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"Don't Get Ahead of the Data"

Artificial Intelligence and Predictive Maintenance in DoD

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EXECUTIVE SUMMARY

This white paper examines the current state of and future opportunities for predictive maintenance as a case study for the adoption of Artificial Intelligence (AI) and machine learning (ML) as a military capability. Building on the work of the Joint Artificial Intelligence Center (JAIC)[1] and the Defense Innovation Unit (DIU), the Department of Defense (DoD) has significantly increased the number of major systems using AI/ML to address predictive maintenance. Collaborating with the military departments, DIU and the JAIC launched a series of projects starting in 2017 exploring predictive maintenance solutions on platforms ranging from the E-3 Sentry and F-16 aircraft to UH-60 and AH-64 rotary wing aircraft to ground vehicles.

The results of these initial projects were generally promising, but the complexity and heterogeneity of maintenance data made it clear that the utilization of AI/ML techniques in this area would require continued iteration and user feedback. Promisingly, the services have continued investment to develop better data sets, better algorithms, and better tools towards the predictive maintenance objective. This goal is strongly supported across the DoD maintenance enterprise and predictive maintenance is clearly developing into a promising use case of AI technology in defense. Based on the pilot efforts examined in this white paper, DoD is off to a solid start, but needs a continued focus on data, prioritization, metrics, building trust across the maintenance enterprise, and other areas to stay on this promising trajectory towards predictive maintenance.

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PURPOSE

This white paper examines the current state and future opportunities for artificial intelligence's use in predictive maintenance as a case study for the adoption of AI as a military capability. Predictive maintenance refers to the use of data-driven, proactive maintenance methods that are designed to analyze the condition of equipment and help predict when maintenance should be performed. Military services were already purchasing data analysis tools focused on predictive maintenance, but this trend has accelerated with the advent of AI and machine learning. Building on the work of the JAIC and DIU, DoD has significantly increased the number of major systems using AI/ML to address predictive maintenance. Has AI/ML helped predictive maintenance attain new levels of capabilities and readiness for DoD customers? It is important to examine the reality of AI in a use case that demonstrates the capability of the technology as well as the readiness of a DoD user to adopt it for a purpose that impacts military readiness.

INTRODUCTION AND BACKGROUND

DoD has expressly recognized that AI has the potential to become a "transformative technology"[2] that will change the operations and capabilities of the warfighter in profound and often unforeseeable ways. Due in part to its potential to provide capabilities across a broad range of uses, DoD designated AI a top modernization area and is investing considerable effort and funds toward developing and acquir-

1. Now the Chief Digital and Artificial Intelligence Office, https://www.ai.mil/.

2. GAO Report, *AI: Status of Developing and Acquiring Capabilities for Weapons Systems*, GAO-22-104765 (U.S. Government Accountability Office, February 2020) (hereinafter "GAO Report").

ing AI tools and capabilities to support the warfighter.[3]

AI is defined in the National Security Commission on Artificial Intelligence's Final Report as "an artificial system developed in computer software, physical hardware, or other context that solves tasks requiring human-like perception, cognition, planning, learning, communication, or physical action."[4] This definition from the National Security Commission is broader than the definition used by DoD, but it also supports the distinction that AI is an engineering discipline. The Commission notes that AI seeks to apply scientific understanding, frameworks, and techniques to create systems with specific behaviors and features.[5]

According to GAO, DoD requested $14.7 billion for science and technology programs as well as $874 million spread across 600 projects to directly support its AI efforts in FY22. The FY23 President's Budget submission included similar funding requests. According to DoD's 2018 Artificial Intelligence Strategy, failure to incorporate AI capabilities into weapon systems could hinder the ability of warfighters to defend our nation against near-peer adversaries demonstrating the key importance of this technology area. Further demonstrating the focus on this technology area by militaries, other nations are making significant investments in this area that may threaten to erode the U.S. military technological and operational advantage.[6]

AI reflects unique characteristics that differ from traditional software. DoD has acknowledged that developing and deploying AI differs from the requirements applicable to traditional forms of software, in that AI requires vast amounts of data for development and continuous monitoring once deployed.[7] The AI learning process is achieved by providing AI algorithms with large data sets that identify the desired outcome, with the AI developer validating that the model is producing the desired results.

Uses of AI for DoD

In reviewing current AI "mission sets" within DoD, GAO found that most AI activities supporting DoD's warfighting mission were in research and development, with a focus on developing autonomy for uncrewed systems, recognizing targets, and providing recommendations to commanders on the battlefield.

