Predicting Mission Outcomes with Warfighter Digital Twins and Artificial Intelligence

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ABSTRACT

U.S. commanders invest significant time and resources planning operations and training Warfighters for battlefield missions. Digital twins and Artificial Intelligence (AI) provide commanders with critical data for mission decisions and train Warfighters for various battlefield scenarios. These digital twins bridge the mission gap by optimizing the mission profile through simulation of the operational environment, Warfighter equipment, and Warfighter human performance. Drone flyovers create environmental digital twins with data on weather, obstacles, avenues of approach, key terrain, observation and fields of fire, and cover and concealment. 3D visualization gaming engines model the integration of Warfighter equipment on-body with respect to size, weight, and power. Warfighter avatars represent individual data including height, weight, heart rate, sleep quality, and physical fitness training scores as well as motion captured in combat training with sensors. Generative AI (GenAI) incorporates mission-specific and open-source information into the digital twin to analyze mission parameters and recommend the best Course of Action (COA). Orchestration software using agentic AI simulates the mission through commander queries, initiating a chain of commands to subordinate agents who respond based on available procedures and data. AI evaluates the effectiveness and precision of operational activities and the Warfighter's physical and psychological systems during action, enhancing learning and readiness. Digital twins powered by AI equip commanders with tools and actionable data. This enables them to leverage their experience, knowledge, and judgment to optimize limited live training time, predict time on target, and improve Warfighter training outcomes while reducing time and cost.

ABOUT THE AUTHORS

Todd Burnett is an Army Senior Executive Advisor with over 12 years of industry experience focused on military training, advancement, and accelerated readiness. Mr. Burnett is a former Command Sergeant Major retired from the Army after 30 years with numerous combats deployments. Mr. Burnett has extensive awards and decorations including the Distinguished Service Medal, Defense Superior Service Medal, Legion of Merit, Bronze Star Medal (with V device), Bronze Star Medal (3rd award), Purple Heart, and Meritorious Service Medal (7th award) among over 66 others. Mr. Burnett earned a Bachelor of Science Degree in Business Administration.

Jake Mathey is a Systems Engineering subject matter expert with 8 years of experience, 6 years in the aerospace industry and 2 years in Warfighter technology. He earned a Bachelor of Science and Master of Science in Mechanical Engineering with a specialty in Systems Engineering. Leveraging his experience as a Certified Systems Engineering Professional (CSEP), he leads digital twin, engineering, and transformation efforts for the Defense Department (DoD).

Dr. Maryrose Blank is an expert in psychology, health, and cognitive performance. With over 15 years of experience, she has helped develop programs for the DOD that use advanced tools, technologies, and training methodologies to optimize unit readiness and sustainable peak performance. She has a Doctorate in Sport and Performance Psychology and is a Certified Mental Performance Consultant with the Association of Applied Sport Psychology.

Dr. James Brown is an expert in neuroscience, experimental psychology, and data science. James has an extensive background in cognitive neuroscience research, brain imaging, and applied machine learning, and over 5 years of experience working collaboratively with DOD clients building and deploying bespoke technical solutions. He has a Doctorate of Neuroscience and Biological Psychology with a specialty in visual neuroscience, and a Master of Arts in Data Analytics and Applied Statistics.

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INTRODUCTION

In the rapidly evolving landscape of military operations, the integration of advanced technologies is transforming the tactical mission lifecycle. Long before any Warfighter boots hit the ground, U.S. commanders invest significant time and resources training Warfighters and planning operations. This preparation is crucial for mission success but is often hampered by unrealistic field training environments and barriers to integrating essential data. Accelerating the readiness of U.S. armed forces necessitates a more effective approach to training and mission planning.

Warfighter training is the cornerstone of military readiness. Advanced simulation technologies offer a revolutionary approach by creating highly realistic virtual environments where Warfighters can train under conditions that closely mimic combat situations. These technologies enable personalized training programs that adapt to the needs of individual Warfighters, enhancing their skills and preparedness.

Readiness is a critical measure of a military unit's ability to deploy quickly and effectively in response to various threats. Historically, achieving elevated levels of readiness has involved extensive physical training exercises. The integration of advanced technologies significantly enhances readiness by providing continuous, data-driven insights into the performance and capabilities of Warfighters and equipment. These technologies facilitate real-time adjustments to training and mission planning, ensuring that forces are always prepared to respond to emerging threats and challenges.

