TARDEC 30-YEAR STRATEGY

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I. PURPOSE

The purpose of this document is to provide the overarching framework within which the Tank Automotive Research, Development and Engineering Center (TARDEC) will develop, integrate, and sustain advanced manned and unmanned ground system capabilities for the current and future force. This document is the single source that presents TARDEC's strategic context and future direction.

II. INTRODUCTION

TARDEC is the ground system expert administratively aligned within the Army's Research, Development and Engineering Command (RDECOM). It provides engineering and scientific expertise for Department of Defense (DoD) manned and autonomy-enabled ground systems and ground support systems; serves as the nation's laboratory for advanced military automotive technology; and provides leadership for the Army's advanced Science and Technology (S&T) research, demonstration, development and full life-cycle engineering efforts.

TARDEC is also operationally aligned as part of the TACOM Life Cycle Management Command (LCMC). In this capacity, it is responsible for critical technical functions within the "acquisition – logistics – technology" system life-cycle model, including: technology maturation and integration, technology subject-matter expertise, technical authority, systems-level engineering analysis, system sustainment and logistics, materiel readiness, and systems engineering. These functions must ensure that all capability developments consider and inform strategic implications to the joint force across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy (DOTMLPF-P) spectrum.

TARDEC associates provide engineering support for more than 2,800 Army systems and many of the Army's and DoD's high-priority joint development programs. The organization is responsible for maximizing the research, development, prototyping, transition and sustainment of technologies and technology integration across ground systems to provide the warfighters enhanced capabilities and ensure readiness.

III. CONTEXT

This strategy is shaped through enduring partnerships with the Training and Doctrine Command (TRADOC), Army Materiel Command and Program Executive Offices (PEO), the Army's research, development and engineering community, S&T organizations across the DoD, other federal agencies, industry (particularly automotive), academia, and international partners. Continuous S&T planning efforts also inform this strategy, including the Strategic Portfolio Analysis Review (SPAR) conducted by the Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA (AL&T)) and the Army G8, the Long Range Research and Development Planning Program (LRRDPP) conducted by the Office of the Secretary of Defense (OSD), and OSD Communities of Interest (COI), particularly the Ground & Sea Platforms COI.

This strategy is also driven by changes in America's strategic, technological, and fiscal environments, following more than a decade of intense conflict and the Army's adjustment to a broader, multi-domain, and joint-mission focus in which the Army integrates joint force efforts to provide direct interface to all aspects of National Power.

The global political environment is becoming more volatile with peer, near-peer, hybrid, and non-state threats competing for positions of advantage. No single superpower or group holds enough power to maintain outright superiority or stability. Instead, global actors are seizing temporary windows of opportunity for specific gains.

The United States global position is affected by over 15 years of active conflict, during which adversaries were free to study US Army capabilities. The enemy has learned strategies, technologies, and tactics, techniques, and procedures (TTPs) and many offensive threats have been countered by developing low cost TTPs to fracture synchronized military efforts. Peers and near-peers have made substantial investments in deterrence including advanced air defense systems, cyber/electromagnetic activities (CEMA), and expert manipulation of the populace. Senior Army leaders are asking TARDEC to view the whole ecosystem, understanding that kinetic victories may still have adverse economic effects.

The Army has recently published several strategic documents which further define the future operating picture of the U.S. military and provide strategic context to TARDEC. The Joint Multi-Domain Battle Concept, the Army Operating Concept (AOC), and the seven Army Warfighting Functional Concepts (AFC) present three problems the Joint Force needs to address to secure U.S. interests in the future operating environment:

1) Quickly deploy and gain forcible entry into an area with advanced anti-access capability and rapidly transition from movement to maneuver
2) Maintain freedom of movement once in theater against area denial capability
3) Disallow the fracturing of synchronized efforts while operating in a Joint, Interagency, Intergovernmental, and Multinational environment

Figure 1: Win in a Complex World. In the future the U.S. has to anticipate all domains being contested while working with an undefined and constantly changing coalition. (*AOC*, 2014)

As the strategic environment changes, so must TARDEC. One of the themes in this strategy is the concept of *operational adaptability* — the ability for Army leaders, Soldiers, and civilians to shape conditions and respond effectively to a broad range of missions and situations with appropriate, flexible and responsive capabilities. Operational adaptability requires flexible organizations and institutions to support a wide variety of missions and adjust focus rapidly to prevent conflict, shape the security environment, and win the nation's wars. TARDEC's strategy supports the rapid development and enhancement of equipment that will enable appropriate, flexible and responsive capabilities to provide decisive land power. It also requires TARDEC to be flexible and adaptable so it may rapidly facilitate acquisition processes by having readily available systems, sub-systems, and component designs for changing strategic and tactical circumstances.

TARDEC must be able to address the proliferation of increasingly sophisticated technologies such as advanced communications, cyber-related challenges, unmanned air and ground systems and non-lethal weapons operated by allies and enemies. Additionally, TARDEC must increase the rate of in-house innovation and leverage innovation in the commercial sector to build a stronger connection between commercial and military technology development to enable more rapid acquisition of new capability. The organization must fully exploit commercial advances to focus on components, sub-systems, full systems, and system architectures which deliver new equipment to the warfighter faster. In addition, TARDEC must identify the capability gaps that commercial entities typically do not fill, due to low product volume and unique requirements, and work to proactively fill those gaps through internal R&D or by working with industry to increase capability of existing non-military components to meet existing needs.

A challenge for TARDEC will be navigating the current financial and economic environments. While there are always fiscal constraints, the current administration has been changing the landscape of the fiscal environment with potentially significant increases across DoD. Many of those increases are geared towards readiness, which impact TARDEC's support for current systems, however investments must continue to be made in future-focused capabilities intelligently with a focus on efficient utilization of financial resources.

While the U.S. remains the preeminent global power, it will continue to confront numerous adversaries that may require it to rapidly deploy forces anywhere at any time. Furthermore, global economic conditions are forcing the country and military organizations to make difficult fiscal choices. These contextual factors create the need for TARDEC to develop adaptable and flexible capabilities that deliver long-term value to the Army while leveraging commercial innovation and partner resources in order to maximize cost effectiveness and accommodate increases in complexity, uncertainty and scope of future operations.

IV. STRATEGIC FRAMEWORK

A. MISSION

TARDEC’s mission is to develop, integrate and sustain the right technology solutions for all manned and unmanned DoD ground systems and combat support systems to improve Current Force effectiveness and provide superior capabilities for the Future Force.

B. VISION

TARDEC's vision is to be the first choice of technology and engineering expertise for ground systems and support equipment – today and tomorrow.

Overall, TARDEC's vision supports the Army's strategic direction by resolving technological challenges and addressing fiscal constraints and priorities in a manner that provide advanced capabilities integrated into DoD ground systems through a number of means, many of which are interrelated. These include: (1) developing, demonstrating, and integrating advanced and cost-effective capabilities for the warfighter; (2) demonstrating maximized adaptability and flexibility of current and future platforms to maintain technological superiority; (3) reducing manpower, logistics and similar burdens on the battlefield; (4) improving operating efficiencies, such as reductions in space, weight, power, and cooling requirements and reducing fuel and energy consumption for ground systems; and (5) developing the engineering services that fully support the full product life cycle from requirements development to sustainment. Each of these means also requires investment in the infrastructure (people, processes, facilities, and tools) to increase the rate at which these capabilities become available to the warfighter. TARDEC must also continue to develop Private-Public Partnerships with strategic partners in industry, academia, and international communities.

TARDEC builds trustful relationships by gaining a thorough understanding of partners' needs and providing products and services to meet those needs. Historically, TARDEC's partners have leveraged TARDEC's technical authority in several key ground vehicle competencies such as Combat Vehicle Propulsion, Tactical and Combat Vehicle Mobility, Fire Suppression, Sustainment Engineering, and Force Projection Technologies. This technical authority extends from the development of new technologies to the integration of sub-systems and full systems, and includes all engineering support services such as technical data management and technical review expertise. To better serve TARDEC's customers in the future, TARDEC will sustain existing technical authority areas and continue to mature towards technical authority in critical emerging areas that include Autonomy-Enabled Systems, Vehicle Security Engineering, and Active Protection Systems. In addition, customer needs change consistently; in some cases those needs are the mission of other RDECOM organizations. In these instances, it is critical for TARDEC to be the entry point into the ground system expertise of RDECOM to bring the full weight of the command to solve current vehicle challenges and provide a system-level solution to the User and Acquisition communities.

TARDEC's vision is enabled through four Organizational Priorities that are pervasive throughout all efforts. These priorities are defined below:

- **Execute the 30-Year Strategy.** Developing capabilities to inform Requirements and deliver significant increase in capability to the warfighter.

- **Advance Public-Private Partnerships.** Creating strategic partnerships that leverage industry partners to augment organic government expertise.
- **Increase Experimental Prototyping Capabilities.** Increase TARDEC capabilities to quickly develop physical and virtual prototypes with our partners to get systems into the Users hands for evaluation and to inform and stabilize requirements.
- **Strengthen the Arsenal of Innovation.** Take advantage of TARDEC's unique geographical location to leverage the commercial domestic automotive industry, robotics, research and development, and academia that exists in Southeast Michigan.

TARDEC's vision is also aligned to the organization's cultural identity – five key tenets by which TARDEC associates collectively characterize the values, norms, and way of life in the organization. The elements of TARDEC's cultural identity are:

- **Excellence in Program Execution.** TARDEC embodies an engineering culture founded on systems engineering and program management best practices. Stakeholders recognize the organization for its technology and engineering excellence.
- **Preferred Source for Ground System Life Cycle Engineering.** TARDEC provides support from program initiation to sustainment and disposal. It is the trusted and valued partner for collaboration with the other research, development, and engineering centers (RDECs) and the Army Research Laboratory (ARL).
- **Center of Innovation.** TARDEC rapidly generates new ideas and shapes them into advanced capabilities and solutions.
- **Committed to Employee Development.** TARDEC continuously develops its people to be the very best in relevant fields.
- **Workplace of Choice.** TARDEC's workforce exhibits ownership in what the organization is doing and is a desirable place to work.

C. APPROACH

In order to organize the major areas of effort within TARDEC and to align the supporting efforts necessary to accomplish this work, TARDEC has defined the following terms that will be used: Value Streams (VSs), Lines of Effort (LOEs), and Key Outcomes (KOs). Each of TARDEC's three VSs contain LOEs which are meant to further subdivide and define each VS. LOEs contain KOs which serve as goals and objectives of each LOE. These KOs may be technical in nature, or may outline strategic plans for interacting with stakeholders and customers.

TARDEC has three **Value Streams** (VSs) that serve as the divisions of the end-to-end activities which, ultimately, deliver required products or services to Soldiers. The first value stream (VS1) titled "*Shape the Future Force*" focuses on developing new concepts and capabilities to inform requirements of the future force. The second value stream (VS2) serves to "*Support Systems across the Acquisition Life Cycle*" and focuses on providing the engineering and technology support required for ground systems as each is realized, upgraded or sustained. Lastly, the third value stream (VS3) is titled "*Strengthen Foundational Competencies*" and focuses on strategically improving TARDEC's core technical and non-technical competencies; the people, processes, facilities, and tools which support all of TARDEC's stakeholders through deliverables in VS1 or VS2. All three VSs are integrated in ways that provide unprecedented value and capability to the Army.

Lines of Effort (LOEs) are subordinate to each VS and enable each respective VS by focusing associated programs and strategic goals within each VS. LOE owners develop and manage objectives that target delivery-oriented outcomes and capability demonstrations. In turn, the LOEs ensure aligned programs achieve stated objectives and contribute to the strategy's execution. This process focuses on what must be done, unifies efforts, and supports task organization to achieve desired outcomes.

Within each LOE are deliverables, **Key Outcomes** (KOs), which may take the form of experiments, models, designs, information, hardware, and/or strategic deliverables. KOs are shaped by LOE objectives, capability gaps, stakeholder feedback, strategic documents, and leadership direction. Some outcomes may support more than one VS or LOE.

Capability Demonstrations (CDs) focus on holistic integration of various components (technology solutions, knowledge, skills, etc.) from across the three VSs to demonstrate a warfighting capability; as such, the CDs rely greatly on capabilities developed in VS1 leveraged through foundational competencies in VS3. CDs drive future ground system concepts, technology investments, and engineering development. In turn, these help to shape strategic decisions about the future force and existing platform upgrades. Some CDs may be delivered as physical or virtual demonstrations to integrate outcomes if that is the most appropriate method. Throughout strategy execution, there will be continuous feedback to inform ground system concepts and developments that support desired outcomes.

V. VALUE STREAMS

VALUE STREAM 1 (VS1): SHAPE THE FUTURE FORCE

The focus of VS1 is to Shape the Future Force by informing the requirements processes that define the future direction of Army ground systems. This is accomplished by working closely with TRADOC to develop and demonstrate new capabilities that are enabled by leap-ahead technologies and architectures which may provide significant increase in capability to future platforms (compared to more traditional evolutionary increases to existing platforms) and influence considerations across the entire DOTMLPF-P. VS1 will rely on the foundational competencies from VS3 which underpin TARDEC's core business functions in order to rapidly provide cutting edge technology, data, and expertise to shape future ground system requirements. New capabilities that are demonstrated during execution of VS1 efforts will be assessed for possible transition to VS2 for integration on current platforms.

As the Army prepares for future missions as outlined in the Army Multi-Domain Battle Concept, emphasis is on developing technologies and capabilities that allow the warfighter to respond quickly in environments that are described in the AOC to be "unknown, but also unknowable and constantly changing." In addition, TARDEC aims to ensure that any proposed new platforms to maximize return on investment by providing leap-ahead increases in capability and demonstrate the ability to remain operationally relevant over extended periods of time.

TARDEC will realize new capabilities as virtual and/or physical experimental prototype demonstrations which are enabled through Foundational Competencies of VS3. The organization has outlined the Digital Physical Prototyping process further described in VS3 to align these efforts while gathering feedback from senior DA leaders, stakeholders, and other partners. Some CDs are currently active, others are in planning stages or will be executed at a future date as technology advancement and resources allow. Active CDs are noted by the year in which program plans and/or demonstrator concepts were developed.

