Mad Scientist

Robotics, Artificial Intelligence & Autonomy:

Visioning Multi-Domain Warfare in 2030-2050

Technical Report

19 May 2017

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Executive Summary

In March of 2017 the TRADOC G-2 and the Georgia Tech Research Institute (GTRI) cosponsored a Mad Scientist Conference entitled *Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare 2030-2050*. These closely related, interdependent technologies (robotics, artificial Intelligence, and autonomy) will exercise key roles in future military operations, including land operations. They are being aggressively explored and exploited by both the economies and militaries of entities ranging from great power nation-states to "super-empowered individuals." They are at the core of the DoD's "Third Offset Strategy." Although some might project a "Cambrian Explosion" of transformative capabilities and applications, because DoD controls a very small and decreasing portion of the research and development associated with these technologies, there is real potential for a "Cambrian Conundrum" wherein defense planners and strategists confront unanticipated, high order consequences from external factors outside military or even national control.

"Secure our Future" is the Nation's ultimate "mission order" to the Army, so application of the Army philosophy of ***mission command*** – particularly its components of ***understand***, ***visualize***, ***describe***, and ***direct*** – were applied to organize the insights of this Mad Scientist project.

Understand. This Technical Report first endeavors to ***understand the relevant trends for robotics, artificial intelligence and autonomy***. Each of these technology areas is explored to establish their definition and a broad understanding of their baseline "state-of-the art." The Report captures Mad Scientist projections for each technology, together with key projected challenges for their further development, and estimates of their relevance for future military operations. The Report then further reinforces understanding of the relevant trends by describing representative threat developments with respect to these technologies, as well as perhaps the most relevant trend of all: the extraordinary speed, scope and convergence of these technologies.

Visualize. TRADOC has identified five key Future Operating Environment (FOE) characteristics. This Technical Report next undertakes to ***visualize the potential of five potential solution approaches that address the characteristics of the Future Operating Environment.*** The five solution approaches emerged during Mad Scientist discussions and included …

<u>FOE Characteristics</u>

- **Contested in all Domains**
- **Unprecedented Speed**
- **WMD Proliferation**
- **Complex Terrain the Norm**
- **Hybrid Combatants**

… Manned-Unmanned Teaming (MUM-T),
… Asymmetric Awareness & Decision,
… Swarming,
… Intelligent Networks for the Internet of Battle Things,
… Autonomous Sustainment.

This Mad Scientist project conducted a concurrent SciTech Futures Crowd-sourcing wargame to connect disparate thought leaders in an exploration of how robotics, artificial intelligence, and autonomous systems – and related technologies – might transform the world, and the implications of that transformation for the Army. Summary tables of the crowd-sourcing ideas relevant to each solution approach are included in the ***visualize*** section (III), but described in greater detail at Appendix B to this report.

Describe. Although the Army continues to explore the issues of multi-domain warfare, it is already possible to ***describe the competitions of multi-domain warfare*** and how the solution approaches previously visualized can be applied to those competitions

Competitions of Multi-Domain Warfare

- **Finders vs Hiders**
- **Strikers vs Shielders**
- **Range & Lethality vs**
- **Close Engagement & Survivability**
- **Disconnection / Disaggregation / Decentralization vs Connection / Aggregation / Centralization**
- **Offense vs Defense**
- **Planning & Judgement vs Reaction & Autonomy**
- **Escalation vs De-Escalation**
- **Domain vs Domain**
- **Dimension vs Dimension**

Direct. As future competitors leverage the technologies of robotics, artificial intelligence, and autonomy in the competitions of multi-domain warfare, success will accrue to those competitors most successful in the institutional contests – already underway – that will shape the outcomes of the future. The final section of this Technical Report addresses ways the Army can ***direct* the drivers of outcome …**

… Strategy and Policy
… Concepts
… Innovation & Adaptation
… Combinations
… Learning

This Mad Scientist project to *understand*, *visualize*, *describe* and *direct* the dynamic and converging fields of robotics, artificial intelligence and autonomy will not only enable mission command but also help set conditions for future adaptation and operational success in multi-domain warfare.

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I Introduction: Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare 2030-2050

Mad Scientist (MS) is a Training and Doctrine Command G-2 (Intelligence) initiative that explores a series of future Army challenges through an open, public dialogue with a broad range of Joint, interagency and international partners; academia; policy institutions; and the private sector. Mad Scientist events are part of the G-2's continuous study of the future Operational Environment out to 2050, as well as the Army Capabilities Integration Center (ARCIC) Campaign of Learning and 2025 Maneuvers.

In March of 2017 the TRADOC G-2 and the Georgia Tech Research Institute (GTRI) cosponsored a Mad Scientist* Conference entitled *Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare 2030-2050*. These closely related, interdependent technologies (robotics, artificial Intelligence, and autonomy) will exercise key roles in future military operations, including land operations. They are being aggressively explored and exploited by both the economies and militaries of entities ranging from great power nation-states to "super-empowered individuals." They are at the core of the DoD's "Third Offset Strategy."

> **"We are on the cusp of a variety of breakthroughs that will be as profound as the internal combustion engine and machine gun was on combat circa WWI."**
>
> August Cole, Mad Scientist Conference, 7 Mar 2017

Conference participants shared a wide range of views with respect to the current state of these technologies, developmental challenges and areas of future research, and of course their potential applications in both military and non-military endeavors. They were guided by two key questions:

> How can Artificial Intelligence (AI), and autonomy effectively support regional, global, Joint, and Army operations in Multi-Domain Warfare, 2030-2050, as well as those capabilities a potential adversary may employ?
>
> How may AI and robotics change the relationship between humans and warfare; what insights will contribute to a greater understanding of conflict and the character of war in the Future Operating Environment?

This Mad Scientist project addresses technologies that – although already enjoying extensive application in our daily lives – have only traversed a small fraction of their

*** For the remainder of this Technical Report, the term "Mad Scientist" will connote any Mad Scientist conference presenter, participant, or crowd-sourcing exercise contributor for the Mad Scientist Robotics, Artificial Intelligence, and Autonomy project.**

projected growth paths. Accurately assessing those growth paths out to 2050 is daunting indeed. However, effective foresight – the process of thinking about our world and how it might change – is critical to yielding better judgments about how to best prepare for whatever the future may bring.[1] It is the intent of this study to paint a picture of key issues for the Army at the intersection of these emerging technologies and landpower, thereby assisting Army leaders in exploring the key decisions and actions needed to defend the Nation in the Future Operating Environment.