Mission planning requires coordinating multiple factors and resources. Advanced modeling and simulation capabilities streamline this process by offering detailed visualizations of different scenarios, assessing potential Courses of Action (COAs), and aiding in informed decision-making. This modern approach not only improves the efficiency of mission planning but also enhances the effectiveness of operations.

Digital twin technology with artificial intelligence is enhancing the tactical mission lifecycle for the U.S. armed forces from training to mission planning. A digital twin is a technically exact, virtual replica of an object, process, or system, constructed from vast amounts of data. This high-fidelity digital twin model with artificial intelligence allows commanders to visualize and rehearse missions in realistic virtual environments, significantly enhancing training, readiness, and mission planning.

DIGITAL TWIN ARTIFICIAL INTELLIGENCE (AI) ONTOLOGY

The digital twin and AI ontology enhances Warfighter mission training through modeling and simulation. The Warfighter improves readiness through the live virtual constructive training ecosystem leveraging Generative AI (GenAI). The live virtual constructive training ecosystem includes training in the areas of fundamental, specialized, service specific, joint, rehearsal, and leadership. This Warfighter training paired with human performance readiness forms the Warfighter digital twin in the digital twin ecosystem. The commander pre-mission training planning utilizes the Military Decision-Making Process (MDMP) connected to the digital twin ecosystem via GenAI and agentic AI. The digital twin ecosystem includes digital twins in the areas of environmental, Warfighter on-body equipment, Warfighter/echelon, and mission assets. GenAI and agentic AI serve as digital threads connecting data, models, training, and simulation results into tangible insights Commanders can use for data-driven decision making. The digital twin AI ontology is displayed in Figure 1.

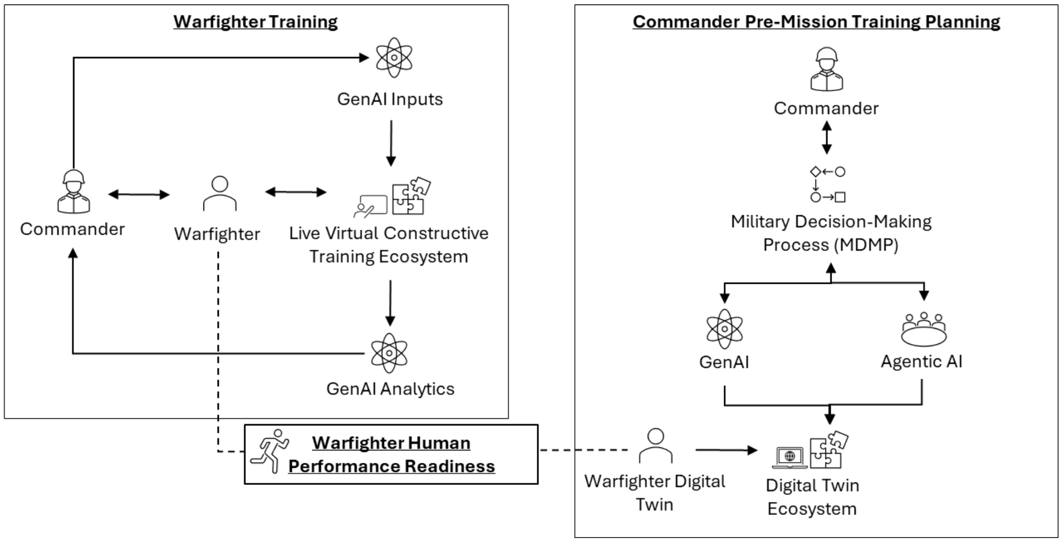

Figure 1. Digital Twin AI Ontology

Warfighter training occurs simultaneously with commander pre-mission training planning according to the red, amber, green management cycle (FM 7 - 0 Training, 2021). The commander pre-mission training planning simulates green cycles including Combat Training Center (CTC) rotations and Combined Arms Live Fire Exercise (CALFEX). The Warfighter training simulates collective tasks recommended from the mission essential task list. During the Military Decision-Making Process, commanders leverage generative and agentic AI to run models and simulations in the digital twin ecosystem, producing the data they need for informed, data-driven decisions.