The CDs that TARDEC has identified are:

- Demonstrate critical combat vehicle subsystems and systems required to inform the next generation of combat vehicles and support future combat vehicle programs of record (PoRs). (2013-present)

- Demonstrate the capability to conduct unit resupply and sustainment operations using optionally-manned and unmanned vehicles. (2013-present)

- Demonstrate unmanned vehicles capable of maneuvering with mounted and dismounted units. (2014-present)

- Demonstrate integrated 360° situational awareness capability in ground vehicle closed-hatch operations, potentially with reduced crew numbers and reduced Soldier cognitive burden. (2016-present)

- Demonstrate beyond-line-of-sight (BLOS) autonomy-enabled technologies that extend the reach of the warfighter above, on and below ground. (2015-present)

- Demonstrate ground vehicle architectures and technologies designed to allow the vehicle to function "as a member of the squad." (Future)

- Demonstrate robust cyber-secured ground vehicle architecture and integrated technologies designed to operate in noisy, complex and hostile electromagnetic and cyber environments. (Future)

- Demonstrate the capability to detect and respond to a variety of threats using onboard and external sources on a single platform and on multiple cooperative platforms. (Future)

- Demonstrate enhanced multi-modal mobility capabilities which provide novel and unconventional solutions to operate in a broad spectrum of challenging environments. (Future)

- Demonstrate multi-role, reconfigurable platforms with interchangeable mission modules for maximum flexibility, scalability and adaptability. (Future)

- Demonstrate advanced signature management capability on ground systems. (Future)

- Demonstrate the use of intuitive ground vehicle user interfaces and vehicle-embedded training to reduce the Soldier's cognitive burden, reduce specialized vehicle training and enhance Soldier performance on ground systems. (Future)

The VS1 LOEs represent the capabilities with the highest potential to increase the operational value of future ground systems and create the largest advantage for the warfighter. Specifically, these areas were selected based on: (1) potential “order of magnitude” technological advances; (2) potential future force and system contributions to capability developments across the RDECOM Ground Maneuver Portfolio; and (3) alignment to the TARDEC priority of increasing experimental prototyping capabilities.

The six VS1 LOEs are:

- LOE 1.1: Manned-Unmanned Teaming
- LOE 1.2: Ground System Architecture
- LOE 1.3: Protected Mobility
- LOE 1.4: Power Generation and Energy Storage
- LOE 1.5: Semi-Independent Operations
- LOE 1.6: Crew Augmentation

LOE 1.1: MANNED-UNMANNED TEAMING

Description. The focus of LOE 1.1 is to research, develop, validate, and field robotics and autonomous vehicle technologies on the battlefield. In the far term, it is envisioned that fully-autonomous systems will be working in concert with manned air, ground, and naval systems, including personnel conducting various dismounted operations.

In March 2017, U.S. Army TRADOC published the Robotic and Autonomous Systems (RAS) Strategy, which focused on efforts to increase operational prospects for the Combatant Commanders. Increasing probabilities of success in contingency planning for Joint Force Commanders will hinge on a capability to defeat a variety of anti-access / area denial (A2AD) weapons, employed by an equally diverse range of adversaries – from very technologically advanced enemies to unsophisticated, yet effective enemies. Currently, military planners believe RAS technologies could provide a means of changing the game – or the rules of the game – and would help to provide U.S. forces more favorable prospects against enemy A2AD efforts. Utilization of RAS technologies in these and future war scenarios is an important component of what military planners describe as a Third Offset Strategy. The U.S. Army’s most recent RAS Strategy provides a high-level plan for integration of these technologies into the force. LOE 1.1 builds on that idea to provide the outcomes that the Army Ground Vehicle S&T Community is taking to operationalize the Army RAS strategy.

To achieve the far-term objective of manned and unmanned systems working synchronously in the battlefield, TARDEC is conducting advanced technology research and development for autonomous systems that can perform basic, non-lethal military applications such as transportation and logistics missions. In the pursuit of these technologies, TARDEC is also advancing the Army’s knowledge base in the areas of RAS controls, software, and longer-term mission validation.

Increasing TARDEC's efforts in RAS and manned-unmanned teaming will allow the Army to leverage the current investment and advances that are occurring in industry and academia. TARDEC and its military ground vehicle partners across the government will be able to increase engagement with key stakeholders and leverage innovation in critical areas such as safety, standards, and architecture development.

The complexity associated with employing RAS across the full spectrum of ground mobility operations, the rapid pace of technology development, and the ever-increasing costs associated with one-off, single-use technology prototypes requires the DoD and Army to create a modular and common research, design, development, and transition approach for RAS capability. This flexible design shall consist of system/sub-system-level functional and logical specifications along with hardware, software, and interface requirements between elements of the system/sub-system. The approach will be based on an operating system that enables both an open software development environment and the ability to harden the software to prevent exploitation.

The open and common meta-architecture, along with collaborative business processes, will align government RDT&E programs, while leveraging commercial and academia investments and advancements, and allow for the agnostic insertion and exchange of hardware and software for RAS systems. The "plug and play" nature of this open, common, and modular model will enable competition across the acquisition life cycle, timely technology insertion and engineering support with the best software behavior application and/or hardware solutions, and the ability to rapidly modernize legacy systems with RAS capability.

A critical success factor in the pursuit of autonomous mobility is standardized development and safe fielding of highly complex RAS. The TARDEC-led common, modular research, design, development, and transition approach for RAS capability guides standardized software development, but does not currently provide a universal standard for safety testing and certification. TARDEC will lead the chartering and implementation of a multi-disciplined and cross-Army safety evaluation and verification process. The lowest echelon is the RAS Safety Office located at TARDEC, empowered to develop and maintain RAS Standards, which synthesize and reference all applicable existing and emerging best practices, standards, guidance, and regulations. The RAS Standards serve as the baseline for the Army's RAS Safety Review Board, a cross-functional and independent technical design review authority made up of key subject matter experts (SME), stakeholders, and decision makers from across the DoD and Army RAS enterprise. The Board will evaluate RAS programs throughout the design and development process to ensure adequate levels of system mobility safety in the design, development, and transition of ground RAS technologies and capabilities. This authority will award an RD&E and Testing-recognized RAS Design Safety Certification, based on expert RAS opinion, experience, testing results, modeling and simulation, technical documentation, and best practices.

Further, the implementation of a common software reference point and the associated safety evaluations will provide insights and experience that will permit development of appropriate test operating procedures for the verification of safe and effective operation of these dynamic systems. Because of the inherent inclusion of feedback throughout the development cycle, broad nature of environments involved, and limited ability to exhaustively physically test every possible RAS scenario, new approaches must be taken including the role of synthetic environments to assist in the validation and verification process. TARDEC will develop and maintain relevant simulation environments through LOEs 3.4 and 3.5, allowing software developers the ability to natively perform validation of system performance and behaviors prior to formal test and evaluation, which also enables transition to virtual training.

Forecasted changes in warfighting, which will almost certainly emerge as RAS technologies and capabilities, are expected to be fielded into the force in greater scope. In the near-term, TARDEC and its stakeholders anticipate that some basic military capabilities shall be fielded – most likely first in the area of supply/re-supply efforts in a peacetime environment on improved roads. However, over the long-term, advances in RAS capability will revolutionize the way the Army fights wars to include full tactical, support, and combat operations.

Key Outcomes.

- VS1 – LOE1 – KO1 (1.1.1): Sensing/Perception/Understanding: Receive, process, fuse, and understand environmental input and couple with autonomous behavior, perception, navigation, and intelligent algorithms to determine best future events and tasks in the context of the function and role of self and other manned/unmanned systems and the operators.
  - Near Term (through 2025) - Static Obstacle Detection and Obstacle Avoidance (ODOA). Limited dynamic ODOA; Limited material classification; Limited negative obstacle identification; Limited sensor range (<100M); Annotated Databases
  - Mid Term (2025-2035) - Extended dynamic ODOA; Extended material classification; Extended sensor range; Basic object relationship understanding; Basic Predictive Dynamic ODOA
  - Far Term (2035-2050) - Path prediction of dynamic obstacles; Classification of world objects; Extended object relationship understanding
- VS1 – LOE1 – KO2 (1.1.2): Electronic Vehicle Assured Control: Electronic, closed loop control of by-wire vehicle systems to provide stable, reliable, and predictable control in the presence of potential malicious or unintended commands.
  - Near Term (through 2025) - Deterministic Control of Platform; Limited stop/maneuver Capability; Message Verification
  - Mid Term (2025-2035) - Preprogramed Rally Point Capability; Message Validation
  - Far Term (2035-2050) - Limp Home Capability; Message Correction
- VS1 – LOE1 – KO3 (1.1.3): Behaviors in Complex Environment: Perform complex activities individually or coordinated with other manned or unmanned assets and

dismounts which allow completion of actions towards mission goals in separate or teaming configurations at various levels of autonomy.

- Near Term (through 2025) - Leader follower with oversight; Coordination with other assets; Driver Assist and Safety; Limited Environment Specific Behavior; Basic Dismount Following; Teleoperation with augmentation; Limited Semi-autonomy off road; Limited on road autonomy through following
- Mid Term (2025-2035) - Extended leader follower; Collaboration with other assets; Basic negotiations with other assets; Basic rule following (rules of the road); Complex environment behaviors; Autonomous Convoy; Basic Tactical Behavior; High speed tele-operation; Extended semi-autonomy off road; Autonomy on road; Navigate to Destination; Dynamic Planning and Re-planning
- Far Term (2035-2050) - Full teaming behaviors (coordination, collaboration, negotiation); Role-Based Mission Reasoning; Policy compliant automated engagement; Rules of the Road engagement; Autonomy on and off road

- VS1 – LOE1 – KO4 (1.1.4): Intelligent Algorithms: Self-learning of tasks and sub-tasks performed or failed, prediction of event or issues and planning in advance to solve problems yet to be encountered.
  - Near Term (through 2025) - Limited on-line learning; Research/Advance Capabilities; Computer vision; Control through neural nets; Intrusion detection
  - Mid Term (2025-2035) - Extended on-line learning; Limited event prediction; Limited solutions to unknown events
  - Far Term (2035-2050) - Extended event prediction; Extended solutions to unknown events
- VS1 – LOE1 – KO5 (1.1.5): Reference Meta-Architecture: Publish and maintain a community-recognized RAS meta-architecture detailing development philosophies, principles, organizing concepts, and system functional/logical specifications for the hardware and software systems, subsystems, components, and defined inter-relationships in providing functional and operational autonomous ground vehicle capability.
  - Near Term (through 2025) - Published Architecture Reference Document; Community acceptance and support of Reference Architecture; Communication
  - Mid Term (2025-2035) - Established process and resources for updating and publish newer version of Reference; Architecture Reference benchmarked beyond Army RAS.
- VS1 – LOE1 – KO6 (1.1.6): Autonomy System Safety: Establish and lead the RAS enterprise in standardizing, evaluating, and maintaining ground RAS development through publishing RAS standards, participating in a multi-agency RAS Safety Review Board and presenting an Army Training Command-recognized RAS Design Safety Certification and ready for test verification based on expert RAS opinion, experience, testing results, modeling and simulation, technical documentation, and best practices.
  - Near Term (through 2025) - Robotic and Autonomy System (RAS) Software Safety Standard; RAS Safety Office; RAS Safety Review Board
  - Mid Term (2025-2035) - RAS Safety Certification accepted by ATC; New and existing programs complete Autonomy Safety Design Review and Autonomy Safety Critical Review prior to ATEC testing; Weaponized RAS system certified

LOE 1.2: GROUND SYSTEM ARCHITECTURE

Description. The Ground System Architecture LOE's purpose is to establish the relationships among system functions, the interfaces, and the allocations to hardware and software. This LOE identifies interface standards for interoperability, which increases competition in the defense market place while reducing integration and life-cycle costs.

Architectures for ground systems can be divided into several domains including but not limited to: networks, computing resources, user interface, vehicle cybersecurity, electrical power, system intelligence, and physical structures. Use of these domains enable engineers to model various concerns, in turn identifying better technical choices in system design that address the operational, functional, behavioral and performance requirements for the overall system.

System architecture development is critical for maximizing the adaptability and flexibility of vehicle platforms to enable greater modularity and commonality across the future fleet. The intent is to make adding, upgrading and swapping software elements of components, subsystems faster, easier, and cheaper. System architecture development enables efficient integration of all new technologies and reduces the future life-cycle cost of upgrading systems.

LOE 1.2 will focus future architectures on being open and adaptable so the ground system will be able to accept both current and future technologies and software. This LOE will also focus on the incorporation and integration of advanced technologies and the impact on the evolution of future system architectures.

Key Outcomes.

- VS1 – LOE2 – KO1 (1.2.1): Develop a common cyber-secured open system vehicle architecture for all ground systems and subsystems to enable systems (such as active protection, autonomous appliqué systems, power distribution and smart mobility) to be easily adapted to specific/discrete platforms. This will reduce integration time, increase system capability and minimize risks to ground systems from cyber-attacks.
    - Near term (through 2025) – Develop an open system vehicle architecture enabling a defense-in-depth cyber deployment supporting distribution of system capabilities and supporting ultra-low latency communications. Develop open power system architectures to support high density power generation and distribution.

  - Mid Term (2025-2035) – Develop a vehicle architecture to support highly reliable communications and robust system degradation against multiple system failures and attacks. Develop open power systems architectures to support simplified integration and adaptation.
  - Far Term (2035-2050) – Develop a wireless open system architecture supporting highly reliable communications and security for operations in high electronic noise environments that provides low probability of interception (LPI) and low probability of detection (LPD).
- VS1 – LOE2 – KO2 (1.2.2): Develop physical ground system architecture to enable rapid and cost effective forward adaptability for changing vehicle requirements and mission roles.
  - Near Term (through 2025) – Verify open and custom system architecture via Hardware-in-the-Loop and physical testing to confirm interfaces have been appropriately defined for autonomous defensive weapon systems to permit fielding of DoD safety board approved solutions.
  - Mid Term (2025-2035) - Refine ground system architecture to allow transition and integration of future survivability technologies. Ensure that infrastructure exists to modify ground platform capabilities in order to keep pace with threat and tactics adjustments by the adversary. Leverage reuse where possible to continue to receive DoD safety board authority to operate. Use advanced simulation capabilities in HWIL to optimize total survivability package.
  - Far Term (2035-2050) - Expand on open ground system architecture to permit sharing of threat information between vehicles in a convoy/formation/combined arms platoon including allied/blue force systems. Optimize survivability packages to balance conventional protection technologies with autonomous defensive weapons systems
- VS1 – LOE2 – KO3 (1.2.3): Publish and maintain a community-recognized RAS meta-architecture detailing development philosophies, principles, organizing concepts, and system functional/logical specifications for the hardware and software systems, subsystems, components, and defined inter-relationships in providing functional and operational autonomous ground vehicle capability.
  - Near Term (through 2025) – Publish an Architecture Reference Document; achieve acceptance and support of Reference Architecture from the Robotics Community
  - Mid Term (2025-2035) – Establish the process for updating and publishing newer versions of the Architecture Reference Document; achieve Architecture Reference benchmarked beyond Army RAS.
- VS1 – LOE2 – KO4 (1.2.4): Demonstrate enhanced power distribution and smart vehicle control systems that improve performance, reduce fuel consumption and enable additional capabilities.
  - Near Term (through 2025) – Demonstrate leap ahead ground vehicle power architecture using wide band gap materials to enable vehicle electrification to support directed energy weapons and future communication systems.