However, DoD has also begun to examine the applicability of AI to such applications as analyzing intelligence, surveillance, and reconnaissance sources; fusing data to provide a common operating picture on the battlefield; supporting semiautonomous and autonomous vehicles; and operating lethal autonomous weapon systems.[8]

In terms of nonlethal applications for AI, DoD has expanded its inquiries into in such areas as support and business operations, financial transactions, predicting maintenance needs, vetting security clearances, and analyzing warfighter health.[9]

These general areas were depicted by GAO in Figure 1.[10]

THE CONDITION-BASED MAINTENANCE CONTINUUM

Current efforts focused on predictive maintenance have their origins in earlier initiatives using sensors and analytics that have been underway well over a decade.

- The condition-based maintenance continuum begins at the lowest level at *reliability-centered maintenance* (RCM), which forms the foundation for component analysis, reliability and maintainability data design, failure mode effects and critical analysis (FMCEA) data, and maintenance plans to inform candidate components for maintenance. At the RCM level of the continuum, the evi-

3. Ibid.

4. National Security Commission on Artificial Intelligence, Final Report, https://www.nscai.gov.

5. By contrast, DoD says that AI refers to computer systems designed to replicate a range of human functions and continually get better at their assigned tasks. GAO Report, 3.

6. GAO Report.

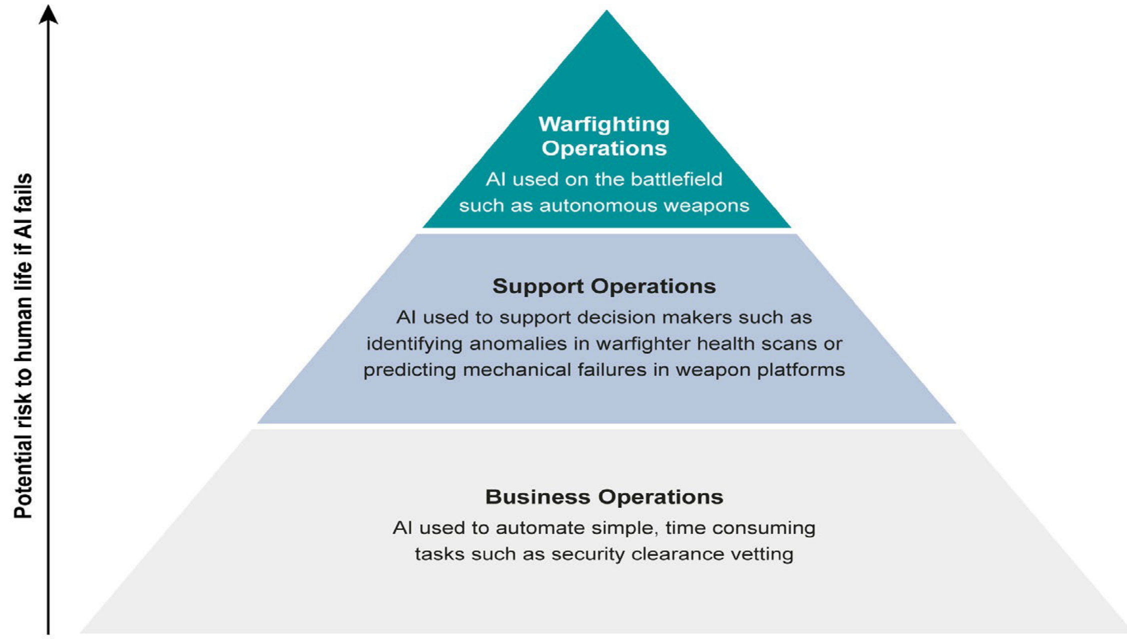
7. Ibid., 11.

8. GAO notes that "DoD is currently pursuing AI capabilities for warfighting that largely focus on (1) recognizing targets through intelligence and surveillance analysis, (2) providing recommendations to operators on the battlefield (such as where to move troops or which weapon is best positioned to respond to a threat), and (3) increasing the autonomy of uncrewed systems," GAO Report, 17.

9. GAO Report. See also, *Artificial Intelligence and Data Analytics (AIDA) Guidebook*, Advanced Technology Academic Research Center (ATARC), March 2022 for an additional discussion of AI features and characteristics, https://atarc.org/teams/aidawg/aida-guidebook-project-team/.

10. Ibid., 7.

Figure 1. DoD AI Mission Sets.