WARFIGHTER TRAINING

Warfighter training utilizes a live virtual constructive ecosystem. The foundation of the ecosystem is data embedded into the training digital twin models in key areas of Warfighter training including foundational, specialized, service-specific, joint, rehearsal, and leadership. The Warfighter trainee interacts with the live virtual constructive ecosystem through training actions. GenAI inputs a variety of scenarios mimicking combat to fight a thousand bloodless battles and updates to target individual weaknesses which improve readiness. GenAI analytics provide training insights, readiness scores, and predictive analysis to the commander who uses this data to instruct the Warfighter. The figure below displays the Warfighter training ontology.

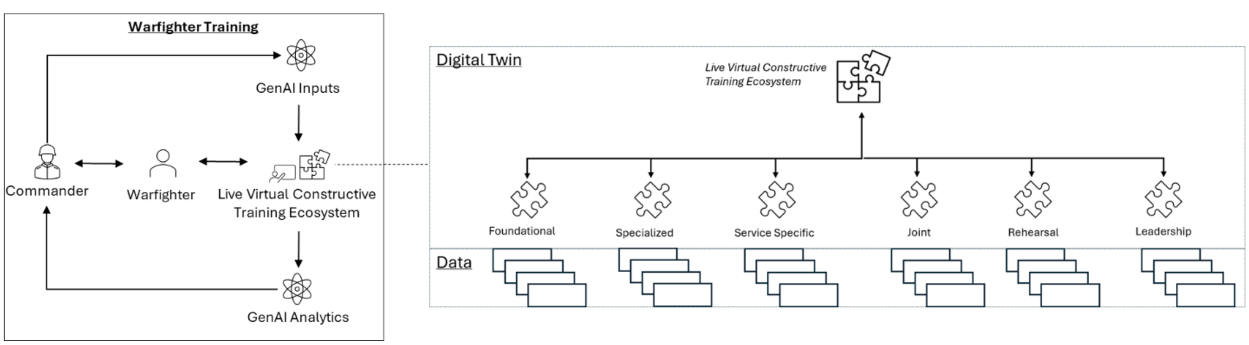

Figure 2. Warfighter Training Ontology

Warfighter Training Use Cases

Defense Department (DoD) training environments are based on an industrial model to produce readiness. All students must attend the same training, in the same format, to achieve certifications or qualifications. This one size fits all approach does not adequately assess individual competencies for meeting readiness requirements. Furthermore, instructor cadre often does not have sufficient bandwidth to support training activities to the level required. There is also a need for a deliberate process to capture, curate, analyze, and disseminate data to provide insights on individual, class, or weapon system readiness programs.

A software solution provides tailored analytics for training systems by capturing and displaying real-time data. Advanced analytics are employed to measure performance and effectiveness in ways that were previously unattainable within DOD training pipelines. The software solution provides relevant analytic results desired by commanders. Military performance standards are used to set the criteria for determining passing and failing scores. These analytics parameters are customizable to adjust grading criteria as training and readiness competencies evolve over time. Trainers leverage data from any training system and provide tailored and responsive analytic results that empower instructors to train students more efficiently and effectively across all training modalities. These software solutions utilize game engines for training visualization. The analytic library can be expanded to analyze key metrics across various training systems. The system delivers after-action reports specific to the student, location, equipment, or cohort for continuous improvement.

The software solution enables organizations to monitor and track competency. Analytic results inform competency-based and adaptive learning models. The software solution maximizes resource utilization, mitigates risk, and meets the needs of individual students. Commanders can monitor training and readiness competency progression along a training life cycle to track individual and organizational training outcomes, uncover trends, and mitigate bias. Figure 3 displays the software solution overview of training device/equipment, data, use cases, and custom analytics/UI.