  - Mid Term (2025-2035) – Demonstrate wireless power transport on-vehicle while improving cost and size, weight and power (SWaP) of the ground vehicle power architecture components.
  - Far Term (2035-2050) – Demonstrate complete vehicle electrification of a ground combat vehicle to improve vehicle signature and stealthy operation.
- VS1 – LOE2 – KO5 (1.2.5): Demonstrate modular, open system, and cyber-secure vehicle electronics systems to reduce system SWaP & Cost and increase system performance.
  - Near term (through 2025) – Demonstrate defense-in-depth cyber open systems that are cost and SWaP neutral.
  - Mid Term (2025-2035) – Demonstrate advanced modular open systems based around robust cyber-secure networking capabilities.
  - Far Term (2035-2050) – Demonstrate formal methods verified cyber secured vehicle.
- VS1 – LOE2 – KO6 (1.2.6): Demonstrate cost saving and adaptable ground vehicle structures to meet varied requirements and mission roles.
  - Near Term (Through 2025) – Passive and Active Survivability solutions. Continue to develop passive and active survivability solutions with an emphasis on active solutions to mitigate the plateauing of passive solutions in the areas of performance and weight/space. Leverage open architecture compliant subsystems to enhance existing developmental off the shelf defensive autonomous weapons systems.
  - Mid Term (2025-2035) - Holistic and Balanced Survivability solutions. Continue to certify compliance for subsystems to open architecture standard to increase subsystems in the registry, providing PMs more options for capability synthesis. Customize autonomous defensive weapons systems for specific threat sets, to meet tailored performance requirements or to minimize investment or life cycle costs. This customization would include a holistic survivability approach (survivability solutions working together) to achieve outer bounds of new cost benefit curve. Dynamically balanced vehicle protection (survivability, mobility and lethality systems working together in real-time) would be developed next to meet midcentury defense demands.
  - Far Term (2035-2050) - Cooperative Survivability solutions. Use open architecture in combination with potential modifications in tactics, techniques and procedures to optimize protection for convoy/formation/platoon by allocating sensing and countermeasure subsystems to specific vehicles and networking messages between all vehicles in convoy. This open architecture would be used to create cooperative vehicle protection (balanced vehicle protection working together with robotics in real-time) which would enable manned/unmanned teaming within survivability systems.

LOE 1.3: PROTECTED MOBILITY

Description. LOE 1.3 focuses on the critical relationship between a ground system's mobility and its survivability. Balancing these two characteristics has consistently been a challenge from initial system acquisition through sustainment as operating environments and threats change during the course of a system's life cycle. A typical outcome is that one of the characteristics is traded in favor of the other, resulting in systems that are not optimized to meet the needs of the warfighter. This LOE aims to enable Army ground systems with the capabilities necessary to enable the Soldier to dominate the future battlefield by providing a mission appropriate balance of survivability and mobility.

The Army envisions the need for expeditionary operations using a rapidly deployed, scalable, tailored, and operationally and tactically significant force as described in *Force 2025* and the AOC. Furthermore, the unknown and unknowable attributes of the complex world described in these documents requires systems to be globally deployable, operationally mobile in all environments, and protected from both symmetrical and asymmetrical threats. This requires new, improved, and adapted capabilities in both mobility and survivability, to meet each commander's specific mission requirements.

The *Army Functional Concept for Movement and Maneuver (AFC-M&M) 2020-2040* describes operations in which Brigade Combat Teams "operating semi-independently possess sufficient mobility, firepower, protection, intelligence, mission command, and sustainment capabilities to conduct cross-domain maneuver at extended supporting range and distance for up to seven days while achieving operational objectives." It also states that "Future Army forces require assured mobility across multiple domains at the time and place of a commander's choosing as they generate windows of opportunity to gain positional advantage." To enable this vision, ground systems will need to effectively maneuver over more complex terrain than current systems and operate at higher levels of efficiency to reduce the frequency of resupply operations.

Additionally, the *AFC-M&M* states "The steady increase of lethality, range, and rate of fire of modern weapons requires Army forces to operate dispersed and adjust tactics accordingly. Future Army forces must operate dispersed to avoid enemy strengths and evade enemy attacks, while retaining the freedom of movement to concentrate combat power rapidly across domains to fight, survive, and win." The ability to execute this doctrine will require a new generation of propulsion and mobility technologies with greater power densities, lower fuel consumption, greater electrical power generation, and superior running gear systems. These technologies will enable the execution of the doctrine by providing a military ground vehicle with an extended range, superior mobility, and ability to enable future electric based technologies for battlefield dominance.

Although the Army envisions a change in operational tactics that rely on increased mobility to enhance system survivability, the *AFC-M&M* clearly emphasizes the role of system protection capabilities. It states that "Future maneuver forces require the capability to maneuver and survive in close combat against enemies with robotic and autonomous systems, unmanned aircraft systems, manned aircraft (rotary and fixed wing), and short to medium- range ballistic missiles to preserve the force during joint combined arms operations", that "The small unit will have the lethality and survivability necessary to win the close fight, and the protection to endure the effects of multiple protracted engagements", and that "Lighter and smaller platforms and systems will increase strategic and tactical mobility for some formations, but U.S. armored brigade combat teams will remain the premier combined arms force with improved mobility, firepower, and protection capabilities."

Battlefield survivability is the product of not just equipment and tactics, but also techniques and procedures for mitigating current and emerging threats. Recent experience with anti-armor IEDs has shown that protection technology, specifically armor, has been successful in pushing the evolution of anti-armor threat devices to sizes that were more stressing to the enemy supply chain, logistically difficult to emplace, and if emplaced, more easily found and cleared. A protection scheme that is lightweight and possesses the inherent ability to adapt to an array of known (as well as unanticipated) threat configurations and environments, and reduces the probability of enemy defeat and thus avoids technological surprise.

In order to realize the above protection scheme, a common cyber-security approach would need to be integrated into the platform. This would enable systems such as active protection, autonomous appliqué systems, power distribution and smart mobility to be easily adapted to specific platforms. Something like this will reduce integration time and increase system capability against emerging threats. For example, see LOE 1.2

This LOE seeks to integrate leap-ahead protection technologies that will focus on defeat mechanisms that can provide vehicle survivability and crew protection that can be more adaptable to the threats expected to be encountered in that operational area through a "holistic systems" approach. The "holistic systems" approach is to first establish performance capability using traditional methods and materials, and then incorporate new materials and systems to achieve the best possible capability for passive systems. Where opportunities exist, TARDEC will then leverage stand-alone active or real-time adaptive measures to meet requirements. And once active/adaptive technologies are validated, TARDEC plans to then make the technology compliant for a modular solution set within that specific threat defeat domain and integrate the new technologies into a holistic solution that optimizes the whole solution for threat specific domains. The new technical approach is to transition from a passive to an active paradigm, and employ the emerging armor-materials-by-design capabilities to construct lightweight ballistic protection technology and couple these technologies with modular active protection systems (MAPS), signature management, and advanced threat detection to create adaptive armor that responds to detected EFPs, RPGs, or ATGMs.

This new paradigm builds on adaptive protection ideas but at the same time, maintains a base level of passive protection provided by armor. The optimized survivability and protection system is to be enabled by TARDEC's emerging concept of adaptive armor; an approach based on coupling a fundamental understanding of materials and ballistic mechanisms to newly demonstrated or emerging abilities in the area of detection, characterization and active controls. While being optimized, this LOE also will strive to achieve some degree of commonality and multifunctional design. Combining Mobility and Survivability technologies for multifunctional purposes could involve the following; 1. Use the engine as another layer of ballistic armor or spall liner, 2. Use of the exhaust of the engine to provide some layer of camouflage in the visible and possibly infrared parts of the spectrum, and 3. Energy harvesting – in the age electric/hybrid vehicles – capture electromagnetic energy from the battlefield to recharge the batteries used for propulsion. For example spintronic radar systems could also be used as electromagnetic energy harvesters and piezoelectric transducers in armor could be used to convert vibrational or ballistic shock waves to electrical energy that is stored in the battery. The idea of commonality is to use various Mobility and Survivability technologies for multiple purposes.

The survivability S&T community plans to execute a long term partnership with the future Vehicle Protection Suite (VPS) program office to facilitate the transition of those validated emerging technologies. The ultimate goal is to act as the technical arm to the program office driven through dialogue and partnerships with industry, the user community and other U.S. Army research and development centers. The desired outcome with engaging internal and external partners is to synchronize VPS technology solutions across the U.S. Army. Technologies and demonstrations within this LOE will provide the capabilities required to achieve the Army's vision for ground system operations. Key outcomes will result in both lighter-weight protection technologies for both the system and its occupants to ensure survival against evolving threats, and innovative ground vehicle propulsion and mobility capabilities to operate in any terrain, in any situation, at any vehicle weight, anywhere in the world. Together, the outcomes enable adaptable systems that have the optimal balance of survivability and mobility to meet each commander's specific mission requirements.

Key Outcomes:

- VS1 – LOE3 – KO1 (1.3.1): Investigate and demonstrate an optimal and active balance of mobility and protection to allow sustained operation anywhere in the world.
  - Near Term (Through 2025) Conduct an assessment of the tools needed to quantify the synergistic effects of mobility on the threat kill chain. The tools may include physics based models, scenario based force models or human in the loop constructed virtual worlds and the co-simulation of each.
  - Mid Term (2025-2035) Based on the near term results, conduct analyses to quantify the interactions mobility and survivability performance in a variety of planning scenarios. These studies will be conducted in the context of analysis of future vehicle concepts.

  - Far Term (2035-2050) Demonstrate embedded battlefield simulations on platforms to enable real-time decisions aids or autonomous intelligent agents for tactical responses to battlefield threats.
- VS1 – LOE3 – KO2 (1.3.2): Enable ground vehicles to effectively maneuver over greater percentages of terrain than current systems and to be adaptable to varying types of complex terrain to meet changing mission needs.
  - Near Term (Through 2025) Develop, integrate and demonstrate state-of-the art running gear hardware and associated software systems, which improve vehicle cross-country mobility, durability, stability, traction, flotation, load carrying capability, and reduce signature, weight, and rolling resistance.
  - Mid Term (2025-2035) Develop, integrate and demonstrate hardware and vehicle systems such as active suspension, preview sensing, track / wheel transformation systems, silent / extreme lightweight running gear to enable semi-autonomous capabilities to navigate all environments and respond to threat-detection systems.
  - Far Term (2035-2050) Develop, integrate and demonstrate next generation of mobility systems for ground vehicle and Soldier support applications such as adaptive running gear, vehicle to ground isolation, quadruped walking machines, for technological superiority.
- VS1 – LOE3 – KO3 (1.3.3): Enable ground vehicles to operate at increased speeds and extended ranges while requiring reduced frequency of resupply.
  - Near Term (Through 2025) Develop, integrate, and demonstrate scalable and modular engine architecture, multi-speed high efficiency transmission for tracked and wheeled vehicle applications, improved effective cooling using advanced thermal management systems for lowest heat rejection, and increased on-board and export electrical power generation with compact hardware, software and control architecture which enable new interconnected capabilities, improve power density, reduce under-armor volume, and improve vehicle propulsion performance characteristics such as: top speed, acceleration, speed-on-grade, braking, cross-country mobility, and vehicle range.
  - Mid Term (2025-2035) Develop, integrate, and demonstrate advanced propulsion and running gear technologies to navigate all environments and coordinate mobility systems with threat-detection systems. Develop new vehicle dynamic control technologies, integrated chassis control algorithms to coordinate the actions of vehicle dynamic controls systems, electric acceleration assists, combustion optimization, and integrated power and population architectures for fuel efficiency and on board electrical power to support advanced weapon systems.
  - Far Term (2035-2050) Develop, integrate and demonstrate autonomous adaptive propulsion capability in unpredictable and threatening terrains. Active vehicle mobility working collaboratively with active protection systems to maneuver the vehicle to defend against immediate threats.
- VS1 – LOE3 – KO4 (1.3.4): Develop, integrate, and demonstrate advanced force protection capability suites (example: technologies to mitigate/defeat the enemy's ability to detect, acquire, hit, penetrate and kill), which enable the system and its

occupants to survive threats and recover from contact while maintaining the optimal balance of mobility and protection.

- o Near term (through 2025) - Integrate and demonstrate off-the-shelf non developmental items as part of Expedited Active Protection Systems, integrate MAPS compliant version of Expedited APS. Demonstrate a system of technologies to provide weight effective soldier protection from blast threats, and innovative Soldier interior protective technologies into several ground vehicle platforms.
- o Mid Term (2025-2035) – Integrate and demonstrate incremental improvements to the modular APS controller and framework (MAC and MAF) used in various ground vehicle platforms as well as underbody and active blast protection technologies. Expand MAF to accommodate multiple active threat defeat mechanisms to provide holistic protection. These holistic solutions will be informed by the modeling results of KO1.3.1.
- o Far Term- (2035-2050) - Build prototypes of systems that include matured protection sub systems that demonstrate a holistic protection system for Soldier survivability and protection while reducing vehicle weight. Demonstrate systems that integrate matured APS, armor and underbody protection systems.

LOE 1.4: POWER GENERATION AND ENERGY STORAGE

Description. LOE 1.4 provides three major capabilities: (1) high-packaging density electrical power generation, (2) advanced energy storage systems, and (3) significant export power for expeditionary missions. This enables integration of energy-based capabilities to achieve higher levels of protection, lethality, mission command, and mobility on Army ground systems in LOE 1.3, as well as providing efficient export power. The power and energy based capabilities of this LOE will be coupled with high efficiency and reduced fuel demand to support sustained semi-independent operations in LOE 1.5.