Source: GAO representation of Department of Defense information. I GAO-22-104765

dence of need for maintenance is provided by design reliability analysis and testing which is enhanced through usage and maintenance data. The execution of RCM takes the form of preventive maintenance schedules; fleet-based fixed time schedules; or preventing failure through replacement or overhaul of systems.

- *Conditioned-based maintenance* (CBM) which leverages data sets from digital source collectors, usage data, maintenance and supply data, and operational context is the next stage of the continuum. At the CBM level of the continuum, the evidence of need for maintenance is provided by design reliability analysis and testing which is enhanced through usage and maintenance data, and further refined by on-board sensors and advanced diagnostics. The execution of CBM takes the form of condition-based maintenance based on the current conditions of an asset; scheduled based on evidence of need; through evidence from continuous sensor data collection; and through near-real time trend analysis.
- Finally, *condition-based maintenance plus* (CBM+), relies on the ability to analyze all relevant data sets to discover the evidence using artificial intelligence, machine learning, algorithms and advanced analytics, digital twins, physics of failure, and digital simulation.[11]

At the CBM+ level of the continuum, the evidence of need for maintenance is provided by design reliability analysis and testing which is enhanced through usage and maintenance data, and further refined by on-board sensors and advanced diagnostics which are analyzed to provide condition insight to an asset. The execution of CBM+ takes the form of forecasting the remaining equipment life and future condition; projecting maintenance needs as probable within mission time; and leveraging AI and ML processing of massive amounts of data to provide on and off-system real time trend analysis.[12]

The DoD approach to CBM+ has been codified in DoD Instruction 4151.22, Condition-Based Maintenance Plus for Material Maintenance, signed on August 14, 2020. That DoDI set the vision for CBM+ where ". . . life-cycle managers will shift focus away from unscheduled, reactive tasks at a time of

11. Emmett Simmons, *The Journey to Predictive Maintenance: Condition-Based Maintenance Plus (CBM+)* (Defense Acquisition University, March 2021), video, 1:23:50, timestamp 5:43, https://media.dau.edu/media/t/1_0izmoxb8.

12. Ibid., timestamp 8:18.

failure to proactive, predictive efforts driven by accurate data and analysis-based decision-making."[13]

Within the Department of the Army, CBM+ processes have been in use for more than a decade with major advances in both Army aviation and tactical wheeled platforms.[14] The Army is currently investing in advances to its CBM+ programs to pursue what it terms "Predictive and Prognostic Maintenance (PPMX), which it defines as the application and integration of appropriate processes, technologies, and knowledge-based capabilities to use authoritative and emerging data to achieve foresight in combat system health management and health management response."[15]

At its core, CBM+ "is maintenance performed based on evidence of need." Predictive maintenance goes one step further and is, as defined in DoDI 4151.22, "a technique to predict the future failure point of a component, so that the component replacement can be planned at an optimal time before it fails."[16]

RECENT DOD EFFORTS IN AI/ML-RELATED PREDICTIVE MAINTENANCE SOLUTIONS

In recent years, the Department of Defense has begun to make targeted investments in AI solutions for predictive maintenance.[17] "This application of Artificial Intelligence has been specifically identified within national policies promoting government use of Artificial Intelligence. Predictive Maintenance is [a maintenance strategy that is at] the apex, or the pinnacle, of the condition-based maintenance continuum."[18]

Initial DIU and JAIC Preventive Maintenance Projects

A 2017 DIU solicitation, initially opened on behalf of the Air Force, helped to increase the DoD focus on predictive maintenance. The Commercial Solutions Opening (CSO) solicitation, sought "software for predictive or condition-based maintenance . . . capable of integrating both historical structured (e.g. sensor reports) and unstructured (e.g. maintenance logs) datasets."[19] The initial DIU project was focused on E-3 Sentry aircraft maintenance and piloting AI/ML solutions for predictive maintenance at the subsystem and component level. Over a two-year effort, the Air Force examined CBM+ software solutions to predict subsystem and component failure under the airborne warning and control system (AWACS) and F-16 platform.[20] Under this effort, the Air Force and DIU employed ML statistical analysts to predict subsystem and component level failures and later employed natural language processing (NLP) to read pilot logs. DIU collaborated with and transitioned this effort to the USAF Rapid Sustainment Office (RSO), expanding this predictive maintenance capability to 22 aircraft, including the F-35 Lightening II fleet.[21]

DIU projects also focused on applying AI/ML solutions to Army platforms. These included major ground combat systems, such as the Bradley Fighting

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13. DoD Instruction 4151.22, Condition-Based Maintenance Plus for Materiel Maintenance, Office of the Under Secretary of Defense for Acquisition and Sustainment, 6, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/415122p.pdf?ver=2020-08-14-152511-117.