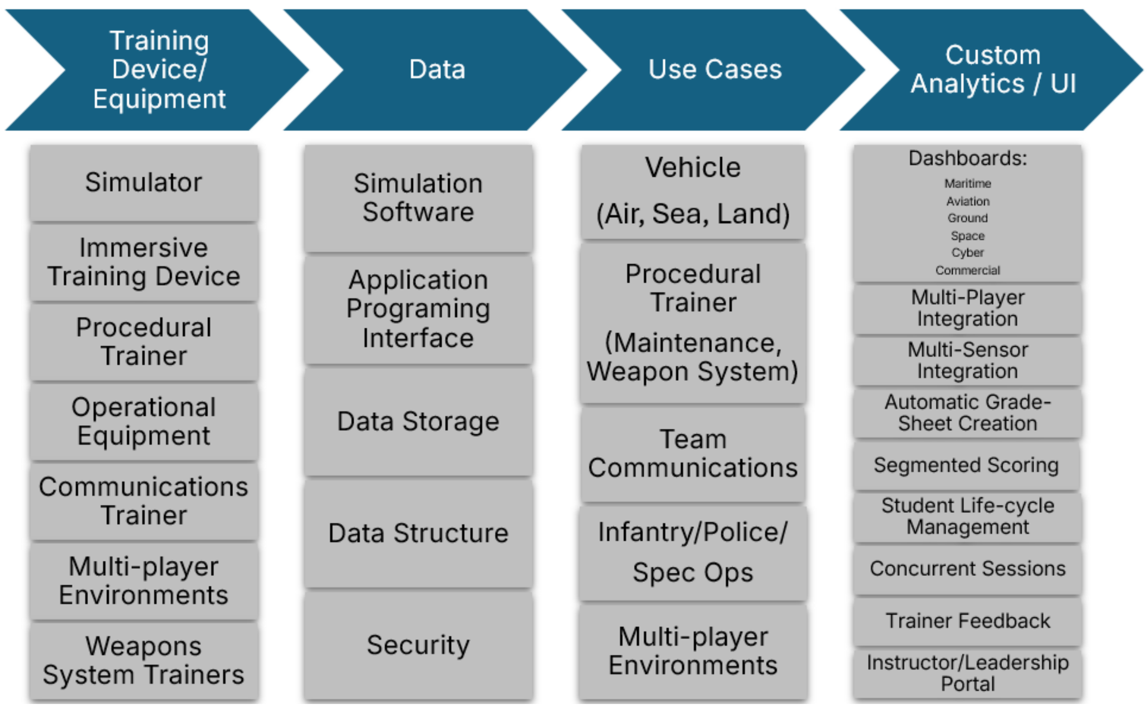

Figure 3. Warfighter Training Use Cases

WARFIGHTER HUMAN PERFORMANCE READINESS

In high-risk operational environments the degradation of human performance due to cognitive fatigue, psychological stress, and physical exhaustion poses a significant threat to mission success and Warfighter safety. Current methods for assessing Warfighter readiness are fragmented, often invasive, and rarely integrated into real-time operational planning (Wilson & Russell, 2007). This research presents a novel, adaptive AI model that addresses these limitations by offering a holistic framework for evaluating and predicting human performance degradation in real-world military contexts. The Warfighter human performance readiness workflow can be seen in Figure 4.