The AOC, Force 2025, and the AFC-M&M project that Armored, Infantry, and Stryker Brigade Combat Teams (BCT) will remain the Army's primary fighting formations in the 2020-2040 timeframe. An essential future requirement of the BCT is to operate semi-independently and support sufficient mobility, firepower, protection, intelligence, mission command, and sustainment capabilities to conduct cross domain maneuver and dispersed operations at extended supporting range and distance for up to seven days while achieving operational objectives. This capability is essential for the BCT to support the doctrine of force dispersion and rapid consolidation to negate an enemy's numerical advantage, strengths, and attacking weaknesses to seize, retain, and exploit the initiative.

The AFC-M&M states "Vehicle stored energy combined with autonomous ground and air resupply will allow BCTs to operate semi-independently for extended periods (7 days or greater)". Substantial gains in energy storage capability are needed to achieve this. High packaging density power generation and energy storage systems are needed to reduce size and weight for expeditionary operation.

The Maneuver Center of Excellence (MCOE) position paper on combat vehicle Power and Energy states that: “Current levels of combat vehicle power and energy do not support the BCT required capability to perform semi-independent operations nor to integrate vehicle technologies requiring additional power”. To support the doctrine of force dispersion, sustainment, and rapid consolidation, MCOE estimates a 50% increase in available electrical power and a 100% increase in stored energy on each combat vehicle is required. This increase in power generation and energy storage has the synergistic effect of enabling other future technologies such as Directed Energy Weapons (DEW), electromagnetic (EM) armor, and high power sensors and communications devices.

TARDEC recognizes these challenges and directly focuses LOE 1.4 efforts on the development and integration of novel electrical power generation and advanced energy storage technologies. These technologies are focused on the capability for ground vehicles to consume less energy, operate for greater periods of time without resupply, be deployable worldwide, and enable expeditionary missions anywhere in the world to provide the US Army a technological edge over adversaries.

LOE 1.4 compliments LOE 1.3 to provide military ground vehicles which are globally deployable, operationally mobile in all environments, and protected from symmetrical and asymmetrical threats. In the short- to mid-term, LOE 1.4 leverages advanced powertrain systems to efficiently generate onboard electrical power. In the mid to far term, LOE 1.4 provides revolutionary capability for power generation and energy storage to serve as a more efficient alternative to traditional primary propulsion power systems, while reducing thermal and acoustic signatures, thus supporting synergistic capabilities for power, energy, mobility, and survivability.

LOE 1.4 also complements LOE 1.5 by reducing demand for fuel and water with fuel cell technology, which enables prolonged operational endurance to extend time between resupply thus enhancing mission effectiveness of the future expeditionary forces.

The ability to execute this doctrine will require new advanced power generation and energy storage capabilities which far exceed current levels, with greater power and energy density, and increased efficiency. These technologies enable other capabilities such as electric weapons, electrified armors, high power sensors and communications, and even energy beaming to become a reality.

Key Outcomes:

- VS1 – LOE4 – K01 (1.4.1): Enable ground vehicles to have the onboard power generation required for lethality, protection, mobility, and communication systems.
    - Near Term (through 2025) – Develop high voltage, high power generation systems with high efficiency, high operating temperature, and high power density components. Develop compact, quiet auxiliary power units to reduce fuel consumption. Demonstrate the systems on existing and future Army vehicle

platforms. Develop advanced propulsion and vehicle hybridization technologies to enable burst power, silent mobility, and improved packaging efficiency.
  - Mid Term (2025-2035) – Integrate and demonstrate high power systems for advanced energy weapons, electrified armor, directed energy weapons (DEW), jamming, and communication capabilities.
  - Far Term (2035-2050) – Develop compact in- hub traction motors and demonstrate series hybrid vehicle architectures to allow power generation through fuel cell and battery sources.
- VS1 - LOE4 – KO2 (1.4.2): Enable ground vehicles to store sufficient amounts of energy for sustained, semi-independent operations.
  - Near term (through 2025) - Develop and integrate advanced 24V common form factor energy storage systems that increase energy density. Develop modular high voltage energy storage systems to enable hybrid/silent mobility, DEW, and advanced survivability capabilities. Explore alternative battery concepts, including structural batteries, to enable integration of significant amounts of energy onboard vehicle platforms in a typical location (i.e. behind armor packages) to enable sustained missions, including silent watch capability.
  - Mid Term (2025-2035) – Develop advanced energy storage technologies in common form factors that will further increase the installed energy density. These advanced energy storage technologies shall be compatible with existing low and high voltage systems.
  - Far Term- (2035-2050) – Develop metal air electrochemistry to achieve greater durations of sustained semi-independent missions.
- VS1 - LOE4 – KO3 (1.4.3): Enable ground vehicles to generate sufficient onboard power for expeditionary missions.
  - Near Term (through 2025) - Develop and integrate efficient quiet power systems onto manned and unmanned vehicles, with export power capability, including the required infrastructure components, to demonstrate expanded capabilities and energy savings. Develop quiet and efficient high power and energy density systems for increased range and reduced logistic burdens. Explore modular vehicle concepts that take advantage of electric powertrains and integrate into vehicle platforms. Explore technology development in hydrogen generation, hydrogen storage, hydrogen vehicle filling, and transportable equipment to reduce the logistical burden and extend expeditionary capabilities without resupply.
  - Mid Term (2025-2035) – Develop advanced, quiet, and efficient technologies that increase reliability and durability, increase power density, and reduce system cost. Demonstrate solid fuel storage technologies that enable extended range and/or long power supply durations while reducing logistics and resupply burdens. Develop wireless power transfer technologies to reduce logistics requirements for fuel distribution.
  - Far Term (2035-2050) – Develop and demonstrate a silent expeditionary capability. Extend expeditionary missions and power generation capabilities by making sufficient fuel on demand over long durations, thus eliminating the logistics trails.

LOE 1.5: SEMI-INDEPENDENT OPERATIONS

Description. LOE 1.5 recognizes that TARDEC must provide technologies that will advance and optimize maneuver support, sustainment and logistics capability on the battlefield to enable semi-independent and distributed operations. Such technologies are required for the Army to meet the vision of an expeditionary Army that can be rapidly deployed in a scalable, tailored, and operationally and tactically significant force as described in Force 2025 and the AOC. In addition, multi-domain battle requires semi-independent operations to enable dispersed operations, thereby reducing vulnerabilities to enemy fires while maintaining the ability to rapidly aggregate to regroup at decisive points to create overmatch. Technologies and demonstrations within this LOE provide potential game changing capabilities to increase the speed and effectiveness of future expeditionary forces by reducing constant logistics burdens and enabling autonomous or semi-autonomous resupply.

The *AOC* states, “The Army’s ability to sustain operations on land is essential to the Joint Force’s ability to implement foreign policy and achieve favorable outcomes consistent with U.S. interests.” Army units must be able to integrate efforts with Joint and coalition forces to sustain high-tempo operations at the end of long and contested supply lines. Innovative technology is required to create new and enhanced capabilities to reduce vulnerability to ground interdiction, reduce logistics demand, improve reliability, and generate water locally, among others. Moreover, every echelon must have scalable organic capabilities to preserve freedom of maneuver even if logistical support slows. Army capabilities must grow through the development of technology to be able to set the theater, that is, establish and maintain the conditions necessary to retain Joint Force freedom of maneuver in future operational environments. The Army combines forward deployed forces and rotational forces to develop, maintain and operate the theater structure. Joint forces depend on the Army to provide essential capabilities in maneuver support, sustainment, and logistics.

Further, the Army must project National Power, which includes the ability to deploy and sustain land power rapidly and effectively. In the Multi-Domain Battle, air and maritime supremacy cannot be presumed, yet the Army is the Joint force element tasked to conduct sustained campaign-quality land operations that compel adversaries through the physical occupation of vital terrain and infrastructure and consolidate gains to achieve sustainable outcomes. Achieving these objectives requires new technology and capabilities to enable faster resupply over dispersed areas, mitigate the effects of obstacles and hazards, and shape the battlefield.

The draft *U.S. Army Functional Concept for Sustainment 2020-2040*, the draft *U.S. Army Functional Concept for Maneuver Support,* and the *Force 2025* concept amplify relevant points from the *AOC* and note that maneuver and sustainment forces must be able to extend operational reach, prolong endurance and allow freedom of action for the Joint force. These points are critical enablers to the future expeditionary Army. The KOs of LOE 1.1 will support the need for semi-autonomous and autonomous resupply; KOs of this LOE will focus on: 1) optimizing logistics, 2) reducing reliance on intermediate staging bases and sustainment forces, 3) enabling self-sufficient combat units, 4) mitigating the effects of obstacles and hazards, and 5) shaping terrain.

Efforts in this LOE will vary from early S&T work to concept refinement with the goal to follow previous successes in transitioning projects directly into programs of record (PoR). For these programs to be successful, several VS2 KOs will be required such as 2.1.1 (technical authority), 2.1.4 (technical requirements authority) and 2.3.1 (Program of Record Integration). The cross-linked competencies will also be essential, particularly System Integration & Prototyping.

Key Outcomes.

- VS1 – LOE5 – KO1 (1.5.1): Military Bridging Capabilities: Develop near-, mid-, and far-term novel manned and unmanned expeditionary gap crossing and breaching capabilities that enable Interoperability with Joint and International Forces, and provide the Operational Commander freedom of movement across a spectrum of terrain in all theaters and environments.
    - Near term (through 2025)- Develop enhanced wet and dry gap crossing and breaching technology to accommodate higher weight vehicles by improving existing launchers and bridge systems through advanced dissimilar joining methods, lighter weight and alternate and composite material systems that have higher Military Load bearing capacity.
    - Mid Term (2025-2035) - Develop smart, flexible, and modular, multipurpose semi-systems that once emplaced can remotely health monitor and communicate with other battlefield systems. Further develop wet and dry gap crossing and breaching systems that can accommodate a variety of terrain conditions, span widths and battlefield needs in both offensive and defensive operations.
    - Far Term (2035-2050) - Develop advanced, novel, semi-autonomous, and fully autonomous self-deploying systems that can be programmed to navigate themselves to the battlefield wet or dry gap and self-launch.
    - Far Far Term (2050 plus), Develop adaptable autonomous systems that can be remotely flown to the gap by self-flight and/or vertical lift, launch the bridge/breacher, and then decouple the main platform which can then return for another sortie.
- VS1 – LOE5 – KO2 (1.5.2): Research, develop and/or standardize fluids, lubricants, fuels, and tribological solutions to simplify life-cycle logistics and improve reliability, availability and maintainability of military ground systems.
    - Near term (through 2025) – Complete research, communicate, and transition the Single Common Powertrain Lubricant (SCPL), Fuel Efficient Gear Lubricant (FEGO), and Energy Efficient Hydraulic Fluid (EEHF) to advance lubricant technology, save fuel, and simplify logistics. Maintain compliance with commercial fuel specifications and coordinate fuel related activities through Tri-Service

  Petroleum, Oil, and Lubricants (TRIPOL) Users Group. Research other ground system performance fluids to serve a current Program Manager (PM) gap/need or innovate through basic research.
  - Mid Term (2025-2035) – Conduct basic research in tribology to innovate coating and surface interactions in legacy and new vehicle fleets. Advance additive technology in fuels and lubricants trying to minimize grades of product across TRIPOL and extend service life of lubricants.
  - Far Term (2035-2050) – Develop fill for life technology in coolants and lubricants to reduce logistics and remove potential for mixing coolants and lubricants in the field.
  - Far Far Term (2050 plus) – Research advanced fuels and lubricants to support new Army vehicles. Research self-healing lubricants to reduce logistics.
- VS1 – LOE5 – KO3 (1.5.3): Develop technology to reduce the logistical burden of the warfighter by improving the Lines of Communication (horizontal construction) and expediting the loading and unloading of material.
  - Near Term (through 2025) – Promote and demonstrate the capabilities which can be gained from the application of Semi and Full autonomous kits onto the Program of Record (PoR) Combat Engineering and Material Handling Equipment. These kits will leverage the emerging capabilities of the commercial market and show gains in productivity and reduced logistical burdens.
  - Mid Term (2025-2035) – Develop practical understanding and technical specifications with the warfighter for implementation of the autonomous solutions which can be integrated onto PoR systems as part of Service Life Extension Programs (SLEP). Work with industry to ensure open and complete communication is achieved.
  - Far Term (2035-2050) – Develop technical specifications for new procurements which maximize the use of semi- and fully-autonomous systems to shape the battle space and facilitate greatly improved resupply while minimizing Soldier exposure to hazards.
  - Far Far Term (2050 plus) – Develop systems which will automatically detect and improve deficiencies in construction and maintenance in Lines of Communication (LOC) without direct user interaction and automatically task assets to correct the issues.
- VS1 – LOE5 – KO4 (1.5.4): Develop technology solutions that reduce life cycle logistics, improve reliability and inform requirements associated with water treatment, generation, storage, and distribution quality analysis in support of semi-independent operations on the Multi-Domain Battlefield.
  - Near Term (Today-2025): Develop new technologies for purifying and generating water in support of distributed units for semi-independent operations. Enhance the warfighters ability to rapidly determine water quality at the point of treatment. Develop new technologies for water accountability and visibility on the battlefield.
  - Mid Term (2025-2035): Develop semi-autonomous water production systems to reduce the logistics and manpower requirements for water sustainment. Develop technologies to enable net-zero water sustainment operations across the multi-domain battlefield.

  - Far Term (2035-2050): Develop advanced, novel, autonomous and fully autonomous self-deploying systems that can be programmed to navigate themselves to water sources, autonomously purify water and link up with distributed units. Provide any warfighter the ability to test for water quality conformance instantly with a hand held go/no-go device.
- VS1 – LOE5 – KO5 (1.5.5): Develop technology solutions to reduce the logistical burden of bulk fuel operations in support of semi-independent operations on the Multi-Domain Battlefield.
  - Near Term (Today-2025): Develop new technologies for storing, transporting and dispensing fuel that will enhance the Army requirement of 850,000 gallons of fuel per operational day. Enhance the warfighters ability to rapidly determine the fuel's quality from any location in the supply line. Develop new technologies for fuels accountability and visibility on the battlefield.
  - Mid Term (2025-2035): Develop fuel caches sources as well as fuel system camouflage and decoy techniques. Develop a standard refueling port and nozzle for air and ground vehicles to assist in autonomous refueling operations.
  - Far Term (2035-2050): As new autonomous air and ground logistics delivery systems emerge, develop new fuel containerization systems designs and refueling capabilities. Develop self-reporting fuel systems for accountability and visibility across the battlefield. Develop novel methods for utilizing captured fuel sources on the battlefield. Provide any warfighter the ability to test for fuel quality conformance instantly with a hand held go/no-go device.