Mad Scientist Conference: Robotics, Artificial Intelligence & Autonomy: Visioning Multi-Domain Warfare 2030-2050

The Mad Scientist Conference was held in co-sponsorship with the Georgia Tech Research Institute (GTRI) in Atlanta, Georgia on 7-8 March 2017. The conference included 18 presentations and one panel of three members. Participants included LTG Kevin Mangum (DGG, TRADOC); MG Robert M. Dyess (Deputy Director, Army Capabilities Integration Center); Dr. Steve Cross, Executive Vice President for Research, Georgia Institute of Technology; Dr. Augustus Fountain, Deputy Chief Scientist (ST) Office of the Deputy Assistant Secretary of the Army (Research & Technology); and Dr. Robert Sadowski, U.S. Army Chief Roboticist, Robotics Senior Research Scientist, and Research, Technology and Integration Director at U.S. Army TARDEC. Conference presentations are listed at Appendix A-3 and are accessible at the following link: https://community.apan.org/wg/tradoc-g2/mad-scientist/p/robotics_ai Notes from speaker presentations and panel discussions are synthesized into this Technical Report.

This Mad Scientist event is the most recent of a series. Others over the last several months have included:

- **Disruptive Technologies.** Co-hosted by Georgetown University, addressed sentient data, internet of sustainable energy, platform mergers, autonomous vs unmanned systems, and the next revolution in computing
- **Human Dimension**. Co-hosted by Army University, explored measuring cognitive potential, man-machine interface, genome sequencing, wearables, continuous diagnostics, and performance enhancers
- **Megacities and Dense Urban Areas**. Co-hosted by Arizona State University, explored the modeling of megacities, population-centric intelligence, invisible geography, hot zone robotics, avatars in the field, and the role of augmented and virtual reality in training for operations in dense urban areas.
- **Strategic Security Environment in 2025 and Beyond.** Co-hosted by Georgetown University, explored the thesis that the direction of global trends shaping the future Operational Environment (2030-2050), and the geopolitical situation that results from it, will fundamentally change the character of warfare.
- **The 2050 Cyber Army**. Co-hosted by the Army Cyber Institute at the United States Military Academy, visualized the Army's Cyber Force in 2050. Although this Mad Scientist project encompassed a wide range of cyber domain topics, its

focus was to better understand what the Army may need to do to build the cyber workforce and develop partnerships in order to address DoD missions in cyberspace in the 2050 time frame.[2]

In addition, the analysts drew on multiple sources relevant to the event topics, including:

- **Joint Concept for Robotics and Autonomous Systems (JCRAS)** (19 October 2016).
- **U.S. Army Robotic and Autonomous Systems Strategy (RAS)** (January 2017).
- **Defense Science Board Summer Study on Autonomy** (June 2016).
- Center for Naval Analyses Andrew Ilachinski Study "**AI, Robots, and Swarms: Issues, Questions, and Recommended Studies**" (January 2017).
- Draft TRADOC Paper: **"The Operational Environment, 2035-2050: The Emerging Character of Warfare.**
- Other references as cited in Appendix E to this report.

Mad Scientist SciTech Crowd-Sourcing Exercise

The SciTech Futures Project is a partnership between the Deputy Assistant Secretary of the Army (Research & Technology) and the USC Institute for Creative Technologies (ICT), one of many US Government efforts aimed at leveraging the collective wisdom and ability of the American public. During the period from 6 to 19 March 2017 it conducted a futures game, sponsored by the Office of the Deputy Assistant Secretary of the Army (Research & Technology) in partnership with the U.S. Army Training and Doctrine Command's (TRADOC) Mad Scientist Initiative. The crowd-sourcing exercise sought to connect disparate thought leaders in exploring how advances in robotics, artificial intelligence, autonomous systems, and related technologies might transform the world - and the implications of that transformation for the Army. Participants leveraged an interactive web site to share their ideas about the future, collaborate with (and challenge) other players, and bid on the most compelling concepts in an online marketplace. The output of the SciTech Futures Crowd-sourcing Exercise is described in more detail at Appendix B.