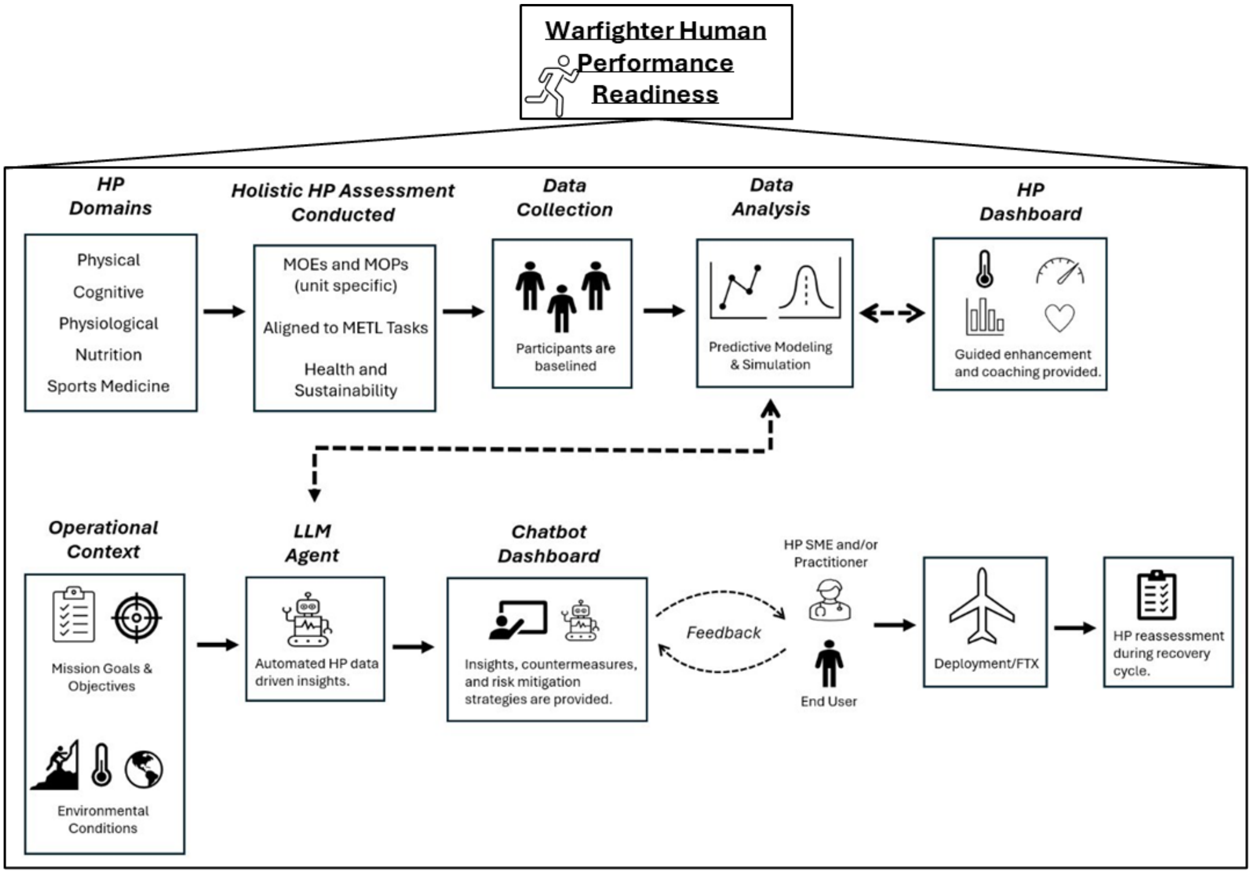

Figure 4. Warfighter Human Performance Readiness Workflow

At the core of this research is the development of an agentic workflow in a modular, AI-driven system capable of modeling, interpreting, and predicting the trajectory of human performance over time. This workflow synthesizes data across cognitive, physiological, psychological, and environmental domains to construct a dynamic, context-aware understanding of performance readiness. Unlike traditional systems that focus narrowly on physiological signals such as heart rate or sleep, this approach integrates insights from psychology, neuroscience, exercise science, and systems engineering to deliver a comprehensive readiness profile (Schmidt, Regele, & Hardt, 2019).

The agentic workflow operates on several interrelated layers:

- **Data Aggregation and Normalization:** The system ingests a diverse range of human performance data, including empirical inputs related to cognitive function, nutrition, health status, and physical fitness. These data points are sourced from a validated synthetic dataset that mirrors operational stressors observed in field conditions. The normalization process ensures compatibility across modalities, facilitating robust cross-domain inference.
- **Multimodal Modeling and Prediction:** Leveraging machine learning and computational modeling, the workflow interprets changes in performance markers over time. It identifies critical thresholds—tipping points where the risk of failure, injury, or diminished cognitive function becomes operationally significant. Through supervised and unsupervised learning techniques, the model extrapolates these thresholds to provide real-time predictions and decision support.
- **Conversational Interface via Large Language Model (LLM):** A distinguishing feature of this system is its integration with a large language model, serving as a natural language interface between users and the underlying data infrastructure. This enables intuitive querying of complex human performance scenarios, making the tool accessible to non-technical users such as field commanders, trainers, and medics. Rather than sifting through dashboards or spreadsheets, users can ask questions like "When is fatigue likely to impair this unit's mission execution?" or "Who is at highest risk for burnout in the next 48 hours?"
- **Simulation and Validation:** The model has been validated through simulations designed to replicate operational tempo, mission demands, and environmental challenges. These simulations highlight the system's capacity to

deliver actionable insights for Warfighter selection, task allocation, and adaptive training regimens. Moreover, predictive feedback loops allow the model to learn from ongoing outcomes, continuously refining its forecasts.

This agentic approach has profound implications for human performance readiness in military contexts. Traditionally, readiness assessments have been reactive relying on post-hoc performance reviews, subjective observations, or biomedical snapshots that fail to account for dynamic cognitive and environmental variables. In contrast, the agentic workflow enables proactive readiness management. By forecasting degradation trajectories, leaders can intervene early, redistributing workload, adjusting sleep cycles, or modifying mission parameters to preserve performance integrity.