LOE 1.6: CREW AUGMENTATION

Description. The Soldier is at the center of all TARDEC does. While technology is rapidly evolving, especially in areas that show great promise to transform the way the Army fights, such as vehicle autonomy, the Soldier is still key and critical for effective decision making and controlling the battlefield. In order to fully understand the environment, efficiently communicate with the team, and meet mission objectives, the Soldier of tomorrow must have the tools and methods necessary to seamlessly interact with the vehicle system and have it serve as an extension of themselves. Developing these methodologies and tools is the focus of this LOE.

Much of the DoD's *Third Offset Strategy* focuses on extending the warfighter's capabilities through the following: autonomous deep learning machines and systems, human-machine collaboration to support decision making processes, assisted-human operations in order to help humans operate more effectively on the battlefield, advanced human-machine teaming where Soldiers work with unmanned platforms, and semi-autonomous weapons systems. Each of these technology focus areas are providing the Soldier with tools to speed decisions, increase performance, or extend span of control.

The AOC states that, "The Army must fit machines to Soldiers rather than the other way around. The Army will pursue advances in human sciences for cognitive, social, and physical development and emphasize engineering psychology and human factors engineering in the design of weapons and equipment."

The AOC also emphasizes the need for improved protection at lighter weights, improved range and lethality, and the use of autonomous systems to extend the Soldier's and unit's reach. Achieving these objectives will require a reduction in crew size and an increase in Soldier performance.

In order to achieve increased crew performance, LOE 1.6 must focus on investigating advanced technologies that will improve crew-station effectiveness in the following areas:

- Soldier monitoring (intent, cognitive load, health, alertness)
- Customization (preferences, current environment/mission/events, learning)
- Autonomy (processes, tasks, systems/subsystems)
- 360 degree situational awareness (sensing, detection, recognition, data assimilation and comparison)
- Intelligence (predicting, anticipating, learning, decision making, augmentation)

Monitoring is necessary to understand the Soldier's state and anticipate his/her needs. Customization is required to fit the machine to the human and serves to reduce training time as well as rapidly adopt the interface to the task at hand. Autonomy will be needed to shed much of the task load and free the Soldier for decision making. 360 degree situational awareness will take advantage of sensing capabilities to aid the Soldier with interacting with his/her environment. Lastly, increased vehicle intelligence with provide the Soldier with extended cognitive ability to better anticipate and predict necessary courses of action as well as learn from experiences that can be applied to future scenarios.

Crew augmentation development is critical for ensuring greater effectiveness and efficiency in execution and to expand the Soldier's control of vehicle systems. Efforts in this LOE will vary from early S&T work to concept refinement and prototyping, taking advantage of enabling VS3 LOEs to build on previous successes and provide a transition path into a PoR. For these programs to be successful, several VS2 KOs will be required such as 2.1 (Technical Program Support), and 2.3 (Tech Alignment & Transition).

Key Outcomes.

- VS1 – LOE6 - KO1 (1.6.1): Gather, sort, and provide mission-related contextual data (battlespace environment, weather, vehicle system status, network, mission goals/objectives, and intelligence) to crew-station operators in a highly customizable (adaptable) and multi-modal fashion to increase performance, reduce cognitive burden, and permit efficient crew-station operations.
    - Near Term (through 2025) – Utilize detailed task assessment and analysis to establish deep understanding of crew-member mission and workflows. Develop

predictive models based on early analysis and assessments to further refine design approaches for Soldier-Machine Integration. Explore unique modalities such as tactile, haptic, acoustic and visual to make interactions more intuitive, better connected to the environment and more immersive. Accommodate Soldier preferences to begin customization of crew-station interface to the individual.

  - Mid Term (2025-2035) – Build on Near-Term objectives and supplement with non-intrusive Soldier monitoring techniques to assess state and intent of individual. Determine when as well as what automations (system services, task efficiencies, state changes) can be employed to increase performance and effectiveness. Use emerging sensor fusion and stitching as well as a-Priori data to provide augmentation to Soldier for greater visual acuity and increased situational awareness of the battlespace.
  - Far Term (2035-2050) – Utilize advanced Soldier monitoring techniques that employ cognitive and neuro-ergonomic best of practices to anticipate individual actions. Coupled with detailed understanding of mission and environment as well as advanced artificial intelligence, modify and automate multi-modal interfaces on-the-fly to maximize efficiency and effectiveness of required interactions for best possible performance.
- VS1 – LOE6 – KO2 (1.6.2): Develop learning, intelligent agents that adapt to changing missions, environments and crew-member intent and provide relevant and timely assistance to crew members. These agents will build on capabilities in 1.6.1 plus utilize advanced data processing techniques, enhanced visualization, augmented reality, and task automations.
  - Near Term (through 2025) – Begin development of a comprehensive knowledgebase that will serve as foundation for learning agents, provide comparison and identification of battlespace objects and generally serve as the vehicle’s memory. This will include imagery, landmark recognition, infrastructure objects, friend/foe intelligence, scene interpretation, agent repositories, local language and customs, etc. Identify promising tasks (i.e. high work load and/or dull, dirty or dangerous) for automation. Establish methodologies and processes to monitor environmental and mission timelines that can be synchronized with task threads for future deployment of intelligent agents. Utilize training based on expert Users to capture most effective processes and behaviors for optimized task execution.
  - Mid Term (2025-2035) – Develop learning algorithms that can assess Soldier patterns and workload from monitoring methodologies and begin development of intelligent agents that can provide solutions for increased performance. These learning algorithms will serve as synthetic teammates to crew members and provide automation of many vehicle functions.
  - Far Term (2035-2050) – Establish use of autonomous deep learning machines and joint human-Artificial Intelligence systems that can assist humans in all aspects of vehicle operations and drastically reduce decision making timelines.
- VS1 – LOE6 – KO3 (1.6.3) Develop distributed and interactive intelligence that unifies teaming across multiple manned and unmanned vehicles and provides coordination of action for a more cohesive fighting force.

- Near Term (through 2025) – Utilize detailed task assessment and analysis to establish deep understanding of intra- and inter-vehicle crew-member mission and workflows. Assess current vehicle system crew-member dependencies, verbal and non-verbal communications and unique vehicle formations and missions that must be maintained. Query Soldiers to understand expectations for other vehicle crew members and capture how intent is communicated for mission execution.
- Mid Term (2025-2035) – Once a teaming baseline is established, assess emerging technologies like gesture recognition, body language interpretation, voice recognition, mission visualization and other collaboration tools that can facilitate team effectiveness and efficiency. Take advantage of emerging Nano-technologies and wearables that can both monitor and augment Soldier capability to achieve greater cooperation across the unit.
- Far Term (2035-2050) – Future developments in teaming will be gleaned from advancements in human-computer interactions, neuro-ergonomic progressions and gains in distributed cognition that permit thought sharing instantaneously. Emerging Artificial Intelligence will permit real-time adaptation of crew-station systems to changing dynamic situations and either automate execution or greatly augment human capability. Team cohesiveness will become synergistic with high levels of trust between crew members as well as with autonomy

* VS1 – LOE6 – KO4 (1.6.4): Establish a modular, interactive development environment complete with simulation capability to trade emerging technologies as viable candidates for future crew-station design. This laboratory will reduce future development and integration time and costs, and allow more capabilities to be added faster.
  - Near Term (through 2025) – Deliver a modular, reconfigurable crew-station integration laboratory that permits rapid evaluation of high potential interactive technologies. This laboratory will support replication of current and future fleet vehicle crew stations and will be supported with realistic simulation tools that allow for generation of environments, critical sub-systems (such as weapons, sensors, etc.) and mission scenarios for evaluation. Evaluate multi-modalities, interface designs, and layering of screen layouts.
  - Mid Term (2025-2035) – Explore next generation candidates for utility such as neuro-ergonomics, automations, and augmentation of Soldier capability. Understand customer needs and identify insertion points for emerging technologies. Utilize advancements in immersive simulation and augmented reality to increase realism of task execution and stimulation of all the senses.
  - Far Term (2035-2050) – Utilize speculative technologies like a brain-computer interface to allow for augmented reality or a complete disconnection from the body and permit control of either a virtual body or an avatar that interacts with simulated crew-station environments or with real world hardware. Explore simulation advancements that make the virtual environment reflect future combat domains.
* VS1 – LOE6 – KO5 (1.6.5): Deliver via sustained evaluation and experimentation, advanced crew station designs and techniques that serve to optimize Soldier-machine interactions while under motion and reduce transition timelines for feeding programs of record.

- Near Term (through 2025) – Acquire appropriate instrumentation to monitor, record and store Soldier interactions, to include neuro-ergonomics, physical interchanges, states and modes, biometrics, health, body position and poses, event data, etc. Explore report generation software that can rapidly process varying data types, conduct performance analysis and produce final reports in a timely fashion that will reduce the evaluation cycle for viable technologies. Establish effects of motion on Soldier, his/her interactions with vehicle systems and between crew members for all tasks and build repository of information to feed future programs of record.
- Mid Term (2025-2035) – Create motion-based crew station in the loop virtual simulation capability to provide greater fidelity to existing static virtual experimentation.
- Far Term (2035-2050) – Create motion-based crew-station avatar to participate in experimentation with other live vehicle systems.

- VS1 – LOE1 – KO4 (1.6.6): Soldier Machine Interface: Optimized unmanned system and manned-unmanned system team performance through reduced cognitive burden for the Soldier while enabling real-time unmanned system status/activity, overall mission effectiveness, and predictive capability of system's intended activity.
  - Near Term (through 2025) - Universal Multi-Modal OCS; Limited adjustable user interfaces; On-line control; 1:1 Span of Control; Visual, Audio & Haptic Feedback; Mission Profile Control
  - Mid Term (2025-2035) - Multi-vehicle control; Predictive interfaces; 1:Many Span of Control; Comment Recognition; Tactical Robotic Language; Limited Multi-Asset Mission Coordination
  - Far Term (2035-2050) - Extended automatic mission command implementation; Human like communication, feedback, & control; Contextual/Natural Communications; Tactical Mission Intent

VALUE STREAM 2 (VS2):
SUPPORT SYSTEMS ACROSS THE ACQUISITION LIFE CYCLE

The efforts in VS2 support the Life Cycle Management of the Army's finest Ground Systems. The actions undertaken in this value stream promote the operational readiness and cost effectiveness of currently fielded ground systems, and those under development and fielding within PoRs. To achieve these results, current systems must: 1) continually accept upgraded capabilities to maintain technological superiority and 2) possess the capacity to accommodate new capabilities that are developed. In addition, the Army must have the means to understand and mitigate the costs of sustaining each platform. Ensuring the mission readiness of the Army's Ground Systems in support of the warfighter, VS2 is linked to both VS1 and VS3. For example, technologies developed under VS1 for future PoRs may be leveraged for current PoRs. Similarly, while VS3 is focused on strategically investing in new or improved engineering-enabling capabilities (Foundational Competencies), VS2 will leverage these capabilities to enhance TARDEC's ability to provide world-class support to all external and internal stakeholders.

The objective of VS2 is to ensure TARDEC is the first choice for affordable engineering service and support for the ground systems community and this is realized through continued development of TARDEC's Technical Authority. TARDEC will continue to be the Army Ground Systems leader in systems engineering activities and capability development. TARDEC's Technical Authority will be leveraged throughout a product's life cycle from concept through development and procurement, to production and sustainment, and eventually disposal. This will be accomplished through three LOEs, which together will define TARDEC's Ground Systems support, along with providing effective and affordable combat-enabling capabilities. Objectives of VS2 can be in the near term, so the structure of these LOEs is different than in VS1, which further defines Near, Mid, and Far Term KOs.

The three LOEs in VS2 are:

- LOE 2.1 - Technical Program Support
- LOE 2.2 - Sustainment Engineering
- LOE 2.3 - Tech Alignment & Transition

LOE 2.1: TECHNICAL PROGRAM SUPPORT

Description: TARDEC's goal is for partners and customers to utilize TARDEC as the technical authority in key competency areas based on TARDEC's demonstrated excellence. That is, in those key areas, partners and customers receive unbiased, reliable answers and excellent service. This is accomplished through TARDEC's world-class workforce with the unique ability to draw upon a wide array of expertise to develop innovative solutions to complex problems.

This LOE focuses on providing partners and customers with engineering expertise in the areas of system-level development and integration, technical data acquisition, technical reviews, requirements standardization, and technical specification development.

Key Outcomes.

- VS2 – LOE1 – KO1 (2.1.1): TARDEC as the system-level technical authority. Demonstrate superior requirements development, concepts, analysis, design, integration, testing and prototyping from the component level to the complete system by performing full-up system level design using TARDEC's organic workforce.
- VS2 – LOE1 – KO2 (2.1.2): TARDEC as the technical data acquisition and management authority. Provide guidance to customers in deciding when and how to acquire and manage technical data and technical data rights from original equipment manufacturers (OEMs). When technical data is to be acquired, assist customers with the acquisition and management of a TDP used to support the vehicle system throughout its life cycle, which enables successful transition to sustainment and a healthy long term industrial base.
- VS2 – LOE1 – KO3 (2.1.3): TARDEC as the technical review authority. Provide well educated, trained, and skilled technical staffing support to customers during program execution and technical reviews to perform independent analyses, provide technically sound feedback, and enable data-driven, informed, unbiased decisions.
- VS2 – LOE1 – KO4 (2.1.4): TARDEC as the technical requirements authority. Lead a continuous and collaborative effort between TARDEC SMEs, customers, and the User community to develop and maintain a common set of standard requirements to be utilized and amended across future PoRs. These efforts enable TARDEC's critical role as an advocate for technology transition and directly influence future efforts.
- VS2 – LOE1 – KO5 (2.1.5): TARDEC as the ground systems standardization authority. Develop, maintain, and support technical specifications (military standards, commercial item descriptions, etc.) that accurately define the functional requirements,

desired capability, and operational environment with sufficient criteria for verifying functionality and performance.

LOE 2.2: SUSTAINMENT ENGINEERING

Description. The Chief of Staff of the Army set his top priority as Readiness. “Readiness for ground combat is – and will remain – the U.S. Army’s #1 priority…Readiness is #1, and there is no other #1.”