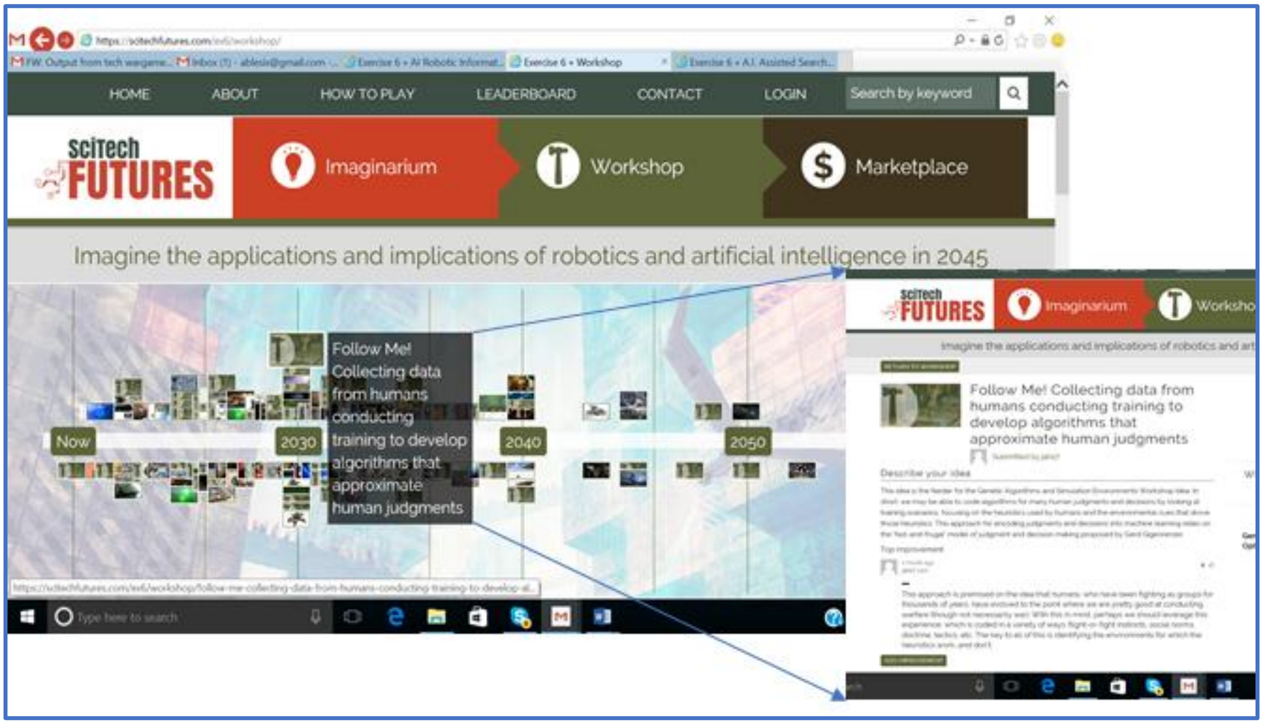

FIG I-1 SciTech Futures Crowd-Sourcing Project: https://scitechfutures.com/ex6/workshop/

Robotics, Artificial Intelligence and Autonomy: "The Coming Cambrian Conundrum"

Although the burgeoning impact of robotics and autonomy has been evident for some time, we are now recognizing the rapidly accelerating emergence of robotics, artificial intelligence, and autonomy in our daily lives. Fossil records demonstrate the sudden appearance – about 542 million years ago -- of complex animals with mineralized skeletal remains. Some describe this "Cambrian Explosion"[3] as the most significant event in Earth's evolutionary history, one that irreversibly changed the biosphere and led to a stunning diversity of body forms and types.[4] Today, many surmise that the impacts of robotics, artificial intelligence and autonomy – together with their derivatives, e.g., "machine learning" -- are about to induce a metaphorical "Cambrian Explosion" of transformative capabilities and applications. For the Department of Defense, however, which controls a minute and ever-shrinking portion of the research in these fields, this Cambrian Explosion is more probably a "*Cambrian Conundrum.*" Defense planners and strategists will confront unanticipated, high-order consequences from external factors principally outside military or even national control.

Many scientists believe that the original Cambrian Explosion's transformative evolutionary developments were triggered by a complex interplay of relatively small environmental changes,[5] and the emergence of better eyes, nervous networks, and the ability to move and interact with the world. A similarly complex interplay is clearly at work across the topics of robotics, artificial intelligence and autonomy as sensors, actuators, and processors get both cheaper and better. The fields of robotics, artificial intelligence and autonomy share a number of enabling technologies, research challenges, and future use cases; it is indeed difficult to discuss one in the absence of the others. "*Autonomous*," for example, is a quality of a *robotic* system; *autonomous* swarms are typically multi-*robotic* configurations. The following statement in a recent Center for Naval Analyses Report demonstrates their seamlessness and interaction: "*In short, **autonomous** systems are inherently, and irreducibly, **artificially intelligent robots***."[6] This Mad Scientist project properly approaches these inter-related topics simultaneously and comprehensively.

> **"While difficult to quantify, the study concluded that autonomy—fueled by advances in artificial intelligence—has attained a 'tipping point' in value. Autonomous capabilities are increasingly ubiquitous and are readily available to allies and adversaries alike. The study therefore concluded that DoD must take immediate action to accelerate its exploitation of autonomy while also preparing to counter autonomy employed by adversaries."**
>
> DSB Summer Study on Autonomy
> June 2016

This Mad Scientist project is also timely: these technologies are at the core of the DoD Third Offset Strategy, and all "Mad Scientists" at the March Conference noted that we are still at the start of the learning curve for both the potential -- and the challenges -- associated with these technologies. The dialogue between technology subject matter experts and military practitioners is both appropriate and necessary, as demonstrated by these two excerpts from Day One Conference discussions:

> "Scientists are great at envisioning technology, but need the assistance of others to understand the opportunities, challenges and pitfalls of it."[7]
>
> Dr. Augustus Fountain, Deputy Chief Scientist (ST) Office of the Deputy Assistant Secretary of the Army (Research & Technology)

> "Technology will outpace experience. 30 years' experience will not help you understand technology that is 6 months old."[8]
>
> Mr. Tom Greco, TRADOC G2

Analysis Approach. "Secure the Future" is the Nation's ultimate "mission order" to the Army, so application of the Army philosophy of *mission command* – particularly its components of *understand*, *visualize*, *describe*, and *direct* – is a useful organizational rubric for the insights of this Mad Scientist project.

The report first endeavors to *understand* the trends, threats and opportunities associated with these technologies, together with the speed, scope and convergence of their technology impacts.

Understand: **Relevant Trends for Robotics, Artificial Intelligence and Autonomy …**

… Autonomy Trends
… Artificial Intelligence Trends
… Robotics Trends
… Threat Trends
… Trend Speed, Scope and Convergence

The report then proceeds to *visualize* how the incorporation of this understanding into five potential solution approaches – dominant and integrating themes throughout the Mad Scientist discussions -- might address the characteristics of the emerging Future Operational Environment.

Visualize: **Solution Approaches that address the Characteristics of the Future Operational Environment**

… Manned-Unmanned Teaming (MUM-T)
… Asymmetric Awareness & Decision
… Swarming
… Intelligent Networks for the Internet of Battle Things
… Autonomous Sustainment

The future will feature the interaction of multiple great powers – similarly equipped with emerging technologies – including robotics, artificial intelligence and autonomy -- and simultaneously trying to address the strategic and operational challenges of the future operational environment. This interaction will drive a fundamental change in the character of warfare, a change characterized as a series of competitions.[9] The next section *describes* the relevance of these solution approaches to those competitions.

Describe: **The Competitions of Multi-Domain Warfare …**

… Finders vs ***Hiders***
… Strikers vs ***Shielders***
… Range & Lethality vs ***Close Engagement & Survivability***
… Disconnection / Disaggregation / Decentralization
vs ***Connection / Aggregation / Centralization***
Offense vs ***Defense***
Planning & Judgement vs ***Reaction & Autonomy***
Escalation vs ***De-Escalation***
Domain vs ***Domain***
Dimension vs ***Dimension***

Finally, the report summarizes how the United States Army might *direct* the drivers that will shape the outcome of these future competitions.