Additionally, this model supports the development of assistive technologies that adapt in real time to the operator's cognitive and physiological state. For instance, an AI-assisted heads-up display could reduce cognitive load when fatigue indicators rise, or an exosuit could modulate support based on biomechanical strain predictions. These innovations would not only extend operational endurance but also mitigate injury risks and cognitive lapses during high-stakes engagements.

In training environments, the workflow enables precision coaching by mapping individual resilience profiles. Recruits and Warfighters can be assessed across multi-day simulations to identify where their performance begins to degrade. These insights can inform personalized training schedules that enhance durability, promote recovery, and reduce attrition. In mission planning, commanders can use model outputs to tailor team compositions based on complementary strengths and vulnerabilities aligning operational objectives with human capabilities.

Another critical advantage of the agentic model is its scalability and modularity. It can be deployed across different branches of the military and adapted to specific contexts such as aviation, special operations, cyber warfare, or logistics. Its open architecture allows integration with wearables, biometric sensors, and mission planning systems, making it a versatile backbone for future human-machine teaming applications.

Ultimately, this research lays the groundwork for a next-generation human readiness platform—a system that transforms data into foresight, and foresight into operational advantage. In an era where warfare is increasingly defined by the speed and adaptability of human-system integration, tools that can preemptively identify performance degradation will be vital. This approach improves not only the physical and cognitive safety of Warfighters but also the mission effectiveness of the teams they serve.

COMMANDER PRE-MISSION TRAINING PLANNING

Digital twins and AI augment the commander MDMP planning. This planning involves mission analysis as well as COA development, analysis, comparison, and selection. In mission analysis, digital twins can be used to analyze the Mission, Enemy, Terrain and Weather, Troops, and Support Available, Time available, and Civilian Considerations (METT-TC). COA development uses digital twins with AI to analyze relative combat power, generate options, array forces, develop concept of operations, assign responsibilities, and prepare the COA statement. COA analysis uses digital twins with AI to war game actions, reaction, and counteraction through methods including box, belt, and avenue in depth. GenAI augments the commander COA comparison and COA selection. The figure below displays the MDMP.

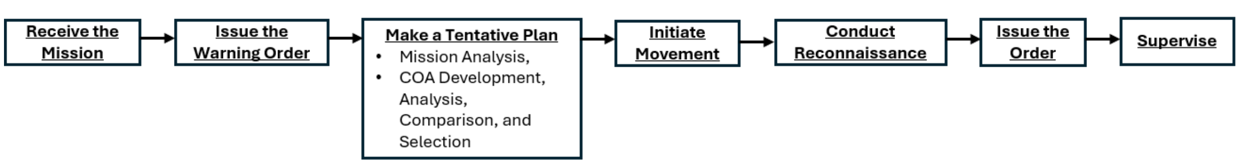

Figure 5. MDMP Process (FM 7 - 8 Infantry Rifle Platoon and Squad, 1992)

The digital twin ecosystem is composed of environment, Warfighter/echelon, Warfighter on-body equipment, and mission asset digital twins. These digital twins provide modeling and simulation based on the mission parameters entered by the commander, GenAI, and agentic AI.

Commanders can use GenAI to input data into the digital twin ecosystem to simulate the mission. GenAI outputs data to the commander to aid the commander MDMP. GenAI rapidly analyzes mission parameters and generates optimized COAs. The commander can query via GenAI to extract required data. Agentic AI can be used to interpret queries and simulate assigning tasks to subordinate agents, ensuring each step is executed sequentially and efficiently. Agentic AI integrates vast amounts of data from various sources including procedures, to provide comprehensive and accurate responses. The figure below shows the digital twin ecosystem within the digital twin AI ontology.