There are many ways TARDEC supports this priority. One of the most significant is through technical support in the operations and sustainment phase of the life cycle, or Sustainment Engineering. TARDEC seeks to be established as the top choice Engineering Support Activity (ESA) and Software Support Activity (SSA) for sustainment of all ground systems. Additionally, sustainment considerations early in the life cycle will allow leverage of competitive contracting to acquire technical data or other required information that will enable sustainment activities in the future.

This LOE ensures the enduring value of future systems by outlining the necessary elements needed to enable full sustainment of ground systems, to include building in reliability from the beginning of a program. Continuous engineering will be required on DoD ground systems to keep them relevant and ready. This includes field technical issues resolution, depot and maintenance support, secondary item support, and software sustainment. The tools and processes developed in support of this LOE must be flexible and adaptable, reducing the logistics footprint, creating solutions that can be quickly utilized to solve field issues, and helping maintainers and Users increase availability of equipment. The following KOs will facilitate TARDEC in performing this mission.

Key Outcomes.

- VS2 – LOE2 – KO1 (2.2.1): TARDEC as the first choice ESA for all ground systems in sustainment. This includes providing quick and viable technical solutions to customer inquiries, field support requests, and troubleshooting knowledge to maintain a high readiness rate on all platforms. TARDEC will also synchronize sustainment execution management processes with customers to enable rapid innovation and agile technical support. This includes improving the metrics tracked in the sustainment arena. Near term objectives will include setting a standard set of sustainment engineering services offered for each system. Far term objective is to be providing them for all systems.
- VS2 – LOE2 – KO2 (2.2.2): Establish and Implement the TARDEC Software Engineering Center as the Software Support Agency (SSA) or Life Cycle Software Engineering Center (LCSEC) for all Army Ground Systems. Army Regulation 750-1 requires the, “transition of software support planning, programming, budgeting and executing system responsibility from the material developer (MATDEV) to the LCSEC prior to the end of the weapon system hardware production (to include block

upgrades), the MATDEV, in coordination with the LCSEC, will obtain DCS, G-4 and ASA(ALT) approval and document the approved transition date. Life cycle software support embraces all software-related activities for a weapon systems embedded operational software." Post Production Software Support (PPSS) is a subset of life cycle software support that begins with completion of the weapon system hardware production. This KO seeks to establish TARDEC SEC as the LCSEC for all Army Ground Systems.

- VS2 – LOE2 – KO3 (2.2.3): TARDEC to serve as the System Level Obsolescence Risk Manager. Obsolescence is a major issue that the sustainment community is witnessing which continues to negatively affect readiness rates. Although this issue prevails across all components on ground systems, electronics obsolescence has the potential to be the critical issue in the future. Access to design information at the subcomponent level, or its associated software, is necessary to resolve these issues before affecting readiness or fielded units. TARDEC will utilize best-of-breed obsolescence management tools and processes to proactively identify material support risk and provide actionable mitigation in support of system overhaul programs and overall system readiness rates.
- VS2 – LOE2 – KO4 (2.2.4): TARDEC to establish and implement the Logistics Engineering (LE) competency to ensure that logistics and maintainability considerations are being taken early on during the development phases in order to drive down O&S costs down stream. The KO will drive to obtain design effectiveness through the introduction of logistics and maintainability information and data, of which will result in more supportable and more maintainable technologies being transitioned from development to fielding and sustainment
- VS2 – LOE2 – KO5 (2.2.5): TARDEC to provide engineering support for RESET, RECAP, rebuild, and overhaul programs. This is accomplished with production readiness by validating Bills of Materials (BOMs) prior to system build. Technical data availability, completeness, and compatibility assessments across communities is also an area of emphasis to include storing National Maintenance Work Requirement/Depot Maintenance Work Requirement (NMWR/DMWR) data and flat file/manufacturing BOM data in a common tool. This will promote TARDEC as the Technical Authority in terms of Manufacturing & Production Engineering, and ensure all technical data is available to the organic site prior to the start of production. TARDEC will also identify, maintain, and grow manufacturing technologies and technical capabilities and competencies in support of organic industrial base critical skills, while partnering with depot/arsenals, universities, and industry.
- VS2 – LOE2 – KO6 (2.2.6): TARDEC to enable rapid acquisition of secondary parts to ensure Users get items expeditiously. This rapid acquisition will be through instantaneous access to complete, accurate, and up-to-date product (engineering, configuration, quality and logistics) data across DoD. This data will pre-position TDPs for secondary item procurement and provide on-demand information such as equivalent products, vendors, replacements for obsolete items though mechanisms like reverse engineering, and hazardous material content. This will help reduce administrative lead time (ALT) for secondary item procurements to near zero days

ensuring that depots and field units are not experiencing readiness problems due to excessive review time for spare parts.

- VS2 – LOE2 – KO7 (2.2.7): TARDEC to establish and implement a technical Sustainment Readiness Review (SRR). This KO seeks to establish a framework for technical reviews, in accordance with the Product Support Strategy (PSS), which will ensure complete system technical data in preparation for sustainment activities (KO2.1.2). TARDEC will serve as the ESA lead to manage technical data and define roles and responsibilities for the post-production support as detailed in the Sustainment Plan Supportability Strategy. The SRR provides a baseline to TARDEC on the state of the system in terms of cost drivers, risk areas, depot/arsenal overhaul/rebuild programs and schedules, and resources available to support the system in sustainment. This will ensure TARDEC will have the proper sustainment support systems in place prior to transition, which will ultimately assist life cycle managers and increase readiness rates.
- VS2 – LOE2 – KO8 (2.2.8): TARDEC to establish/implement Design for Reliability (DfR) engineering process and provide DfR engineering support to S&T programs. DFR support to TARDEC S&T projects focuses on ensuring that reliability is considered in the early stages of technology development by incorporating DfR activities. DfR activities include a set of techniques that are used to modify the initial design of a system to improve its reliability in order to ensure the system design meets its reliability goal. The techniques that comprise DfR include reliability allocation, reliability prediction, reliability block diagrams and fault tree analyses, Failure Modes and Effects Analysis (FMEA), physics-of-failure methods, and root-cause analysis. This will result in the reliability improvement of all technology being developed and transitioned, and of which will ultimately improve sustainment and increase readiness rates.

LOE 2.3: TECH ALIGNMENT & TRANSITION

Description. This LOE describes how TARDEC aligns, develops and transitions new technologies to current and new platforms. TARDEC's ability to develop and maintain close working relationships with the PMs is critical for success of this LOE. These relationships are developed through frequent communication and dialogue at all levels of the organization, including SMEs, matrix personnel, Chief Integration Engineers, and leadership. TARDEC ensures communication with the pertinent original equipment manufacturers and collaborates where appropriate to ensure the PM gets the best solution with the best cost, schedule, and performance.

Working closely with the PMs, TARDEC synchronizes S&T investments with PoR timelines through the SPAR process. The LOE 2.3 objective is to improve the fidelity of the data gathered during this exercise by roadmaps linking products from RDECOM's tech base to initial acquisition, modernization, and upgrade plans for all ground systems.

TARDEC applies best practices from systems engineering and project management through a gated programmatic-review process to generate, resource and track project execution to deliver real solutions that address PM needs. TARDEC actively manages item cost, project cost, project schedule, and system performance requirements to ensure a viable transition.

The needs for TARDEC S&T projects come from warfighter outcomes, capability needs analysis (CNA) Gaps through Joint Capabilities Integration Development System (JCIDS), formalized requirements documents, directed requirements, JUONS/ONS, and PM-specified needs lists. Additionally, TARDEC will decompose platform capability gaps, life-cycle cost drivers, and size, weight, power and cooling (SWaP-C) margins to identify additional opportunities for improvement. Because the PM's needs change over time, TARDEC will actively manage requirements and adjust as necessary to ensure the end product is the right solution.

Finally, the importance of linking S&T efforts to warfighter needs is crucial. TARDEC will use Transition Agreements (TA) to maximize communication, collaboration, and commitment with transition partners. This is done for all projects that have 6.3, 6.4, and 6.7 funding that are informing requirements or transitioning to Acquisition. The TA is written jointly with the transition partner to promote a cooperative environment conducive for a successful transition.

Key Outcomes.

- VS2 – LOE3 – KO1 (2.3.1): PoR Integration. Drive an increased number of technology products to the field by implementing the processes, tools, and training, as described in VS3, necessary for executing customer priorities and life-cycle requirements such as safety, readiness, and affordable maintainability. Enable TARDEC to identify and align technology programs and services to specific acquisition program events. Develop and mature technology in coordination with the customer to ensure transition.
- VS2 – LOE3 – KO2 (2.3.2): Rapid upgrades and prototyping for PoRs. Ensure TARDEC services are ready and available to respond to acquisition program requests for design, systems integration, rapid upgrades, prototyping, and low-volume production. Deliver the necessary products for transition to high-volume production partners. Provide adaptable and flexible options for customers: quick to fund, in-house skill growth, competitive cost and schedule, and competitive TDP output.
- VS2 – LOE3 – KO3 (2.3.3): Restore the performance of PoRs through engineering change proposals (ECPs). Work in partnership with PM offices and the User community to ensure technology solutions are feasible and affordable. Recommend options that satisfy PoR requirements. Guide technology development towards meeting performance and affordability targets by applying in-house skills and competencies.

VALUE STREAM 3 (VS3): STRENGTHEN FOUNDATIONAL COMPETENCIES

The focus of VS3 is to strategically improve TARDEC's core functions through the people, processes, tools, and facilities which support all of TARDEC's stakeholders through utilization in VS1 or VS2. VS3 uses an integrative approach of LOEs supported by Technical and Mission Enhancing Competencies which allow TARDEC leadership to make decisions to strategically grow, sustain, or divest in the VS3 resources that form the organization's foundation. This undertaking aims to position TARDEC to provide superior products and services, such as military ground system engineering, experimentation, analysis, system integration, experimental prototypes, manufacturing, assessment, and sustainment engineering services to VS1, VS2, and other stakeholders in a reduced cycle time.

TARDEC's suite of virtual and physical engineering tools accelerate innovation by enabling rapid development and evaluation of both future vehicle concepts and current fleet upgrades. In the digital environment, TARDEC evaluates technology solutions in virtual simulations prior to physical prototype builds. For example, the TARDEC Virtual Experiments Capability (TVEC) tool leverages video game technology to replicate operational scenarios and receive Soldier feedback on future vehicle concepts. In the physical environment, TARDEC utilizes its unique lab capabilities to manufacture, integrate, and assess physical experimental prototypes to validate performance. The synergistic coupling of advanced design, manufacturing, integration, and assessment tools is known as the Digital-Physical Prototyping (DPP) and forms the foundation for delivering advanced solutions to the warfighter.

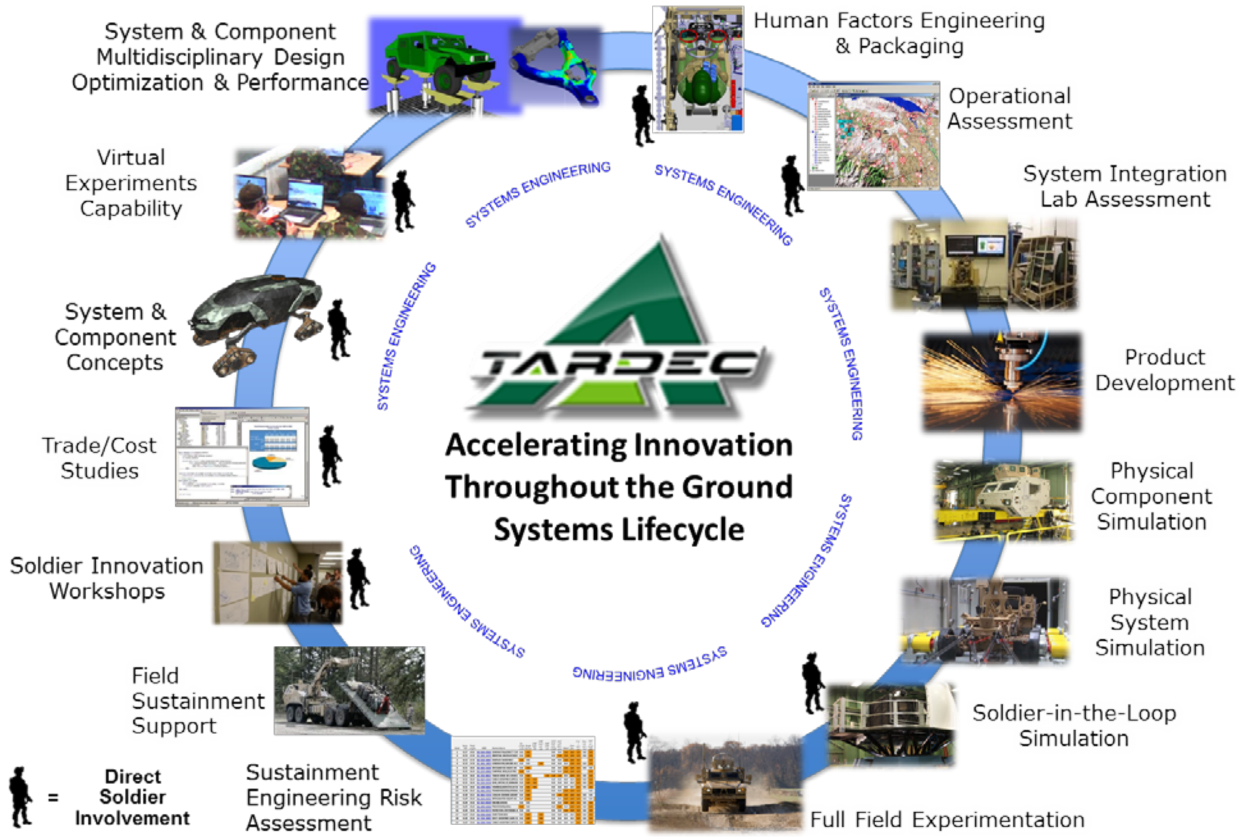

Figure 2: TARDEC Digital Physical Prototyping Process (DPP)

The VS3 LOEs represent the core functions required to support TARDEC's mission and vision, without which TARDEC will not be able to succeed. These LOEs each integrate several aspects of TARDEC's Technical Competencies into higher level concepts and provide overall strategic perspective on how TARDEC needs to function to achieve the goals of VS1 and VS2.