Direct: The Drivers of Outcome …

… Strategy & Policy
… Concepts
… Innovation & Adaptation
… Combinations
… Learning

The actions we take today with respect to these key outcome drivers will shape our future success in leveraging these technologies – and mitigating their risk.

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II *UNDERSTAND*: Relevant Trends for Robotics, Artificial Intelligence and Autonomy

To understand the potential impact of robotics, artificial intelligence, and autonomy we must first review the definitions, baseline, projected trends, challenges and fundamental relevance for each. This review will also address these trends from a threat perspective, assess the rate and scope of technological progress, and illustrate how these technologies interact and converge.

> ***Understand:* Relevant Trends for Robotics, Artificial Intelligence and Autonomy …**
> **… Autonomy Trends**
> **… Artificial Intelligence Trends**
> **… Robotics Trends**
> **… Threat Trends**
> **… Trend Speed, Scope and Convergence**

Autonomy Trends

Autonomy Definition. The Joint Concept for Robotics and Autonomous Systems defines autonomy as follows:

> "… the level of independence that humans grant a system to execute a given task. It is the condition or quality of being self-governing to achieve an assigned task based on the system's own situational awareness (integrated sensing, perceiving, analyzing), planning and decision-making. Autonomy refers to a spectrum of automation in which independent decision-making can be tailored for a specific mission, level of risk, and degree of human-machine teaming."[10]

The phrase "spectrum of automation" alludes to the fact that there are different **degrees to autonomy,** identified by Mad Scientists as:[11]

> **Fully Autonomous:** "Human Out of the Loop": no ability for human to intervene in real time.
> **Supervised Autonomous: "**Human on the Loop": humans can intervene in real time.
> **Semi-Autonomous:** "Human in the Loop": machines wait for human input before taking action.
> **Non-Autonomous (Remote Control)**: human in the loop via remote controls; no autonomy in system.[12]

Mad Scientists noted that there are also three unique dimensions to the idea of autonomy and that these dimensions constitute fundamentally distinct concepts that are problematically applied to the same word.[13] First, there is the autonomy dimension of the human-machine command and control relationship – described above in the *degrees of autonomy*. Next, there is a dimension that addresses the innate sophistication of the machine, a sophistication manifested in a range that includes:

Automatic: Simple, threshold based
Automated: Complex, Rule-Based
Autonomous: Self-learning / evolving
Intelligent: Human level cognition of a problem

As sophistication increases, autonomous systems are paradoxically both more capable but also less explainable. The final, and most critical dimension to the idea of autonomy is the complexity of the task performed. In the words of one Mad Scientist, "*Both a landmine and a toaster are automatic systems. A system is autonomous with respect to what task*?"[14] No system is "fully autonomous" with respect to all tasks.

Autonomy Baseline. Mad Scientists agreed that autonomy is already here in many aspects of our daily life, citing numerous examples in the fields of agriculture, environmental monitoring, utilities management, and many others.[15] Even news coverage applies autonomy:

> "Social media bots, like it or not, shape the information environment. During the 2016 US presidential campaign debates and on election day, the Oxford Internet Institute estimates that 17 – 27% of all the tweet traffic was generated by "highly automated accounts" or bots."
>
> Mad Scientist SciTech Crowd-sourcing Exercise[16]

Autonomy is also already evident on the battlefield. At least 30 countries have defensive, human-supervised autonomous weapons such as the Aegis and Patriot.[17] The AH-64D Apache attack helicopter's Longbow fire control radar already "automatically searches, detects, locates, classifies, and prioritizes multiple moving and stationary targets on land, air, and water in all weather and battlefield conditions."[18]

Some "fully autonomous" weapon systems are also emerging. The Israeli Harpy drone (anti-radiation loitering munition) has been sold to India, Turkey, South Korea, and China. China reportedly has reverse-engineered their own variant. The U.S. has experimented with similar systems in the Tacit Rainbow and the Low Cost Autonomous Attack System (LOCAAS) programs. Although both these projects have been cancelled, they illustrate our willingness to explore high levels of autonomy.[19]

Autonomy Projections. Mad Scientists expect autonomy to evolve from solutions that are reactive, single platform, point solutions under minimal human control to solutions that are flexible, multi-modal, and goal-oriented featuring trusted *man-machine collaboration*, *distributed autonomy* and *continuous learning*.[20]

Collaborative Autonomy will be learning and adaptation to perform a new task based on mere demonstration of the task by end-users (factory workers, service workers, consumers, Soldiers) to teach the robot what to do.[21]

Distributed Autonomy will be dynamic team formation from heterogeneous platforms to include coordination in settings with limited or impaired communication and the emergence of new tactics and strategies enabled by multiagent capabilities.[22]

Continuous Learning will be a continuous, incremental evolution and expansion of capabilities, to include the incorporation of high-level guidance (such as human instruction, changes in laws / ROEs / constraints) and “Transfer Learning:” bootstrapping from knowledge learned on other tasks, in other domains, and by different platforms. “Learning to Learn” will exploit opportunities to learn based on self-awareness of current limitations.[23]

Projections for the transportation industry are particularly well-developed, as illustrated by the Wall Street Journal article at FIG II-1.[24] Mad Scientists imagined ubiquitous autonomous vehicles able to drive, talk, entertain, and even self-maintain.[25]

Autonomous vehicles could serve Amazon in its warehouses, but also someday on highways.

Driving Itself Toward A Transport Future

◆ **Trucks:** Amazon has a fleet of more than 4,000 dedicated trailers for hauling cargo between its growing number of warehouses. The mode is considered ripe for driverless technology because of the regularity of truck routes.

◆ **Drones:** Amazon in 2013 announced a drone program, which in December made its first customer delivery: a package containing popcorn and a Fire TV video-streaming device to a U.K. customer several miles away. Drone deliveries might make most sense for rural areas—assuming regulations adjust to allow them.

◆ **Airplanes:** Amazon has said it is leasing 40 aircraft and building its first air-cargo hub in Kentucky. Planes already have autopilot, but some experts envision self-aware aircraft that require only human assistance.

◆ **Ocean Freight:** Amazon has begun handling shipment of goods to its U.S. warehouses from Chinese merchants selling on its site, taking over the role from freight-transportation companies. Ship designers, their operators and regulators are gearing up for a future in which cargo vessels sail the oceans with minimal or even no crew.