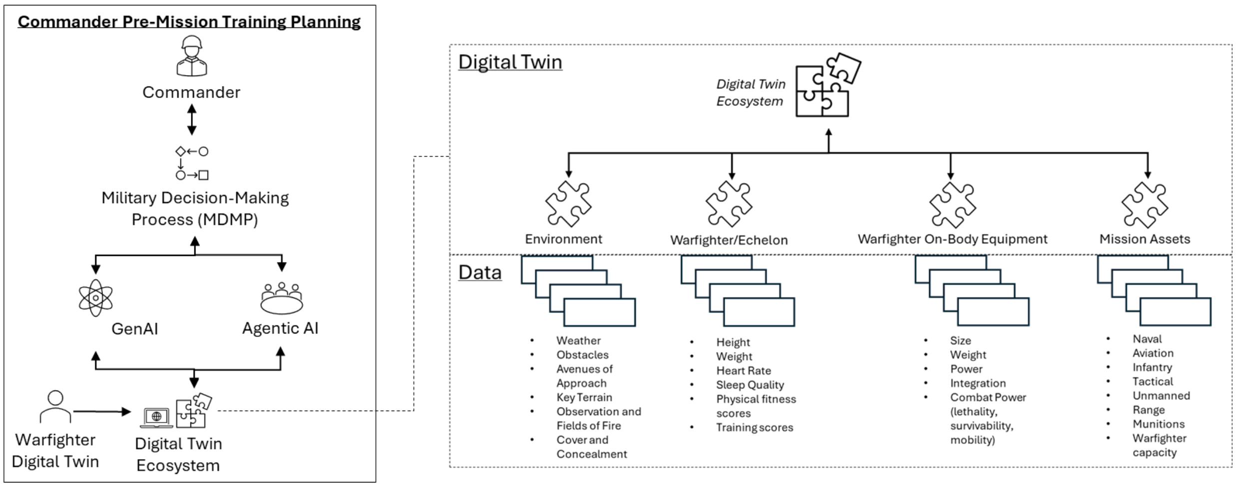

Figure 6. Commander Pre-Mission Training Planning

Environment Digital Twin

Commanders have a critical need for new ways to conduct mission planning based on real-time data about the mission, terrain involved, and potential scenarios. One of the main challenges for high-fidelity mission planning is obtaining the most current terrain and environmental data to simulate different COAs. While tools like Google Maps or satellite data provide a view of the terrain from above, they can be outdated and may not offer enough context about terrain type, topology, and landscape contours.

Drone flyovers are used to capture real-time terrain data through Light Detection and Ranging (LiDAR) scanning. This LiDAR scanning information is sent back to Warfighters in the field rapidly following data collection. Terrain data captured via drone flyovers is ingested into computer aided design tools to create a high-fidelity area of operations map for the mission planning digital twin. This 3D model allows for different angles to be shown, delving deep to assess various topographical and terrain features. It serves as a basis for mapping routes, anticipating difficult terrain, and simulating troop activity. Points of interest on the map are assessed for mission planning upon receiving the operation order and drone-captured terrain data.

Route planning COAs can be analyzed via the environment digital twin. Heavily forested terrain versus uncovered terrain represents an example COA comparison. The heavily forested terrain provides additional cover during the approach and minimizes the risk of being detected. Once the environment, Warfighter/echelon, and Warfighter on-body kit are optimized, the simulation can be run to see how the squad could move to the objective. During the simulation, the squad starts in a wedge formation, shifts formation as they move through dense terrain, and returns to a wedge once out of the dense terrain. This simulation helps capture squad and Warfighter performance metrics, which are then correlated with movements and formations for review in the after-action review. The figure below shows a digital twin visualization of the environment for mission planning.

Figure 7. Environment Digital Twin

Warfighter On-Body Equipment Digital Twin

The Warfighter on-body equipment digital twin can provide Warfighter Model-Based Systems Engineering (MBSE), 3D visualization, analysis, and power simulation. The equipment digital twin can be utilized to optimize equipment kit for weight, combat power, march, and electrical power.

The Warfighter baselines may include all end items that can be tracked and managed with MBSE. MBSE can store data on equipment for various roles and configurations. Visualization can enable commanders to view equipment configurations and determine integration issues prior to the mission. The Warfighter equipment baseline configurations can be compared to determine weight differences. This overall weight can then be optimized for the mission and Warfighter human performance capabilities. The figure below shows the modeling and simulation tool user interface for equipping a Warfighter. The equipment can be dragged and dropped onto the Warfighter showing updates to equipment percent of body weight and power metrics. Different operating environments can be analyzed via data entered including temperature, elevation, and oxygen percentage. Various Warfighter body forms can be modeled including male and female with data on height, weight, and age. Human performance data from wearable sensors can be ingested into the model and used for feedback in the Warfighter equipping process. Walking and running can be modeled to show the impact on range of motion and equipment integration.