The five VS3 LOEs are:

- LOE 3.1: System Sustainment
- LOE 3.2: Full System Experimental Prototyping
- LOE 3.3: Ground Vehicle Full System Architecture
- LOE 3.4: Modeling & Simulation
- LOE 3.5: Software, Computers, and Cyber-Security

LOE 3.1: SYSTEM SUSTAINMENT

Description.

TARDEC has been supporting Army readiness for decades though a continued focus on system sustainment. Whether it is developing requirements and deliverables to enable sustainment in the development of a new system through the acquisition process or helping current fleet systems meet readiness goals through engineering changes to resolve issues encountered in the field, TARDEC has been and will continue to support system sustainment and Army readiness so that ground systems are ready and useable to train and fight with. The development of that competency is the focus of LOE 3.1.

Numerous government and Industry partners have a role in system sustainment. TARDEC's role is usually referred to as the ESA and is defined in a systems Post Production Support Strategy, governed by Army Regulation 700-127. This designation is sometimes associated with systems near the end of production but in reality TARDEC starts as the ESA at program initiation when new programs start requesting technical support. Our role as the role as ESA continues to provide tailored engineering support and services throughout a systems life cycle. As the ESA, TARDEC provides the majority of the engineering support to the PEOs that develop and acquire the ground systems for the Army. TARDEC helps to develop the designs, specifications, and requirements for these systems and can influence deliverables and trades that are made during these early stages that will likely affect readiness and the ability to sustain the systems in the future.

TARDEC can influence system sustainment by ensuring reliability and maintainability is considered in the early stages of technology development and concept refinement by incorporating Design for Reliability (DfR) activities. The DfR process is a rigorous and iterative set of activities which focus on the identification and removal of failure modes and mechanisms during the design phase. TARDEC will continue to incorporate this into its technology development programs.

TARDEC has invested in the growth of a Logistics Engineering team which works closely with the Reliability team to ensure that, not only are requirements developed and decomposed appropriately, but also logistics, reliability, and maintainability considerations are part of the design and development phases early on which supports a common goal to minimize Operational and Sustainment (O&S) costs upon successful technology transition to program offices and customers in the future.

Furthermore, once a system gets deployed and technical issues start arising in the field, TARDEC has the responsibility to resolve those issues quickly and get the system back in the fight. To do this, TARDEC requires a strong contingent of platform engineers that are familiar with those systems and how each is employed and supported. To support this endeavor, TARDEC will need facilities to allow for the use of system integration laboratories (SILs) and Facility Vehicles to enable the technical workforce to quickly troubleshoot and resolve sustainment issues. Also, TARDEC will need to keep all of its technical competencies strong since issues can and have arisen on any component on that ground system. Not only will TARDEC need a strong sustainment engineering competency, but also needed are SMEs in TARDEC's technical competencies to provide the full spectrum of support quickly and holistically, while keeping an eye to potential future systems that must be sustained in the future that may require a different skillset than previous systems.

Full system sustainment embodies quick resolution of technical issues from the field, depot and maintenance support, secondary item support, software sustainment and a host of other items across the life cycle. Fiscal resources dedicated to sustainment, particularly in late stages of the life cycle, are typically small so the tools and processes must reflect some of TARDEC's key tenants; that is the tools and processes must be flexible, efficient and adaptable to be quickly utilized to solve field issues and help maintainers and users. It was stated at the 2015 DoD Maintenance Symposium that "software sustainment is really just continuous software engineering." The same could be said for sustainment engineering in general (which has a great effect on readiness). Continuous engineering will be required on the DoD's ground systems to keep them relevant and ready and TARDEC will continue to fully support and lead these efforts.

LOE 3.2: FULL-SYSTEM EXPERIMENTAL PROTOTYPING

Description.
This LOE enhances the Army's capability to develop and demonstrate full-system Experimental Prototypes (XPs) that are relevant for the Future Force and described in the CDs of VS1. It is through these XPs that the Army shapes and informs the requirements of future PoRs by demonstrating advanced capabilities to the warfighter. The ability to do this well is at the heart of VS1 and, over time, supports VS2 by reinforcing TARDEC as the Technical Authority in Ground Systems and positions the Army for future successful Programs of Record. Ideally, TARDEC will consistently develop operationally-relevant, full-system XPs through exceptional in-house capabilities and effective collaboration across the government and civilian sectors, guided by operational needs decomposed in VS1 and detailed as CDs in Appendix A.

Additionally, this capability is essential to the success of future PoRs. The Army's recent history highlights the difficulty in ensuring that new requirements are both technically achievable and operationally relevant. Army S&T is positioned to address these challenges through the development and demonstration of XPs as an essential component of pre-Milestone A groundwork.

It is important to note that this capability collaborates (rather than competes) with Industry. This is because 1) TARDEC focuses on the leap-ahead, high risk technologies that Industry is less-incentivized to pursue, 2) the XPs are not designed to be mass-produced but rather to demonstrate advanced capabilities, and 3) TARDEC will leverage industry expertise to fill critical technology and service gaps via through Public Private Partnerships.

In order to achieve the ideal end-state described above, TARDEC must draw on all of its technical competencies to be proficient in the activities listed below:

1. Crafting initial requirements
2. Virtual full-system prototype development
3. Physical full-system prototype development
4. Virtual and physical testing
5. Demonstrating advanced capabilities and informing final requirements
6. Leveraging strategic partnerships

LOE 3.3: GROUND VEHICLE FULL SYSTEM ARCHITECTURE

Description.

Ground vehicle systems consist of vehicles, vehicle mounted on-the-move mission technology, and vehicle support systems. This technology must be integrated together across a spectrum of engineering/technical disciplines, required system properties and attributes, and ground vehicle system types that range from the simplest tactical truck to autonomous combat systems. Systems continue to push the boundaries of state-of-the-art performance and are increasingly smarter or more autonomous and have increased emphasis on certain system properties or quality attributes such as cyber security, adaptability, weight, and modularity. Traditional approaches to system architecture have not been able to address these system needs without significant increases in system acquisition and sustainment costs as well as increased time to develop and field. New system developments are nearly unaffordable and/or potentially obsolete by the time they arrive to the field, let alone sustainable over a 40- or 50- year life cycle without significant cost and reinvestment. Additionally, traditional system architecture approaches do not sufficiently capture the operational behavior and contextual knowledge required to effectively specify, assess and integrate autonomous or smart technology. The Ground Vehicle Full System Architecture (GVFSA) enables advanced technology integration to achieve advanced system capability and system properties while improving system affordability, enabling more rapid system development and fielding cycles, and plug and play enhancements to fielded systems.

A GVFSA framework will be developed that identifies and integrates the following critical dimensions of system architecture: logic, execution, physical assembly, vehicle deployment, and contextual knowledge. Physical assembly and vehicle deployment form the physical architecture typically captured in a CAD model. Physical assembly reflects an engineering bill of materials (EBOM) view of technology components and the vehicle deployment reflects the vehicle physical distribution of technology components along with the physical properties. The logic dimension shows how those same technology components interact to achieve critical operational/system behavior and begins to capture non-physical properties such as performance attributes. The execution dimension reflects how the technology components and associated behavior are constrained by system resource limitations and enables full definition of all non-physical properties or quality attributes. The contextual knowledge dimension enables connection of the system behavior to mission and external world events and effects so that operationally intelligent behavior can be assessed in terms of required autonomous technology.

The logic dimension for the entire ground vehicle system domain will be structurally organized as a set of technology components linked by capability classes or major technology areas. These technology component areas include but are not limited to: Structure, Mobility, Survivability, System Command Control and Communications (SC3), Tactical Command Control and Communications (TC3), Lethality, Intelligence/Reconnaissance, Surveillance, and Target Acquisition/Electronic Warfare, and Mission and Special (Force Projection, Sustainment, Security and Stability Operations, and CBRN).

These areas include technology components that can range from physical, control systems, higher level computational hardware and software, and in most cases, automation. These technology areas are often developed in stove pipes where system properties and integration constraints are not considered fully. Advanced CAD models can help manage physical properties and constraints but are not required acquisition practice, typically are not employed by mission technology developers, and do not help rationalize logic and non-physical properties and constraints. The most extreme impact of this has resulted in GFE supplied mission components that are physically bolted onto the vehicle, isolated from the rest of the system operation, and sub-optimized across the entire range of system properties, quality attributes, and constraints. The GVFSA framework as a standard needs to extend into the technology architectures identified above and form the basis for full system conceptualization. The component based logic once defined relative to operational and other high level system behavior will form patterns of reuse that need not change unless the operational tactics that they support change.

In order to address the full range of non-physical system properties, the technology components and associated behavior logic must be assessed in an execution context over a range of system resource constraints. The system resource constraints include power, computation and information, and cognition or intelligence. Technology components are arranged in execution layers that are either system applications or system resource providers. All technology has a purpose or a “mission” and can be thought to have an “executable”, even a structural component. These executable layers form the basis of a ground vehicle common operating environment (GVCOE). Dependencies between layers are isolated and identified and cover the full range of technical and engineering disciplines: structural support, power, computation, control system, information management, software, and hardware/software applications and autonomous agents. Physical and quality attribute constraints can be introduced in the selection of particular systems architecture alternatives and the impact on the system behavior logic and non-physical quality attributes can be assessed through trade space exploration.

The GVCOE enables not only the technology component in an execution context, but compatible technology components in other layers. This enables component reuse with both the understanding of the application behavior logic it performs and the dependency it might have on other components. Critical among this is the SC3 technology component set. SC3 provides common computational technology component resources in the following execution layers: information management, operating environment, operating system, resource access including user interface, and computation. These include any specialized components to augment handling specialized system quality attributes such as cyber security. SC3 also provides the ability to manage power distribution and control of system loads as well as mission management components. It should be noted that effective mission command at the system level requires full access to all the system resources and cannot be performed by an isolated “command, control, communications, and computers box” and a radio. This becomes more obvious as the system becomes smarter and acutely obvious for autonomous systems. The system computation resources can then be fully distributed or tightly integrated and/or introduced in redundant quantities depending on the system performance needs and other quality attributes as well as physical properties and constraints.

The GVCOE provides the overarching reference model to manage technology component reuse and system composability. Specific technology components compatible with each other can be selected from the overarching GVCOE model and used to create specific system COE for particular system architecture. The GVCOE will be supported by an ecosystem that manages access to a product line repository and associated data to support rapid assessment of existing prototype and fielded components. This enables rapid composition of system architectures with full understanding of the system behavior and performance dependencies. Over time, systems fielded with system architectures conformant to the GVFSA framework can be upgraded with advanced technology components proven on other systems with only integration regression testing required.

To support the evolution of smart systems to fully autonomous systems, the context knowledge required for the system to intelligently respond to external events and manage desired effects must be explicitly captured and defined as well as integrated with the system component-based behavior logic. A concept data model will be defined that will support the development of system logical and physical message standards as well as support autonomous or agent-based world model design. The full range of operational scenario variables, such as mission, enemy, terrain, troops available, time, and civilian considerations, will be addressed along with specification of system operational behavior goals and the capture of system state information. The concept data model will support consistent assessment of system architecture from conceptualization through final test and increase early simulation testing of system executable logic integrated with executable scenarios in virtual and analytical environments.

The GVFSA provides the overarching framework, GVCOE model and specific system COEs, and supporting product line ecosystem. It will provide the overarching formulation and integrating framework for the following more detailed technology-based architecture views, ecosystems, and key outcomes:

1. Mobility and Prime Power Architecture
2. Autonomous Mobility Architecture
3. Survivability/APS Architecture
4. Force Projection Architecture (such as bridging)
5. Vehicle Electronics and Electrical Power Load Distribution Architecture
6. Software and Cyber Security Architecture
7. Physical and Structural Architecture

LOE 3.4: MODELING & SIMULATION (M&S)

Description.
As TARDEC strives to develop and integrate ground vehicle technology, develop demonstrators/prototypes, and support PMs and PEOs, M&S is a key enabler for early and effective evaluation of ideas, concepts and designs. M&S technologies enable early and better decision making throughout a development cycle. They provide the ability to consider multiple alternatives and perform trades and optimizations before committing to hardware prototyping. Additionally, as prototypes are developed, M&S testing and experimentation capabilities allow evaluation of hardware in a laboratory environment. This provides the benefit of subsystem testing before system integration, early solider feedback, and early characterization and validation of components and models. Laboratory evaluation also provides a controlled, repeatable, and accurate ability to rapidly evaluate component, subsystem or system durability and performance.

The Modeling & Simulation Line of Effort (LOE) consists of a broad spectrum of competencies and capabilities necessary to rapidly develop and accurately concept and evaluate ground systems prior to production and fielding. The scope of the M&S LOE includes the generation of new and modified ground vehicle concepts and assessment capabilities (both computer-based and physical), which are used to develop and assess Army Ground Systems at all relevant levels from component to force-on-force. Furthermore, they include a broad range of assessment functions to include physical architecture evaluations, trade studies, performance analysis, optimization, human interaction, testing, force effectiveness, etc. TARDEC has built a capability to generate new and modified ground system concept models and perform vehicle development and assessments in each of these areas over the past 30 years. It is the purpose of this LOE to attempt to project TARDEC's needs for M&S tools over the next 30 years.

TARDEC's M&S capability must be ready and able to provide rapid and reliable analysis and testing to develop and assess Army Ground Systems of the future. These will be driven by complex and unknown operational environments and threats. To accomplish this, TARDEC M&S will need to quickly develop and assess system modifications and employment schemes. Readiness will demand that TARDEC have virtual representations of Army Ground Systems and operating environments available to enable adaptation/modification, which in turn drives the need for a digital twin capability. Furthermore, Army Ground Systems of the future will continue to grow in dependence on software, particularly software which increasingly enters into the decision making process through task automation, artificial intelligence, prioritization, etc. TARDEC M&S must therefore have an ability to run with mission software in the loop and be able to assess its function in a wide variety of circumstances. Army Ground Systems will also grow in the number and types of sensors and information which they receive, process, and generate. This implies that sensor, environment, and network modeling will become increasingly important. Army Ground Systems will continue to be increasingly interdependent. Systems-of-Systems will become the norm and the Army's effectiveness on the battle field will be determined by the combined participation of multiple systems to include UAVs, UGVs, etc. TARDEC M&S tools must be ready to assess these systems of systems.

