicles there is not a driver in each vehicle to process and react to the


An Army autonomous vehicle, palletized load system, arrives at the Port of Shuabia in Kuwait on 24 June 2023. U.S. Central Command and U.S. Army Central are leading the way in innovation with autonomous vehicles, enabling the integration of emerging technologies. (Photo by Capt. Katherine Alegado, U.S. Army Reserve)

warnings the automotive system provides."[25] As a result, additional information and training are necessary to "allow operators to coordinate with maintenance assets to prepare to support the unmanned vehicles following missions."[26] Not stated explicitly but related to these observations, autonomous vehicles with no crew rely on the associated operator for this function which increases the workload for the few remaining operators and has not to this point resulted in a related balancing of maintenance support capability to mitigate the lack of operator availability to conduct the first and most basic level of maintenance. The beginnings of this revelation first appear in this risk assessment and the continued line of logic should inform future efforts. Cutting operators decreases the first and most consistent maintenance operation and displaces that workload on existing maintenance organizations lacking the needed redesign to account for this displacement. As the Army transitions to seeking commercial solutions, those companies sell their maintenance support structures as a package deal. Army maintainers who can function at the tactical level of autonomous application will lack the skills required to conduct meaningful maintenance on these increasingly complex systems. Commercial vendors will continue to sell their innovation and associated support but by nature of their external relationship to the military, lack the ability to provide significant functional maintenance at the tactical level, which will leave the Army with higher maintenance costs, lower tactical capability, and longer lead times to return battle damaged autonomous platforms back to the tactical echelon.

Training remains at the heart of the entire conversation on systems maintenance and takes on a special relevance when it comes to maintaining autonomous systems. The gap between the military approach to maintenance and the industry approach to maintenance continues to widen and remains fundamentally linked to training programs aimed at core competencies relevant to emerging autonomous technology. The military has the added challenge of ensuring maintenance training includes future battlefield considerations like increased lethality and multidomain

threats that do not apply in the same way to the civilian sector. In *The MANTIS Book: Cyber Physical System Based Proactive Collaborative Maintenance*, the authors describe future maintenance as an informed blending of collaboration between humans and autonomous systems.[27] Failing to prioritize the understanding of this collaboration will result in the need for wholesale replacement of large systems within the autonomous system, or in the worst case, the replacement of the entire system. Both are expensive and unsustainable.[28] Whether this collaboration and human-machine teaming represents the introduction of cybernetic or autonomous diagnostic capacity on an external platform or the blending of technology and technician for the purpose of self-diagnosis on an autonomous platform and human maintenance based on the system information, both represent the essential need for training a human within a maintenance system to the same level as the new technology. Humans represent the physical manipulation of the system while autonomous platforms represent the digital manipulation of the system. Without the correct training, the "man-machine collaboration," which remains essential, cannot exist in a functional way.[29] In a distant future, there may be technology that can maintain itself, but given the kinetic environment that the Army must operate in, maintenance remains a human endeavor because maintenance today "includes all technical, administrative and management actions implemented during the lifetime of a machine" and autonomous systems still require human collaboration for that.[30]

Returning to 2016, the DSB made several critical recommendations relevant to ensuring the human side of the collaboration described above will remain trained and capable of maintaining autonomous systems. The competition between the military and industry for talent frames this retention challenging in a more meaningful way than most fields. Traditionally, the military has retained the capability to conduct its own training but the state of autonomous innovation and advancements in the civilian sector relevant to the *2020 Army Artificial Intelligence Strategy* imperative to "maximize human/machine potential" through an AI-enabled force means the Army can no longer insulate its training programs from the civilian sector for fear of falling behind.[31] The DSB recognized in 2016 that the commercial sector was and remains "an effective competitor for talent."[32] Any effort for the military to turn inward for training and modernization in this field continues to put the military at "a serious disadvantage to retain experience—talented operators, maintainers, supervisors, and technology leaders."[33] To overcome this disadvantage, the DSB argued for "necessary measures," including "categorizing autonomy trained personnel in the highest pro pay category" and "offering significant re-enlistment bonuses and officer retention bonuses."[34] The DSB also recognized the need to "formalize broad exchanges between government, military, and commercial enterprises for extended periods—closer to months rather than days—so that both government and commercial personnel can learn and understand emerging technologies and capabilities as well as the range of user concepts and applications."[35] All suggestions generated in 2016 by the DSB could have benefited the current ability to modernize maintenance at pace with autonomous innovation. Unfortunately, eight years after the publication of these recommendations, the Army has not resourced these opportunities to the degree required to keep maintenance on track.