◆ **Cars:** Amazon has a network of citizen drivers making deliveries as part of its Flex program. It has also experimented with direct-to-car delivery in tests with auto makers BMW and Audi. Self-driving vehicles could play a role in package delivery, while high-tech cars in general facilitate Amazon’s payment and services push.

—Laura Stevens

FIG II-1

Autonomy Challenges. Mad Scientists acknowledged that the future projections for the field of autonomy simultaneously pose challenges:

Goal-Oriented Autonomy. Decision and adaptation like a human will struggle to include the incorporation of ethics and morality into decision-making.[26]

Trusted Collaboration. The challenge of trust between man and machine is a dominant theme of both the Mad Scientist observations as well as other writings on this topic. Machine’s must properly perceive human goals and preserve their autonomous system integrity while achieving joint man-machine goals in a manner explainable to – and completely trusted by -- the human component.[27]

Distributed Systems. Rethinking the execution of tasks using multiple, distributed agents while preserving command-level understanding and decision adds an additional layer of complexity to the already challenging task of designing and building autonomous systems.[28]

Transfer Learning: Learning by inference from similar tasks must address the challenges of seamless adaptation to changing contexts and environments, including the contextual inference of missing data and physical attributes.[29]

High Reliability Theory. "Normal Accident Theory" holds that, no matter what organizations do, accidents are inevitable in complex, tightly–coupled systems. "High Reliability Theory" asserts that organizations can contribute significantly to the prevention of accidents.[30] Because of the significant complexity and "tight–coupling" of future autonomous systems, there is an obvious challenge in the application of high reliability theory to emerging technologies that are not yet well comprehended.[31]

Relevance of Autonomous Systems. For the foreseeable future, no autonomous system will have the breadth, robustness and flexibility of human cognition, but autonomous systems offer the potential for speed, mass, and penetration capabilities in future lethal, high threat environments – while minimizing risks to Soldiers.

Artificial Intelligence (AI) Trends

AI Definition. Richard Potember of the Mitre Corporation offers the following definition for AI. AI is …

> "… conventionally, if loosely, defined as intelligence exhibited by machines. Operationally, it can be defined as those areas of R&D practiced by computer scientists who identify with one or more of the following academic sub-disciplines: Computer Vision, Natural Language Processing (NLP), Robotics (including Human-Robot Interactions), Search and Planning, Multi-agent Systems, Social Media Analysis (including Crowdsourcing), and Knowledge Representation and Reasoning (KRR). The field of Machine Learning (ML) is a foundational basis for AI"[32]

Mad Scientists cited numerous key components to the field of AI, including:[33]

Automated Perception using a range of modalities: v*ision, sonar, lidar, haptics;*
Robotic Action such as *locomotion* and *manipulation;*
Deep Reasoning: *planning, goal-oriented behavior, projection;*
Language Technologies: *language, speech, dialog, social nets;*
Big Data: *storage*, *processing*, *analytics* and *inference;*[34]
Machine Learning to include a*daptation, reflection, knowledge acquisition.*

Mad Scientists treated AI and Cognitive Computing as interchangeable terms.[35]

AI Baseline. Physical robots are merely one type of AI entity. Others include cyber agents, decision aids, the internet of things, and increasingly: munitions and networks.[36] Mad Scientists described AI as a key component of the "Fourth Industrial Revolution." (FIG II-2). Currently there is a $153B market for AI-enabled technology -- with an estimated annual creative *disruption impact* of $14-33 trillion.[37]

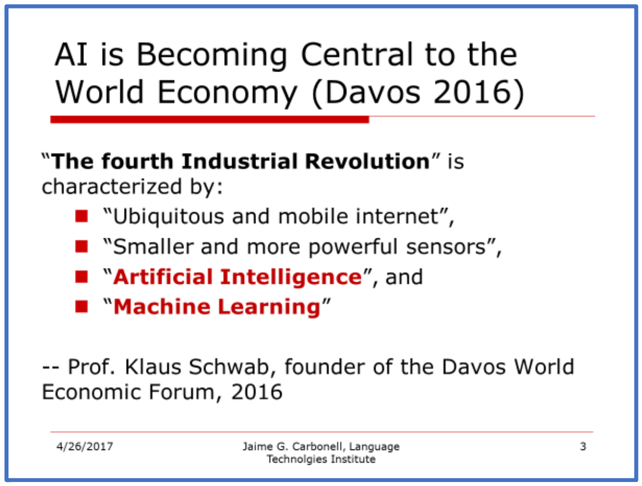

FIG II-2: Carbonell Presentation Mad Scientist Conference Day One

AI technology is currently advancing at breakneck speeds, with recent interesting accomplishments in a broad range of areas to include:[38]

- Unsupervised learning, generative modeling;
- "Deep Learning" exploiting Deep Neural Networks (DNNs) to facilitate automated interpretation of vision and speech (Neural Language Processing;
- Reinforcement learning for decision-making and robotics "training";
- Multi-task networks, transfer learning;
- Use of simulated data;
- Large-margin methods (SVM) for entity classification;
- Graphical models.

> **"Last week, the biggest investment firm in the world laid off a bunch of its top stock pickers and replaced them with computer programs. This is happening all over Wall Street. Firms are moving away from having humans decide what stocks to buy and sell and towards having humans program computers and then letting the computers decide what to buy and sell. Computers are cheaper than humans. They are more disciplined. They can think about more things at once. Like, they can scan Facebook for trends, they can count the number of cars in Wal-Mart parking lots, and then use all that to figure out what stock to buy and sell and do it automatically. This is the way the world is going. This is what the stock market is becoming."**
>
> NPR Planet Money Podcast: "BOTUS"
> Episode 763, April 7, 2017

AI Projections. AI touches virtually every area of computer science and in the words of one Mad Scientist: *"Everything that we formerly electrified, we will now 'cognitize':*[39]*no more "dumb data*."[40] Big parts of the global economy will be run by AI, with widespread disruption to the electrical infrastructure, healthcare, additive manufacturing, transportation sector, supply chain management, and farming. This disruption is not confined to “blue-collar” labor markets, it is also advancing in “white-collar” fields such as financing and equity trading.[41]

Autonomy and learning are already pervasive in sensing, but will increasingly take over decision-making as well.[42] Mad Scientists project future AI capable of reflection, curiosity and teamwork.[43] AI may extend language translation capabilities, perhaps even to other species.[44] Individuals may eventually exercise ubiquitous personalized agents (“COGs”), and artificial intelligence will extend the boundary of “self.” Human judgment will remain essential, but the line of decision allocation between humans and machines will be shifting in coming years.[45]

AI Challenges.