14. Journey to Predictive Maintenance, timestamp 13:50.

15. Ibid., timestamp 14:15.

16. DoDI 4151.22, 14–15.

17. Kelley M. Sayler, *Emerging Military Technologies: Background and Issues for Congress*, "The JAIC has undertaken a number of National Mission Initiatives for AI, including predictive maintenance, 13 humanitarian aid and disaster relief, warfighter health, and business process transformation (Congressional Research Service, CSR Report R46458: April 2022), https://crsreports.congress.gov/product/pdf/R/R46458. Predictive maintenance uses AI "to predict the failure of critical parts, automate diagnostics, and plan maintenance based on data and equipment condition," "Summary of the 2018 Department of Defense Artificial Intelligence Strategy," (Department of Defense, February 12, 2019), 11, https://crsreports.congress.gov/product/pdf/R/R46458.

18. Journey to Predictive Maintenance.

19. Defense Innovation Unit Annual Report 2019, https://assets.ctfassets.net/3nanhbfkr0pc/ZF9fhsMe6jtX15APMLalI/cd088a59b91857c5146676e879a615bd/DIU_2019_Annual_Report.pdf.

20. Interviews with DIU and JAIC officials.

21. DIU FY 2021Annual Report, https://www.diu.mil/latest/diu-fy-2021-annual-report-a-preview-into-fy-2022. Also, Journey to Predictive Maintenance.

Vehicle,[22] as well UH-60 Black Hawk and AH-64 Apache rotary wing aircraft. On the latter, DIU found impacts such as 24% reduction in severe in-flight malfunctions 40 flight hours in advance.[23] DIU transitioned these projects to the Army in 2020.

The Joint Artificial Intelligence Center (JAIC) similarly launched a number of projects with Service partners during the same time period. The JAIC established a Mission Initiative around joint logistics, which included predictive maintenance, and launched a partnership with the U.S. Army Artificial Intelligence Task Force[24] as well as Special Operations Command (SOCOM) in 2020. This project focused on the 160th Special Operations Aviation Regiment (SOAR) and specifically the HH-60 Pave Hawk (Special Operations derivative of the Black Hawk) helicopter. Deploying a machine learning tool known as a Work Unit Code (WUC) Corrector, the objective was to analyze and collate unstructured data such as maintenance logs on the engine and other subsystems with more structured maintenance data to improve operational readiness.[25] The JAIC similarly focused on enabling the Services in their efforts and transitioned the capabilities to their respective Service partner.

Partnering with the JAIC, the Air Force worked to "expand its 'predictive maintenance' using artificial intelligence and machine learning to another 12 weapon systems."[26] The Air Force made a push to look at systems maintenance through CBM+ and enhanced reliability centered maintenance (ERCM) approaches which, "[lays] artificial intelligence and machine learning on top of the information systems that we have, the maintenance information system data, that we have today, and understanding failure rates and understanding mission characteristics of the aircraft and how they fail."[27]

Projects Transitioning to Services

Overall, across the services and DoD, investments continue to be made in bringing maintenance practices up to the current state of technology, leveraging data analytics and prediction though AI/ML models.

The Air Force's Rapid Sustainment Office was established in 2018 to modernize maintenance operations and the sustainment enterprise and one of RSO's focus areas is employing AI/ML to optimize fleet maintenance and predict / prevent aircraft failure. In its 2021 annual report, the RSO noted a number of accomplishments focused on CBM+, including

- Fielded CBM+ on more than 3,200 aircraft
- Removed over 500 parts before failure
- Launched data analysis on 6 new platforms
- Established a secure CBM+ data environment[28]

Army AI2C efforts similarly continue to include predictive maintenance. Sustainment is one of the Army's ten AI modernization portfolios with a focus on reducing life cycle costs through efficient maintenance programs.[29] To this end, the Army recently awarded a $10.5 million contract to expand the capabilities of predictive maintenance techniques.[30]

The Navy is maturing its CBM+ capabilities by investing in sensor data captures across multiple platforms. As of 2021, NAVSEA reported installing the sensors necessary for CBM+ on 94 of 177 surface ships, collecting data from three thousand to five thousand sensors per

22. Sonja Jordan, *Army Investing in Predictive Maintenance for Bradleys* (National Defense, September 2018), https://www.nationaldefensemagazine.org/articles/2018/9/26/army-investing-in-predictive-maintenance-for-bradleys.