Given that TARDEC, for the most part, uses COTS M&S tools, they will naturally grow and adapt to take advantage of multi-core and GPU architectures. TARDEC expects that they will have to drive tool advancements and improvements in areas unique to Army Systems (i.e. Blast, active defense, crew augmentation, etc.). Regarding human-in-the-loop, Virtual Reality (VR) and Augmented Reality (AR) will become increasingly mainstream allowing the Army to leverage these technologies for immersive viewing of new and improved ground vehicle designs (i.e. CAVE Automatic Virtual Environment) to multi-player gaming (i.e. TARDEC Virtual Experiment Capability).

Analytics Modeling & Simulation core competency supports TARDEC's 30-Year Strategy efforts on mobility, protection, power, thermal & signature, and systems engineering. The Analytics M&S competency can be in the form of research, technology and software development, and technical support. Furthering this competency and its fidelity is TARDEC's Physical Simulation Team's (PST) characterization capabilities. PST is able to leverage state of the art, unique characterization rigs in order to gather vehicle and component level data. This data can be used to evaluate the individual Analytics models in the areas of Mobility, Stability, Transportability, Durability, Blast, and Vehicle Performance.

In addition to application- and capability-driven improvement, TARDEC M&S must also improve processes. To be responsive and flexible TARDEC needs consistent, validated, configuration managed representations of all ground systems, referred to as "digital twin." To achieve the vision of digital twin, TARDEC needs an integrated information management system which is capable of storing and executing M&S representations as well as interconnecting them across M&S domains to evaluate the interplay of multiple subsystems and systems. This implies a robust system characterization capability capable of capturing the essential parameters from a physical system (this should include mechanical, electrical, sensors, etc.). In this regard TARDEC M&S must be capable of simulation at multiple levels of fidelity which are consistent in gross performance and validated against the representative system. Tools and capabilities are also needed to more tightly couple design and analysis by automating the steps between design and analysis. This should occur within the mechanical, electrical, and software domains. TARDEC also need to integrate the functions of analysis, lab testing and field testing. Lab testing needs to be used to validate/tune parameters in the models to assure consistency.

LOE 3.5: SOFTWARE, COMPUTERS, AND CYBER-SECURITY

Description.
The Department of Defense and its combatant commanders and servicemen will continue to rely more and more on computers and software to provide safe, secure, capable, reliable systems of systems to provide the combat overmatch capability required to defend the nation and protect the freedom of all people around the world. These systems of systems will need to be adaptable, interoperable, and ever evolving to remain relevant in an ever changing combat environment. The warfighter will continue to face creative, determined enemies who will continue to challenge them in unpredictable ways. The U.S. Army must be able to respond to a greater scope of mission at a moment's notice. To do this will require the rapid exchange and processing of information and the ability to make effective decisions to execute appropriate coordinated responses thus enabling decisive mission success. The ability to evolve to rapidly changing environments, circumstances, and threats is essential to ensure mission success.

TARDEC's strategy supports the development and rapid enhancement of equipment that will enable appropriate, flexible and responsive capabilities to provide operational adaptability resulting in decisive land power anywhere at any time. Systems and technologies must be capable of reliable joint operations in contested environments. TARDEC develops, acquires, integrates, manages and supports many software intensive electronic computer systems and subsystems to provide new and enhanced capabilities to the warfighter. Computer electronics, software engineering, and cyber-security are applicable disciplines to nearly all of the technology demonstration and maturation work delineated in the TARDEC Strategy as well as to PM managed systems and vehicles that will need to evolve to remain relevant and ready.

It is expected that the demand for these cross-cutting competencies will continue to escalate. Competing industries such as automotive, medical, and internet companies will tax the available resource pool and drive up the costs for these engineering services. TARDEC must be ready to provide attractive employment opportunities to recruit and retain the engineering talent required to support the demand.

In addition, TARDEC must acquire knowledge and skills to keep up with the emerging industry trends and technologies in the computer, software, and Cyber-Security domains. TARDEC must invest in the latest tools and techniques in these engineering and science disciplines to allow this capability to be leveraged and make TARDEC the first choice for computer, software and Cyber-Security engineering support.

Nearly all essential military vehicle functions and capabilities are primarily enabled by computer electronics and software. Key electronics/software enabled functional elements include: Crew Station Controls and Displays, Mobility, Transmission and Engine Controls, Active Suspension Management and Controls, Video Management, Sensor and Discrete Signal Management, Audio and Visual Alerts, Position Location Navigation, Vehicle Health Management & Diagnostics, Power Management, Threat Management, Target Engagement and Fire Control; Automotive Controls, Situational Awareness, Command and Control, Communications, Active Protection and Hit Avoidance, Autonomy and Robotic Systems, Maintenance and Configuration Aids, Supply Management, Vision aids, Embedded Training, Decision Aids, and Information/Data Management.

More and more functionality and capabilities are being demanded all the time. Most of the Army's current fleet are at or have exceeded design margins and lack the capacity to take on much more. The size, weight, power and cooling, (SWaP-C) and life cycle costs impacts of adding more capabilities to already overburdened systems and crew will require novel approaches to architecture, design, integration and operation. Modular, standard/common computer, software and power architectures will be needed to reduce the burdens of integration and replenish the SWaP-C design margins of new and updated systems so they have the ability to adapt and evolve. TARDEC will need to invest in these architectures to be able to get capabilities in the hands of the warfighter as fast and cost effective as possible.

Historically these combat and tactical systems required human interaction and control to coordinate activities. The men in the loop perform directed actions from command and control chain that executes based on an individual interpretation of mission directives with limited situational awareness in a dynamic environment. Information often gets obsolete before the interpreted appropriate response can be executed. Requiring Soldiers to reside inside or within the proximity of the systems often places them in harm's way. Software systems and computers can process information faster and coordinate an appropriate action faster than humans can. A system of systems approach to shared information and coordinated response can provide a more effective proactive response while removing the Soldier from harm. To enable these system of systems to process more and more data in a time-critical, contested environment, the Army will require trusted, rapidly configurable, cyber-secure communication & data networks whose reach can be expanded. The Army's vehicles will need to connect to and expand these networks to enable communications. Systems of Systems that can employ predictive decision aides that coordinate responses and interact to perform as a unit. Artificial Intelligent Systems, Unmanned/Autonomous crew support aides that support/enhance missions and operations with minimal crew interactions reduce physical and cognitive burdens of the warfighter. The vehicle electronics and software architectures must be able to accommodate the integration and evolution of the C4ISR sub-systems and components.

TECHNICAL COMPETENCIES

The Technical Competencies in VS3 are identified as the basis of TARDEC's technical body of knowledge. Technical Competencies are enablers of VS1, VS2, and VS3 LOEs and will inform requirements, technology and performance trades, PoR milestone decisions, test methods, concept development, risk mitigation, and training. Technical Competencies encompass TARDEC's expertise to design, develop, integrate, analyze, assess, mature, and support ground systems and critical technologies. Implementation Plans for each of these competencies set the goals to enhance the necessary technical expertise for TARDEC's future and are detailed in in a separate 30-Year Strategy Appendix D that is for TARDEC internal use only.

TC 1 Force Projection Technology
TC 2 Ground System Cyber Engineering
TC 3 Ground System Physical Simulation & Test
TC 4 Ground Systems Autonomy Capability Development & Integration
TC 5 Ground Systems Materials
TC 6 Ground Systems Software Engineering
TC 7 Ground Systems Technical Planning & Management
TC 8 Ground System Development, Fabrication, Integration, and Engineering
TC 9 Ground Vehicle Advanced Concepts Development
TC 10 Ground Vehicle Performance Analysis & Assessment
TC 11 Ground Vehicle Power and Mobility
TC 12 Ground Vehicle Survivability & Protection
TC 13 Platform Engineering
TC 14 Product Life Cycle Support
TC 15 Quality Assurance and Engineering
TC 16 Sustainment Engineering
TC 17 Vehicle Electronics and Architecture

MISSION EHNANCHING COMPETENCIES

Mission Enhancing Competencies encompass TARDEC's competencies that are fundamental to TARDEC's business processes. These competencies are often found in supporting roles to the Technical competencies, but are no less critical to the success of TARDEC's mission. Implementation Plans for each of these competencies outline goals across a wide range of fields that support TARDEC as a whole, from personnel to facilities management and beyond, and are detailed in in a separate 30-Year Strategy Appendix that is currently for TARDEC internal use only.

MEC 1	Acquisition / Contracting Management Support
MEC 2	Administrative Support
MEC 3	Business Development / External Collaborations
MEC 4	CIO / Information Technology
MEC 5	Facilities Management
MEC 6	Leadership & Supervisory
MEC 7	Logistics
MEC 8	Operations
MEC 9	Portfolio Management
MEC 10	Project Management
MEC 11	Resource Management
MEC 12	Safety, Environmental & Occupational Health
MEC 13	Strategic Planning & Communications
MEC 14	Value Engineering
MEC 15	Web Engineering
MEC 16	Workforce Development
MEC 17	Workforce Management

VI. PATH FORWARD

As the U.S. military moves into future operational environments, TARDEC recognizes that in order to provide the warfighter with a differential advantage in any situation, future ground systems must be designed to give the commander the ability to rapidly adapt and respond on the battlefield. TARDEC's capabilities, that is the people and their skills and tools, are uniquely positioned to continue informing the future requirements for existing, emerging and currently undefined ground systems that will, ultimately, provide the warfighter an advantage.

A set of subordinate Implementation Plans provide a detailed description of execution for each VS3 Competency. The TARDEC 30-Year Strategy will be updated periodically or as prescribed by the TARDEC Director or higher headquarters to ensure that TARDEC remains on the leading edge of ground system capability development.

APPENDIX A. STRATEGIC REFERENCES

1) *Army Operating Concept* and *Force 2025 & Beyond* Briefing to Maneuver Conference, Perkins, David G., Commanding General, U.S. Army Training and Doctrine Command (TRADOC) (Sept. 11, 2014), http://www.benning.army.mil/mcoe/maneuverconference/2014/presentation/ppt/GENPerkins.pptx

2) *Capstone Concept for Joint Operations: Joint Force 2020* (Sept. 10, 2012)

3) TRADOC Pamphlet (Pam) 525-3-0, *U.S. Army Capstone Concept* (Dec. 19, 2012)

4) U.S. Army Combat Vehicle Modernization Strategy, Draft Version 0.996, Maneuver, Aviation and Soldier Division, Army Capabilities Integration Center (ARCIC),TRADOC

5) TRADOC Pam 525-8-5, *U.S. Army Functional Concept for Engagement* (2014, February 24)

6) TRADOC Pamphlet 525-3-4, Draft Revision 0.5, *U.S. Army Functional Concept for Fires*

7) TRADOC Pamphlet 525-3-5, Draft Revision 0.73, *U.S Army Functional Concepts for Maneuver Support and Protection*

8) TRADOC Pamphlet 525-3-3, Draft Revision 0.3, *U.S Army Functional Concept for Mission Command*

9) TRADOC Pamphlet 525-3-6, Draft Version 0.7, *U.S Army Functional Concept for Movement and Maneuver*

10) TRADOC Pamphlet 525-4-1, Draft Version 0.7, *U.S Army Functional Concept for Sustainment*

11) U.S. Army RDECOM Strategic Plan (2015), *Enabling Battlefield Dominance Through Technology*

12) U.S. Army Robotics and Autonomous Systems Strategy 2015-2020, Draft Version 0.36

13) TRADOC Pamphlet 525-3-1, *U.S Army Operating Concept: Win in a Complex World* (Oct. 31, 2014)

14) Army Publishing Directorate Home Page. Army regulations, Department of the Army (DA) pamphlets, Field Manuals, Army Doctrine Publications, Army Doctrine Reference Publications. http://www.apd.army.mil/

15) TRADOC Publications. http://www.tradoc.army.mil/tpubs

16) Joint Electronic Library. http://www.dtic.mil/doctrine/new_pubs/jointpub_operations.htm

APPENDIX B. ACRONYM LIST

ALT: Administrative Lead Time
AOC: Army Operating Concept
ARIBO: Autonomous Robotics for Installation and Base Operations
ARL: Army Research Laboratory
ASA (AL&T): Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology
BOM: Bill of Materials
CAN: capability needs analysis
CD: Capability Demonstrations
CIO: Chief Information Officer
COI: Communities of Interest
CONOPS: concept of operations
DA: Department of the Army
DMWR: Depot Maintenance Work Requirement
DoD: Department of Defense
DOTMLPF-P: Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy
DPT: Digital-Physical Thread
ECP: Engineering Change Proposal
EOD: Explosive Ordnance Disposal
ESA: Engineering Support Activity
GSPEL: Ground System Power and Energy Laboratory
GSS: Ground System Survivability
GVPM: Ground Vehicle Power and Mobility
JCIDS: Joint Capabilities Integration Development System
KO: Key Outcome
LCMC: Life Cycle Management Command (LCMC)
LCSEC: Life Cycle Software Engineering Center
LIRA: Long-range Investment Requirements Analysis
LOE: Line of Effort
LRRDPP: Long Range Research and Development Planning Program
MAPS: Modular Active Protection System
MATDEV: Material Developer
MC: Mission Command
M&S: Modeling and Simulation
NMWR: National Maintenance Work Requirement
OEM: Original Equipment Manufacturer
OGA: Other government Organization
OSD: Office of the Secretary of Defense
Pam: Pamphlet
PLE: Product Life cycle Engineering
PM: Program/Product Manager

PMO: Program/Product Management Office
PoR: Program of Record
PPSS: Post Production Software Support
PSS: Product Support Strategy
RAM: Reliability, Availability and Maintainability
RAS: Robotic and Autonomous Systems
RMS: Records Management System
RDECOM: Research, Development and Engineering Command
RDEC: Research, Development and Engineering Center
RDT&E: Research, Development, Test and Evaluation
R&D: Research and Development
SE: Systems Engineering
SEA: Systems Engineering Activity
SIL: System Integration Laboratory
SME: Subject-Matter Expert
SRR: Sustainment Readiness Review
S&T: Science and Technology
TACOM: Tank-automotive and Armaments Command
TARDEC: Tank Automotive Research, Development and Engineering Center
TARGET: TARDEC Gated Evaluation Track
TDP: Technical Data Package
TRADOC: Training and Doctrine Command
TTA: Technology Transition Agreement
TVEC: TARDEC Virtual Experiments Capability
UAV: Unmanned Aerial Vehicle
UGS: Unmanned Ground System
VS: Value Stream

APPENDIX C. CAPABILITY DEMONSTRATIONS

Separate attachment. For Internal Use Only at this time

APPENDIX D. VALUE STREAM 3 IMPLEMENTATION PLANS

Separate attachment. For Internal Use Only at this time.