Figure 8. Warfighter Equipment Kit Digital Twin

Combat power is a metric assigned to the Warfighter mobility, lethality, and survivability. A West Point study bench marked combat power for the Warfighter (Taylor Andrews, 2020). Combat power represents the trade space between mobility, lethality, and survivability that can be optimized based on the mission requirements. For example, adding additional magazines to a Warfighters kit increases lethality but decreases mobility due to additional weight. Equipment loadout can be optimized through tradeoff analysis to understand the impact kit has on mobility, lethality, and survivability.

The Warfighter equipment can be tailored for the mission type. Garrison and attack equipment loads differ and can be tracked with MBSE. This equipment list can be modified based on the mission through calculating march calories burned using the Pandolf Equation. The Pandolf Equation calculates the metabolic cost of walking based on the Warfighter weight, equipment weight, terrain factor, walk velocity, and terrain slope grade. This data paired with the Warfighter digital twin can give commanders the capability to estimate time to reach a waypoint across echelons. Commanders can identify Warfighters with varying human performance levels to plan equipment distribution actions which optimize the echelon time to reach waypoints.

The equipment digital twin can simulate electrical power based on factors such as activities, weather, and duration. The simulation can output energy consumption, batteries required, and recharging required. This allows electrical power to be planned based on mission lengths including 24-, 48-, and 72-hour missions.

Warfighter/Echelon Digital Twin

The individual Warfighter digital twin can be created from Warfighter training, Warfighter human performance, consolidated profile, and health data. The Warfighter digital twin visualization may be created using photogrammetry scanning and AI. The Warfighter digital twin data can connect to live data from military databases. The data affects the movement and capabilities of the virtual Warfighter in simulated training operations.

The individual Warfighter data can be aggregated to simulate behavior across organizational levels. This highlights the emergent properties of Warfighters coming together with various training, human performance levels, and health backgrounds to perform a mission.

The echelon reporting function can provide the ability to configure and analyze aggregations of Warfighters, equipment, and mission assets across echelons. Echelon reporting shows aggregation, dependencies, and analysis. Critical areas for echelon reporting include communications, weapons, and human machine teaming. Electrical power, combat power, and march calculations can be assessed and optimized at various echelon levels using the echelon reporting digital twin.

Mission Asset Digital Twin

Digital twins of mission assets can show modeling and simulation for vehicles in areas including naval, aviation, infantry, tactical, and unmanned. Wargaming generally occurs on physical 2-dimensional maps with cards and yarn to represent assets and routes. Mission asset digital twin visualizations with data can be overlaid on 3-dimensional environments for Wargaming. The allows modeling and simulation to seamlessly analyze and predict COAs. During training, the one system remote video terminal allows Warfighters to monitor and downlink surveillance video and data. These mission assets are stored in their respective echelon in the digital twin ecosystem for modeling and simulation.

IMPLEMENTATION

The digital twin AI ontology must be operationalized in a modeling and simulation environment to provide value to commanders. The following process is used to operate the digital twin AI ontology.

1. **Data:** The data is connected from source to database and collected. The live constructive training environments and digital twin ecosystems provide large data sets for data collection.
2. **Cloud:** This data is uploaded to the cloud and augmented with synthetic data. Data uploaded to the cloud requires establishing cloud infrastructure and cyber accreditation.
3. **Software:** Software is used to convert manual processes to software defined systems. This requires selection and procurement of software for modeling and simulation.

4. **Simulate and Test:** The data uploaded to the cloud in software-defined systems is simulated and tested. This provides the basis for AI integration.
5. **AI:** AI runs simulations and tests to provide insights and optimization for data-driven decision making.
6. **Operationalize:** This process is continuously improved and iterated on to meet mission requirements.

CONCLUSION

Digital twins with artificial intelligence bridge the gap for training, readiness, and mission planning. Live virtual constructive training enables Warfighter to address weaknesses in skillsets and enhance their skills and preparedness. Warfighter human performance readiness utilizes data to enhance training and aid in mission readiness assessment. Mission planning digital twins with artificial intelligence takes data from the operational environment, Warfighter equipment, Warfighter/echelon, and mission assets to augment commander decision making. These digital twins equip Commanders to leverage their experience, knowledge, and judgment to optimize limited live training time, predict time on target, and improve Warfighter training outcomes while reducing time and cost.

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