23. DIU FY 2021 Annual Report and DIU briefing.

24. Now the Army Artificial Intelligence Integration Center (AI2C), https://armyfuturescommand.com/ai2c/.

25. "JAIC partners with USSOCOM to deliver AI-enabled predictive maintenance capabilities," JAIC, December 17, 2020. https://www.ai.mil/news_12_17_20-jaic_partners_with_ussocom_to_deliver_ai-enabled_predictive_maintenance_capabilities.html. Interviews with current and former JAIC personnel, April–June 2022.

26. Theresa Hitchens, "Air Force Expands AI-Based Predictive Maintenance," *Breaking Defense* (July 2020), https://breakingdefense.com/2020/07/air-force-expands-ai-based-predictive-maintenance/.

27. Ibid.

28. USAF RSO fact sheet and 2021 Annual Report, https://www.aflcmc.af.mil/welcome/organizations/rapid-sustainment-office-directorate/ (accessed June 9, 2022).

29. Artificial Intelligence Integration Center (AI2C), Army Futures Command, U.S. Army, https://armyfuturescommand.com/ai2c/.

30. Byron Spice, "$10.5M Army Contract to CMU Lab Will Expand Use of AI in Predictive Maintenance," Carnegie Mellon University, School of Computer Science (June 1, 2022), https://www.cs.cmu.edu/news/2022/auton_predictive_maintenance.

ship. That data is pushed to an environment where a digital twin is leveraged to compare information and flag deviations and anomalies in the data.[31] The Navy is also looking to digital twins to help improve efficiencies and decrease costs with jet engine parts.[32] The Marine Corps has also developed predictive maintenance prototypes for its Joint Light Tactical Vehicle and MTVR troop transport vehicle through a partnership with DIU.[33]

An effort that has transcended all services has been data imputation and fusion. To help reduce data gaps and incompatibility, the Army and Air Force have undertaken major efforts to cleanse data and create secure data sets for use across multiple programs. Using secure resources such as the Engineering Research and Development Center (ERDC), these secure data lakes continue to grow, creating future opportunities for CBM+ and predictive maintenance solutions.[34]

IMPACT AND OBSTACLES

The initial impacts of these predictive maintenance efforts across the Department have been similar – they are works-in-progress. There have been promising insights in some of the tools that transitioned to the Services, but there have also been issues. The 160th SOAR, for example, put AI on the HH-60 Pave Hawk in Afghanistan to monitor engine health and found it 84% accurate in predicting engine failure. Army PEO Aviation, on the other hand, utilized the prototype products developed under DIU and found them to have some benefits and some limitations. Overall, the tremendous complexity of maintenance records made it difficult to capture all the relevant data needed. Gaps in data incorporated into the tools raised questions about their reliability and their accuracy was often fair (60% or greater), but not high enough to be completely trustworthy. In addition, incorporating AI/ML tools on existing platforms can be extraordinary difficult with proprietary sensor data and other aspects.[35]

Focusing on each of the major obstacles to wide spread adoption of AI/ML solutions will help identify the path forward for predictive maintenance in DoD.[36]

Data

The biggest challenge is clearly the level, complexity, and heterogeneity of maintenance data. This is not a new problem in any way, shape, or form. From the multiple levels of parts to multiple levels of sensor data for various sub-systems and components, from proprietary data streams to incompatible file structuring—not to mention all the hand-written maintenance and dispatch logs—it is exceedingly difficult to get a clear picture of all the maintenance streams of any major defense platform. CBM+ was a goal before predictive maintenance and the data picture for the former is incomplete. It is, therefore, not surprising that putting an AI/ML algorithm on top of an incomplete set of data will naturally lead to many false positives and inaccurate results. More broadly, the lack of a coherent DoD-wide data strategy that supports intra and inter department data sharing and portability using well defined and enterprise-wide data standards and protocols also hinders progress.

Traditional Maintenance Mindset

Since the advent of mechanized vehicles in the military, mechanics have conducted preventive checks and maintenance, but repairs or replacements were by nature reactive to parts when they failed. Adopting a predictive approach therefore requires a fundamental shift in how maintainers conduct their work. Taking a proactive or predictive approach is a very different mindset and requires a new way of thinking and a new set of tools.

Cost and Prioritization

There are always tradeoffs in programs. Desired capabilities are not always funded because the program top line is generally fixed and the program manager has to prioritize among capabilities. It may be cost prohibitive, for example, to put predictive maintenance sensors in small programs or in all subsystems of larger programs. Moreover, sustainment capabilities such as maintenance almost

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31. Journey to Predictive Maintenance, timestamp 25:28.

