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DIGITAL TWINS OF WEAPONS AND MILITARY EQUIPMENT FOR FAILURE PREDICTION AND SUSTAINMENT OPTIMIZATION

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Introduction

The increasing technical complexity of modern weapons and military equipment has made lifecycle support, readiness management, and predictive sustainment central issues of defense capability. Recent U.S. defense and Army materials treat digital twins as a practical instrument for predictive maintenance, efficient repair operations, and lifecycle management rather than as a purely experimental concept. The Defense Business Board’s 2024 report on the digital ecosystem explicitly states that digital twin systems should use detailed information from product lifecycle management and design systems to support predictive maintenance and enhanced AI/ML capabilities, while Army digital engineering assessments likewise connect digital twins with predictive maintenance and efficient repair operations for maintainers and sustainers. The objective of this study is to determine how digital twins can improve failure prediction, maintenance planning, and overall operational readiness of military systems.

Methodology

The research is based on a systems approach, structural-functional analysis, and scenario-based modeling of the sustainment cycle for weapons and military platforms. A digital twin is interpreted as a dynamically updated digital representation of a physical system that combines design data, operational parameters, maintenance history, and sensor-derived condition information. The analytical framework includes four interconnected functions: state monitoring, degradation assessment, failure prediction, and maintenance decision support. The study compares traditional scheduled maintenance with condition-informed and model-supported sustainment. The working hypothesis states that failure prediction and sustainment efficiency improve when a digital twin integrates engineering data, operational observations, and lifecycle feedback into a single decision environment. This interpretation is consistent with current defense guidance that treats digital twins as part of a broader digital engineering and lifecycle ecosystem.

The first argument of the study is that the principal value of a military digital twin lies in its ability to connect engineering design with operational reality. In conventional support systems, maintenance decisions are often based on fixed intervals, generic assumptions, or fragmented technical records. Such an approach does not fully account for mission intensity, environmental stress, subsystem interaction, or cumulative degradation. By contrast, current U.S. defense materials describe the digital twin as being integrated into requirements, development, manufacture, engineering, test, and lifecycle management, and after fielding reflecting actual product performance. This means that the twin can function as a continuously refined representation of the system rather than as a static engineering model.

The second argument is that digital twins create the analytical basis for predictive rather than reactive sustainment. Army and AMCOM materials explicitly connect digital twins with predictive maintenance for aircraft and with improved readiness. In operational terms, this means that maintenance can be triggered not only by elapsed time or visible failure, but also by model-based indications of abnormal wear, performance drift, or elevated risk of subsystem malfunction. Such an approach is especially relevant for aircraft, armored vehicles, missile systems, and other platforms whose mission availability depends on early recognition of degradation patterns that may not yet have produced overt failure. The transition from scheduled intervention to prediction-supported intervention allows maintenance resources to be concentrated where they produce the greatest readiness effect.

The third argument is that the military usefulness of digital twins depends on data integration quality. A twin cannot support reliable prediction if it is disconnected from authoritative engineering baselines, incomplete sensor streams, repair records, or actual operating conditions. The Defense Business Board emphasizes a joint product lifecycle management environment as an authoritative source of truth, while NATO technical work on digital twin interoperability highlights the importance of connected digital representations and interoperability across defense systems. Therefore, the twin should be understood not merely as a model, but as a data-governed operational architecture. Without consistent digital thread continuity, prediction accuracy degrades and the twin risks becoming only a visualization tool rather than a sustainment instrument.

The fourth argument concerns decision support. A military digital twin has value not only when it detects degradation, but when it supports action. If the model can estimate probable failure windows, compare alternative maintenance timings, or identify components whose degradation most strongly affects mission readiness, commanders and sustainment personnel gain a more rational basis for intervention. Army digital engineering assessments specifically tie digital models to repair efficiency and sustainment planning, while broader defense digital ecosystem materials associate digital twins with AI-enabled lifecycle optimization. In this sense, the twin becomes a decision-support layer connecting engineering insight with logistics and readiness management. At the same time, the study identifies important limitations. Prediction quality depends on sensor coverage, model fidelity, data governance, cybersecurity, and interoperability between technical and sustainment systems. NATO publications on digital twin interoperability and defense modeling indicate that interoperability remains a practical challenge, and defense budget materials show that digital twin applications are also being explored for operational technology cybersecurity contexts. This implies that a poorly integrated or poorly protected twin may introduce new vulnerabilities even while promising better maintenance efficiency. For military use, digital twins must therefore be tested not only for engineering accuracy, but also for resilience, security, and usability in real sustainment workflows.

Results and Conclusions

The study supports the hypothesis that digital twins can significantly improve failure prediction and sustainment optimization for weapons and military equipment when they function as integrated lifecycle representations rather than isolated simulation models. Their practical value lies in linking design knowledge, real operational data, and maintenance history into a single analytical environment capable of supporting condition assessment, degradation forecasting, and maintenance prioritization. The main conclusion is that digital twins should be treated as a strategic sustainment capability for modern defense systems. Their effectiveness is highest when they are embedded in a broader digital engineering architecture with authoritative data, predictive analytics, secure interoperability, and direct connection to readiness management. The practical significance of the study lies in its applicability to aircraft, armored platforms, missile systems, naval assets, and other military equipment for which readiness, maintenance timing, and lifecycle cost are critical performance factors.

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