The U.S. Army Ordnance Corps and School, the Army proponent for maintenance, has made efforts toward these recommendations. The Ordnance Strategic Plan 24-30 seeks to "build the future technician," adapting the verbiage used by several industry innovators in the field of autonomous vehicles.[36] This line of effort within the strategy addresses the need for modernization within the ordnance corps but does not go far enough toward the radical blending of military and industry efforts described by the DSB. Resourcing remains the primary barrier to entry and undoubtedly, an unconstrained maintenance strategy from the Ordnance Corps and School would involve large-scale and lengthy training with industry requirements to ensure the maintainers of today become the technicians of tomorrow. Without the opening of the aperture for the flow of resourcing to critical efforts like those recommended by the DSB though, the Army locks its maintenance transformation to incremental progress while at the same time unlocking its acquisition of autonomous systems, shedding the incremental acquisition and widening the gulf between systems and those who maintain systems.

The Ordnance Corps and School also has a line of effort built into their strategy that aims to "Transform

the Ordnance Corps," which includes "incorporating emerging technologies [and] capabilities" as well as "aggressively advocating for funding Army of 2030-2040 targets" that certainly include the required maintenance capability for those emerging technologies.[37] Unfortunately, the degree of resourcing required to truly posture Army maintenance for autonomous vehicles and enable Army maintenance to evolve and adapt at pace with autonomous technology resides many echelons above the Ordnance Corps and School. The U.S. Army does not have the available resources to fully fund maintenance support for the future without creating significant risk in other efforts. Unconstrained resourcing remains an unrealistic goal when fiscally responsible resourcing of associated maintenance requirements could solve many of the underlying problems. Adjustments to force structure including updates to the "Manpower Requirements Criteria (MARC)," directed by the Department of the Army, to ensure organizational designs account for maintenance demand going forward could account for the lack of crew availability for operator-level maintenance and counterbalance to increase maintainer requirements across all Army organizational designs.[38] Increasing access to training-with-industry opportunities, especially for maintenance managers, could result in a better trained force operating in a better designed organization. Creating professional incentives for technicians who have advanced credentials in the maintenance of autonomous systems could increase retention. Blending the digital skills of the Signal Corps or Cyber Corps with the physical skills of the Ordnance Corps could result in a new military occupational specialty, custom built for maintaining autonomous platforms. All these suggestions require resourcing. In 2024, the Army remains constrained, grappling with retention problems across the board and modernization challenges in every field. While that is an unfortunate reality, aggressively pursuing innovation and acquisition of autonomous systems without an equally aggressive pursuit of transformation across the Ordnance Corps and through maintenance capabilities at all echelons will end up creating more problems than it solves.

Given the significant advances in autonomous technology over the last eight years, research into understanding the full scope of supporting these requirements must catch up. Significant research into a side-by-side comparison of current and future maintenance tasks will help identify the exact areas of increased workload as well as the associated training investments needed. Additional research into the scope of practice for a maintainer or technician should include detailed analysis of the kinds of tasks and ways in which Army proponents across the force can participate to optimize the maintenance field. Autonomous vehicles require significantly more digital maintenance support and should warrant a discussion among the Sustainment Center of Excellence, the Cyber Center of Excellence, and other Army commands that own portions of these new maintenance responsibilities. Research into the feasibility of a new military occupational specialty for autonomous maintenance or a direct study of existing niche maintenance military occupational specialties could shed light on the added challenges of training and retaining skilled digital maintainers already in the force, but in specific applications. Researchers have a lot of ground to cover, and every bit of quality scholarship will help bring attention to the urgency of this problem.

Maintenance is an essential consideration for all platform-based forms of movement and maneuver. The Army has generated and directed allocation rules for maintainers inside organizational designs because the Army cannot overstate or forget the importance of maintenance in organizational design. For this specific function, the "nature" of maintenance, like war, remains unchanged, but the "character" of maintenance is undergoing seismic adjustments that will require accounting for an agile and adaptive maintenance operation now, as these technologies are in their relative infancy.[39] Army and DOD senior leaders cannot afford to fundamentally adjust maintenance after the fielding of autonomous vehicles. Maintenance operations must evolve concurrently to remain relevant and reliable. The national, DOD, and Army strategies all stress the importance of remaining ahead of our adversaries with respect to AI, machine learning, and autonomous capabilities. Unlike many examples from the past, the Army cannot remain relevant and ensure the support structures exist by itself. Industry continues to lead the way for autonomous technology. The Army continues to focus on the agile and adaptive acquisition of autonomous technology but has not acknowledged, articulated, or resourced

an equally agile and adaptive maintenance support structure. But just as the Army learned with the acquisition of the "Big Five" technological advances, we remain in an environment that requires human-machine collaboration and teaming. Well-trained soldiers still have a place working with autonomous platforms to achieve the best outcome with the lowest risk. Behind that, well trained maintainers in purpose-built maintenance formations end up enabling the true potential of these systems. To enable that potential, maintenance considerations require senior leader time, attention, and resourcing in concert with technological innovation in the AI and autonomous fields. ■

## Notes

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