32. George Mason University College of Engineering and Computing, "SEOR seniors create conditioned-based maintenance system for U.S. Navy, June 3, 2022, https://cec.gmu.edu/news/2022-06/seor-seniors-create-conditioned-based-maintenance-system-us-navy.

33. Interview with DIU personnel; DIU Annual Report 2020, https://assets.ctfassets.net/3nanhbfkr0pc/3vxak4123q9hhog2rvpqfo/385542158e5b6ca62e7fa63c03bcfe0d/diu_-_2020_annual_report_final.pdf.

34. Interviews with JAIC, AI2C, Headquarters Department of the Army, and PEO Aviation officials.

35. Interviews with JAIC, AI2C, 106th SOAR, Headquarters Department of the Army, and PEO Aviation officials.

36. Interviews with JAIC, AI2C, DIU, 106th SOAR, Headquarters Department of the Army, and PEO Aviation officials.

always have a lower priority than weapons systems in the program hierarchy.

Legacy vs. New Systems

The predictive maintenance prototypes also have demonstrated how much harder it is to add this capability to existing systems. AI is not a bolt-on capability. Furthermore, the older the system, the harder it is to gain accurate maintenance data for predictive approaches. For instance, the pilot efforts on the E-3 were much more challenging than those on the F-16. Designing in a predictive capability at the front end of program development will clearly be more effective, but acquisition officials have to do both.

Incorporating Images and Video

Current predictive maintenance efforts principally focus on data inputs, electronic sensor data, and handwritten maintenance logs. Utilizing visual inspections, images, and video would add additional levels of precision to these initiatives. Images are beginning to be used in some use cases, but there is much more that could be done. Using models developed for manufacturing industry and even Project Convergence demonstrations at the tactical edge point the way for incorporating these capabilities in the future.[37] The challenge with images and video is bandwidth, but this can be overcome in time with secure data lakes and more precise tools.[38]

Commercial Predictive Maintenance Models

DoD pilots and initial projects for predictive maintenance generally utilized commercial companies that employed tailored AI/ML algorithms to support private and public sector customers. Some of the impetus behind DoD's push for these commercial predictive maintenance efforts was the perceived advances using AI/ML in industries such as commercial aviation, automotive, and healthcare. There is an emerging literature examining these efforts to use AI/ML predictive maintenance approaches such as artificial neural networks, support vector machine, and decision tree in these industries. Interestingly, although there is a clear recognition of the benefit of these approaches, understanding the broad impacts of predictive maintenance solutions in commercial industries is similarly challenging to that in defense.[39] While predictive maintenance is more generally accepted and regularly used in automotive sector, for example, there are still challenges with datasets and understanding the generalized applicability of predictive maintenance approaches in commercial industry as well.[40]

CONCLUSIONS AND RECOMMENDATIONS

With a perceived massive potential return on investments in terms of readiness and cost savings, this application of AI/ML technology is clearly gaining momentum across the Department of Defense, federal government, and in commercial industries.[41] Preventive maintenance (PMx) is one prominent use case in DoD and the results thus far have been promising on a number of levels. The vision for its use on defense systems is a clear priority of senior Department officials, from the initial DIU and JAIC projects and organizational focus areas of AI2C and RSO to the investment in pilot projects and continuing programs. If anything, there was perhaps a bit of over optimism in the initial PMx efforts. CBM+ has been codified in a DoDI only since 2020 and has yet to achieve its desired end state so it was just not feasible to leap frog straight to PMx based on tailored commercial AI/ML algorithms.

The reality is that maintenance is extremely complex and has many layers.

37. See, for example, Mei Chen, Deepak Trehan, and Michael Yang, "Using Thermal Imaging Data to Increase the Accuracy of Predictive Maintenance Models," *BCG Gamma*, October 23, 2019, https://medium.com/bcggamma/using-thermal-imaging-data-to-increase-the-accuracy-of-predictive-maintenance-models-12281774953f and Sydney J. Freeberg, "Project Convergence: AI Vs. Uncertainty," *Breaking Defense*, May 3, 2021, https://breakingdefense.com/2021/05/project-convergence-ais-vs-uncertainty/.

38. Interviews with PEO Aviation and AI2C officials.

39. Çınar, Zeki M., Abubakar Abdussalam Nuhu, Qasim Zeeshan, Orhan Korhan, Mohammed Asmael, and Babak Safaei. 2020. "Machine Learning in Predictive Maintenance towards Sustainable Smart Manufacturing in Industry 4.0" Sustainability 12, no. 19: 8211, https://doi.org/10.3390/su12198211.