Maturity. Current AI systems are frequently “brittle”: narrow applications that can generate “very dumb” results when operated outside of narrow constraints. They are also vulnerable to spoofing.[46]

Big Data and Active Learning. *Big Data* is the fuel that drives deep learning, and is “big” not only from a quantity perspective. It is also “big” from the perspective of a high level of complexity (potential relations among entries) and dimensionality (attributes per entry).[47]

Welcome to the Big Data Revolution. Data now streams from daily life: from phones and credit cards to computers and sensor-equipped buildings. In 2013, IBM released some numbers pointing to the fact that 90% of ALL of the world’s data has been produced in the past TWO years (and we’re confident to assume that it has since grown even higher.) The exponential growth of online data can largely be attributed to the advent and maturing of social media, analytics platforms and the ongoing move of mobile tech from analog to digital technologies. “There is a big data revolution,” says Weatherhead University Professor Gary King. But it is not the quantity of data that is revolutionary. “The big data revolution is that now we can do something with the data.”

Bedrock Data Web Site

Paradoxically, Big Data is often associated with “Knowledge Sparsity” because only a tiny fraction of the vast amounts of Big Data is effectively labeled. Less than .01% of all galaxies in the Sloan Sky Survey have consensus labels; less than .0001% of all web pages have topic labels. Less than .0001% of all financial transactions are investigated and labeled as fraudulent / non-fraudulent. Mad Scientists described “Active Learning” as a potential technique to address knowledge sparsity by teaming AI capabilities with external assistance that selects the portions of Big Data with maximum potential impact on learning.[48] [49]

DoD Problem Set. Mad Scientists acknowledge that there are unique characteristics of the DoD space including a lack of data, more complex sensing phenomena, the requirement for multi-source fusion and distributed sensing, and the high consequences of military decision-making. Current DoD acquisition processes, moreover, cannot keep pace with the transformative rate of change in the AI field.[50]

Explainability. The complexity of AI systems is a double-edged sword, wherein enhanced capability is paradoxically paired with decreased explainability.[51] The nature of machine learning – particularly machine learning based on deep neural networks -- is

> **"Deep learning, which came of age in the past two years thanks to faster processor architectures, uses multiple layers of neural networks to intensify the training—patterns of patterns. As you go deeper down the stack of neural networks, signals emerge for patterns that humans don't consciously sense ... As professor Tommi Jaakkola explained to the MIT Technology Review, once a neural network becomes extremely large, "it has thousands of units per layer and maybe hundreds of layers, then it becomes quite un-understandable." This can cause some trouble."**
>
> Andy Kessler, The Wall Street Journal: "Bad Intelligence Behind the Wheel: Machine learning will bring amazing innovations—and dangers and lawsuits" (23 April 2017)

such that we often don't understand exactly how it works.[52] The way such systems are currently designed, moreover, such understanding is not possible. This is at the heart of "trust" issues between the man-machine team.[53]

Therefore several Mad Scientists projected a future dichotomy between "Safe AI" and "AI in the Wild." Safe AI might come with guarantees, constraints, transparency, and a "universal 'undo' button." "Wild AI" would approach full autonomy with unrestricted adaptability, curiosity, and exploration – and no ironclad guarantees.[54] Artificial General Intelligence (AGI) might fit into this latter category and be a potential game-changer of existential proportion.

Relevance of AI Systems. AI can both reinforce and mitigate the accelerating scope and pace of warfare, integrating decision making across domains and enabling sub-millisecond decisions.[55] Expertise is perishable and doesn't scale: enhanced decision making AI can restore balance to the OODA loop; complementing past investments in

> **"Human personnel alone cannot adequately respond to the cyber threats facing the US military today, Deputy Secretary of Defense Robert Work told Congress Wednesday. "This is an area where we will not be able to solve it with people," he told the Senate defense appropriations subcommittee … "We're putting together the structure to watch our networks …" Work said. But he emphasized the need to develop "artificial intelligence and learning machines to push back" against cyber threats because "there just are not enough people to defend our networks against all of the attack surfaces that we have."**
>
> Wilson Brissett, Air Force Magazine Daily Report 4 May 2017

"Observe" and "Assessment" with improved focus on "Orientation" and" Deciding."[56] AI "Battle Buddies" may enhance a Soldier's personal Situational Awareness through proactive intelligence gathering and analysis. [57] [58] Training can be enhanced through virtual / augmented realties.

AI may facilitate the visualization of combat effects in the cyber domain through augmented reality. Some challenges, particularly data challenges, have such magnitude that adequate numbers of people can simply not be mustered to address them.[59] AI will be essential in such instances.

Robotic Trends

Robotics Definition. The Joint Staff Concept for Robotics and Autonomous Systems (JCRAS) defines robotics as …

> **"** … powered machines capable of executing a set of actions by direct human control, computer control, or a combination of both. They are comprised minimally of a platform, software, and a power source."[60]

The JCRAS goes on to note that "Robotic and Autonomous Systems (RAS) is an accepted term in academia and the science and technology (S&T) community; it highlights the physical (robotic) and cognitive (autonomous) aspects of these systems. For purposes of the JCRAS concept, RAS is a framework to describe systems with a robotic element, an autonomous element, or more commonly, both. As technology advances, there will be more robotic systems with autonomous capabilities as well as non-robotic autonomous systems."[61]

Robotics, particularly advanced robotics, typically leverage both AI and autonomy and are the physical manifestation by which we experience these trends in our daily lives.