40. Arena, Fabio, Mario Collotta, Liliana Luca, Marianna Ruggieri, and Francesco G. Termine. 2022. "Predictive Maintenance in the Automotive Sector: A Literature Review" Mathematical and Computational Applications 27, no. 1: 2, especially pp. 17–18, https://doi.org/10.3390/mca27010002.

41. *Army Investing in Predictive Maintenance for Bradleys*, "Many commercial firms are already employing machine learning for predictive maintenance. Caterpillar, Airbus and other organizations within the energy sector have been leveraging AI to gain insight into the health of their equipment, as well as to increase availability of their vehicles."

Data is truly king and it is really hard to get the full picture needed to conduct predictive analysis. The progress to date is undeniable, however. Prototype capabilities have transitioned to Service customers. These customers have tested, employed, and retested these prototypes. They have found them useful in some cases and faulty in other ones. Most importantly, the services have continued investment in projects to develop better data sets and better algorithms towards the PMx goal. This sustained support provides evidence that this perspective has support across the enterprise and has not become an issue of bureaucratic resistance. While prioritization will always be an issue, predictive maintenance is clearly developing into a promising use case of AI technology in defense.[42]

Current trends are of course not a guarantee of future success. The following recommendations could therefore help to keep the Department moving towards the goal of predictive maintenance:

- *Focus on data first and foremost.* Increasing the clarity of data through efforts such as the JAIC (now CDAO) ERDC dashboard is imperative to achieving the accuracy required to fully achieve a predictive maintenance end state. More broadly, DoD-wide efforts to support intra and inter department data sharing and portability using well defined and enterprise-wide data standards and protocols will help in this area and many others.
- *Add additional data sources when ready.* Creating better methods to store, cleanse, and analyze data will facilitate the use of AI/ML tools on additional data sources such as visual inspections, images, and full-motion video to increase the precision of predictive maintenance capabilities.
- *Continued prioritization will be essential.* CDAO's new and prominent role for the Department should facilitate DoD leadership attention and resources in this important area.
- *Establish effective metrics.* The clear priority for the services in predictive maintenance is to improve operational readiness. Cost savings are important as well, but articulating the real benefits of predictive approaches needs to be specific and measurable to build credibility over time.
- *Be clear-eyed in terms of expectations.* Progress will be incremental and it is important to be transparent about the gains and limitations of projects to key stakeholders in the Department, in industry, and on Capitol Hill.
- *Build in predictive maintenance tools and approaches into acquisition program development and sustainment.* The CBM+ DoDI underlines the procedures necessary to build in key performance parameters and metrics to help incorporate predictive approaches throughout the program lifecycle.[43] Maintaining this focus will be critical in predictive maintenance. Flexibility in intellectual property licenses and data interfaces will be important as well.
- *Create trust in user community on predictive maintenance capabilities.* Maintainers will only adopt technologies and tools that they trust so continuing to iterate developing AI/ML capabilities with user groups will be essential for adoption over time.
- *Enable maintainers to transition to a proactive maintenance culture.* Adapting maintenance from a reactive culture to a proactive one will require changes in training and procedures that will involve a great deal of sustained attention. Defense Acquisition University and service training commands could serve central roles in this effort.

Based on the pilot efforts examined in this white paper, DoD is still in the early stages of its journey towards predictive maintenance. The AI/ML algorithms will continue to improve, but developing a true predictive maintenance capability will take continued data effort and prioritization for years to come. DoD is off to a solid start, but needs to stay on this promising trajectory.

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42. The just-released DoD Inspector General Report on predictive maintenance arrived at similar findings on the current state of predictive maintenance in DoD. See Audit of the Department of Defense's Implementation of Predictive Maintenance Strategies to Support Weapon System Sustainment (DODIG-2022-103), June 15, 2022, https://www.dodig.mil/reports.html/Article/3063635/audit-of-the-department-of-defenses-implementation-of-predictive-maintenance-st/.

43. DoDI 4151.22, 9.

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Prior to joining GMU, McGinn served as the senior career official in the Office of Manufacturing and Industrial Base Policy in the Department of Defense, leading a staff of 80 personnel and managing an annual budget of approximately $200 million in efforts to analyze the capabilities, overall health, and policies concerning the industrial base on which the Department relies for current and future warfighting capabilities.