There is a taxonomy for Robotic Systems that includes the following ranges of control: [62]

- **Remote Control**. A mode of operation wherein the human operator, without benefit of video or other sensory feedback, directly controls the actuators of a UMS on a continuous basis, from off the vehicle and via a tethered or radio linked control device using visual line of sight cues. In this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the user.[63]
- **Augmented Teleoperation**. A mode of operation wherein the human operator leverages video or other sensory feedback to directly control the actuators of a UMS on a continuous basis.[64]
- **Semi-Autonomy**. The condition or quality of being partially self-governing to achieve an assigned mission based on the system's pre-planned situational awareness (integrated sensing, perceiving, analyzing) planning and decision-making. This independence is a point on a spectrum that can be tailored to the specific mission, level of acceptable risk, and degree of human-machine teaming.[65]
- **Full Autonomy**. Full independence that humans grant a system to execute a given task in a given environment.[66]

Robotics Baseline. DOD has already experienced an **"**Accidental Robot Evolution**,"** with thousands of air and ground robots developed, deployed and employed in Iraq and Afghanistan.[67] Up to now the default perception has been robots as caged "stupid machines" to do routine and dangerous work. Increasingly, however, robots are coming "out of the cages" and migrating into our daily lives.[68]

Robotics Projection.[69] Mad Scientists projected a future that features ever more advanced human-robot collaboration, a collaboration that in turn will accelerate the development of improved robotics through rapid machine learning, adaptive controls, rapid algorithm development, and custom motion control systems.[70] Novel mechanisms and high performance actuators will emerge as new construction paradigms are merging component design to generate compact multi-function systems that are both highly capable and energy efficient.[71] Mad Scientists projected that human-robotic system interaction will include conversational assistants, intent and emotion recognition, augmented reality, self-aware explainable systems, and multi-modal communications.[72]

> **"According to a recent study by research firm Global Industry Analysts, annual spending worldwide on military robotics will rise from $5.6 billion in 2012 to $7.5 billion by 2018. This growth will include everything from bomb-clearing robots to pack robots that can carry gear overland, unmanned underwater vehicles that can surveil the seas, and UAVs, more commonly known as drones. The Teal Group, a U.S. consulting company, speculated in 2013 that global spending on drones — military and civilian — could cumulatively reach $89 billion over the next 10 years."**
>
> Michael Horowitz, Foreign Policy Magazine, 2014
> The Looming Robotics Gap

Robotics are already beginning to transform production capabilities; this process will accelerate as collaborative robotic autonomy enables robotic learning and adaptation by simple demonstration. Although a typical current production line today features only 1 product per line, changeover cycles of 2 weeks, and a part cycle time of 6 seconds; future robotics-enabled production will be a flexible configuration of 10+ products per line, nearly zero time required for changeover, 6 second cycle times and sub-millimeter precision.[73]

One Mad Scientist asserted a future for "Self-Organizing Matter" in the 2030-2050 timeframe, a future where almost every object will have some degree of self-assembly and self-configuring capability,[74] As the migration of robotics into our everyday experiences advances, robotic appearances may change. It is not likely that they will evolve to be ever more human in appearance, because humanoid shapes are sub-optimal for many jobs or tasks. Robotic forms can be tailored to the task rather than the other way around. Future robotics will be less immediately recognizable as "robots" and our *human* terrain will morph to accommodate optimal *robotic* physical configurations.[75]

Robotics Challenges.

One to Many Control. Current robotic controls must extend from singular entities to control of multi-robot systems: *formations* vice *individual* interaction. How do address individual control of truly large robotic teams?[76]

Additive Metallic Manufacturing. To date the application of robotic 3D additive manufacturing has focused on the use of resins and polymers to inexpensively generate shapes and applications amenable to those materials. 3D printing of metal parts requires relatively large and expensive machines, very high-powered lasers and expensive technicians, although there are efforts underway to extend the desktop 3D printing approach to metal manufacturing. Solving the 3D metallic manufacturing problem would truly revolutionize manufacturing.[77]

> **"Approximately 32,000 people die each year in auto accidents. If autonomous vehicles were able to cut that down to 20,000, people would be uncomfortable with the idea of deaths resulting from robots…even at only 10,000 deaths it would not be acceptable even though humans cause many more."**
>
> Dr Magnus Egerstedt
> Mad Scientist Presentation, March 2017

High Expectations. Humans will expect high reliability performance from robotic systems: 'death by robotic accident' will be unacceptable, even for instances where more frequent death by human accident is already tolerated for non-robotic systems.[78]

Cognitive Trades. Robotics generate risk reduction and performance enhancements, but trade the best cognitive computer available: the human brain. This trade can be mitigated by "Centaur Warfighting": human-machine teaming that is not only possible but in many cases preferable.[79] Hybrid human-machine cognitive architectures may be able to leverage the precision and reliability of automation without sacrificing the robustness and flexibility of human intelligence.[80]

Destructive Disruption. One should also note the potential disruptive impact of the robotics revolution, not only with respect to warfare but across the entire global economy, particularly through the displacement of a substantial portion of the labor force. The debate on the extent of that disruption – and whether this disruption is beneficial or detrimental – remains undecided. Some have argued that technology has always created more jobs than it has destroyed. They claim "Robots Will Save the Economy" and cite robotics as necessary for further improvements in productivity across a wide range of labor-intensive tasks.[81] Others believe that the extent of the robotics revolution is so fast and so radical that it will exceed the capacity of the labor force to adapt.[82] It is safe to assert that the robotics revolution will challenge even the most adaptive societies and that those less adaptive may experience significant destabilization.

Relevance of Robotic Systems. Robotic systems mitigate the risk of combat while providing significant performance advantages such as speed, efficiency, and resilience. Robotic sensor applications, for example, might include precision sensor positioning, sensor placement in adverse environments, and multiple, distributed sensors and platforms.[83] Just as robotics may advance manufacturing to the next "industrial renaissance,"[84] they may also enable transformative efficiencies in the transportation and sustainment of land forces.

Threat Trends

The United States is not the only competitor researching and fielding these technologies. The threat perspective must account for nation states, violent non-state actors (VNSAs), and – according to Mad Scientists – potentially the technologies themselves.