Previous to DoD, he spent a decade in senior defense industry roles at McGinn Defense Consulting LLC, Deloitte, QinetiQ North America, and Northrop Grumman. Before industry, McGinn served in DoD as Special Assistant to the Principal Deputy Undersecretary (Policy) and as a political scientist at RAND. He has published numerous influential articles and monographs, testified before the U.S. Congress and the United Kingdom House of Commons, presented to senior government and industry audiences around the world, and is regularly interviewed on critical national security issues.

McGinn was commissioned into the U.S. Army and served with distinction as an infantry officer and is a graduate of Ranger and Airborne Schools. He holds a Ph.D., M.S., and M.A. from Georgetown University and a B.S. from the United States Military Academy.

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He is the former lead acquisition and procurement policy counsel for former Chairman Darrell Issa of the House Oversight and Government Reform Committee. In that capacity, Beutel wrote and managed the Federal IT Acquisition Reform Act, or FITARA, which was signed into law as part of the FY2015 National Defense Authorization Act.

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A nationally recognized expert in IT acquisition management and cloud policy, Beutel has 25 years of private sector experience and was the founder and co-managing director of the first Dell Government Relations Team, working directly with Michael Dell for many years in support of Dell's Washington policy initiatives.

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Benjamin McMartin, Esq. CPCM is a Senior Fellow in the School of Business at George Mason University. His appointment is with the Center for Government Contracting. McMartin is the managing partner of the Public Spend Forum, a firm dedicated to enabling open government markets worldwide. He is a nationally recognized expert, speaker, and author in federal procurement and non-traditional acquisition methodologies, who spent more than a decade developing some of the most unique procurement solutions for the Department of Defense.

McMartin is a regular speaker on topics related to alternative acquisition methods, public procurement policy, and acquisition reform. He previously served as Chief of the Acquisition Management Office for the US Army Combat Capabilities Development Command–Ground Vehicle Systems Center, and prior to that, as a Procuring Contracting and Agreements Officer for the US Army Contracting Command–Warren.

McMartin earned his J.D. from the University of Detroit-Mercy Law School and has been a member of the Michigan State Bar since 2008. He is twice the recipient of the Army Achievement Medal for Civilian Service, and a recipient of the Army Civilian Service Commendation Medal. He is DAWIA Level III certified in Contracting; a Certified Professional Contracts Manager (CPCM); and Fellow of the National Contract Management Association.

The White Paper Series

The purpose of the Center's White Paper Series is to promote research and discussion on topics of interest and importance to the government contracting community.

Comments from the community are welcome and may be sent to govcon@gmu.edu.

- NO. 1. *Unintended Consequences of Small Business Contracting,* Craig R. Reed, Ph.D. NOVEMBER 25, 2019
- NO. 2. *Pricing Intellectual Property in Defense Competitions: Toward Theoretical and Practical Advice for government Officials and Government Contractors,* James Hasik, Ph.D. NOVEMBER 25, 2016
- NO. 3. *The Cost of Saving Money: The Negative Impact of Roller Coaster DoD Funding,* Jennifer Taylor. NOVEMBER 25, 2016
- NO. 4. *The Value of Intellectual Property in Government Procurement Auctions,* James Hasik, Ph.D. JULY 14, 2020
- NO. 5. *The DoD Budget Process: The Next Frontier of Acquisition Reform,* Eric Lofgren. JULY 29, 2020
- NO. 6. *Building Resilience: Mobilizing the Defense Industrial Base in an Era of Great-Power Competition.* Jerry McGinn, Ph.D. SEPTEMBER 28, 2020
- NO. 7. *What Future for Remote Work in Federal Contracting?* James Hasik, Ph.D., JANUARY 14, 2021
- NO. 8. *Building Industrial Resilience with a Little Help from Our Friends,* Jerry McGinn, Ph.D. JUNE 5, 2021
- NO. 9. *Achieving Defense Exportability, Frank Kenlon,* AUGUST 16, 2021
- NO. 10. *Implementing Responsible AI: Proposed Framework for Data Licensing, Implementing Responsible, Maj.* Andrew Bowne and Mr. Benjamin McMartin, APRIL 29, 2022

George Mason School of Business

Center for Government Contracting

The vision of the Center for Government Contracting is to establish the first-in-the-nation university center to address business, policy, regulatory and other issues in government contracting.

Activities to implement this vision will focus on three lines of effort: ***Research***, ***Education & Training***, and ***Collaboration***.

The George Mason University School of Business is uniquely positioned to create this center by virtue of the composition of our faculty and students as well as our geographic co-location with the Federal Government and many headquarters and major facilities of companies that make up the $500 billion government contracting (GovCon) industry.