Nation States

Russia. Russians view these robotics, artificial intelligence and autonomy technologies as key to a next "Kondratiev Sixth Wave."[85] They have fielded a system called the URAN-9, an unmanned combat vehicle with a 30 mm gun and anti-tank guided missiles. At 9 tons it is readily air-liftable and demonstrates the advantageous robotic trade space between reduced (or eliminated) human survivability requirements and system size, weight and power (SWAP).[86]

FIG II-3: Sadowski Presentation
Mad Scientist Conference Day One

China. China is also investing heavily in advanced research,[87] through both overseas purchases as well as impressive domestic research investments, particularly in the field of quantum computing – a potential breakthrough enabler for artificial intelligence. China has fielded armed UAVs and also developed unmanned ground vehicles, such as the Snow Leopard 10, which can detect and detonate bombs. According to the Defense Science Board, "every major manufacturer for the Chinese military has a research center devoted to unmanned systems."[88]

> **"Another player is China, long the leader in small consumer drones. Chinese company DJI alone has around 70% of the global market, and now the Chinese military is seeing what they can do with this new technology. At an aerospace exhibition in December, state-owned China Electronics Technology Group Corporation (CETC) displayed a video of nearly 70 drones flying together. The drones flew in formation and collaborated in an intelligence-gathering mission. Those drones could also cooperate in a 'saturation attack' on an enemy missile launcher. They all dive in to attack simultaneously from different directions – far too many at once for the defenders to stop."**
>
> By David Hambling, BBC (UK), April 27, 2017
> The Next Era of Drones will be Defined by 'Swarms' (27 Apr 2017)

> **"Chinese internet firm Baidu Inc has agreed to acquire U.S. computer vision firm xPerception for an undisclosed amount to support their renewed efforts in artificial intelligence… xPerception, which makes vision perception software and hardware with applications in robotics and virtual reality, will continue to develop their core technology under Baidu's research unit, the Chinese firm said in a statement on Thursday.**
>
> **"The acquisition of xPerception is the latest in a recent series of notable investments aimed at strengthening Baidu's position as a global leader in AI," it said. Baidu is targeting foreign personnel and technology as part of a wider drive to refocus company resources on developing artificial intelligence capabilities."**
>
> Technology News, Reuters: 13 April 2017

Violent Non-State Actors (VNSAs). Mad Scientists assessed that as these technologies are increasingly embedded into our human infrastructure, a wide range of VNSA and super-empowered individual threats become very feasible.[89] Terrorists are traditionally conservative and imitative with respect to technology but today increasingly look to robotics, artificial intelligence, and autonomy for multiple reasons.[90] Some groups have an ideological orientation towards technology – either to leverage it or undermine it. Many groups find existing methods insufficient to achieve their aims; these technologies "lengthen the levers of asymmetry." VNSAs confront a need to circumvent protective measures and make it more difficult to apprehend / kill VNSA operatives. Use of these technologies reinforces the psychological impact of terrorism, and also enhances the competitive status of the employer. As these technologies permeate our infrastructure, a very high level of exploitable resources will be available; e.g. driverless cars, and the costs associated with adopting new technology are often low. The marginal cost to proliferate an AI capability through software replication, for example, is close to zero.[91]

Some VNSAs are taking on complex engineering tasks and will train, hire or kidnap the human capital they need to staff their R&D entities.[92] Syria has emerged as an innovation incubator that features VNSA use of drones, teleoperated rifles, remote gun turrets and chemical weapons. ISIS recruits for engineers.[93] Generally far less burdened by acquisition bureaucracies, some adversaries are closing the technology gap faster than we are widening it.[94]

Cyber and Dark Networks. Cyber networks are the "Battlespace" of "Cyber Agents:" software code that incorporates automation and artificial intelligence to act in the cyber domain.[95] VNSAs frequently leverage Dark Networks, a component of the cyberspace that is integral to the threat development of these technologies. Global Dark Networks are mature, largely self-organizing and include competing supply chains that circumvent regulatory controls.[96]

"Algorithmic Warfare." Mad Scientists observed that conflict is extending below the platform level, below the platform component level, and even below the electronic chipset level as logic solutions compete "algorithm vs algorithm." Algorithms are the subtle 'secret sauce' that powers these technologies, and underscores the need for robust STEM programs to ensure the appropriate intellectual talent is available to devise the most innovative, effective and efficient code. Deputy Defense Secretary Bob Work has very recently established an "Algorithmic Warfare Task Force" to accelerate the integration of big data and machine learning into DoD operations.[97] [98]

Rogue Technology. Mad Scientists noted a high probability that the future will include the threat of rogue technology that will be agile, high velocity, complex, networked, and "pop-up" in unexpected, non-linear events.[99] They further posited that future adversaries may be both human and AI.[100] Although hotly debated, there are a number of pathways by which fully sentient artificial consciousness (strong AI) could be achieved in the 2030-2050 timeframe.[101] Early detection and control might be the only available avenues to preclude existential rogue AI threats.

Technology Trends: Speed, Scope and Convergence

Consequential in their own right, particularly in the hands of adversaries, the impact of these technology trends is exacerbated by their collective speed, scope and convergence.

Speed. Some Mad Scientists posit that the rate of progress in these technologies will be "faster than Moore's law."[102] As our adversaries close the technology gap and potentially overtake us in

The Need for Speed: "…the study concluded that autonomy will deliver substantial operational value across an increasingly diverse array of DoD missions, but the DoD must move more rapidly to realize this value. Allies and adversaries alike also have access to rapid technological advances occurring globally. In short, speed matters—in two distinct dimensions. First, autonomy can increase decision speed, enabling the U.S. to act inside an adversary's operations cycle. Secondly, ongoing rapid transition of autonomy into warfighting capabilities is vital if the U.S. is to sustain military advantage."

DSB Report on Autonomy, 2016

select areas, there is clearly a "need for speed" as cited in the DSB Report on Autonomy.[103] The speed of actions and decisions will need to increase at a much higher pace over time.[104]

Scope. It may be necessary to increase not only the pace but also the scope of these decisions if these technologies generate the "extreme future" characterized by Mad Scientist Dr. Ed Canton as "*hacking life*" / "*hacking matter*" / "*hacking the planet*." In short, no aspect of our current existence will remain untouched. [105] Robotics, artificial intelligence, and autonomy – far from narrow topics – are closely linked to a broad range of enabling / adjunct technologies identified by Mad Scientists to include:

- Computer Science, particularly algorithm design and software engineering
- Man-Machine Interface, to include Language / Speech and Vision
- Sensing Technologies
- Power and Energy
- Mobility and Manipulation
- Material Science to include revolutionary new materials[106]
- Quantum Science
- Communications
- 3D (Additive) Manufacturing
- Positioning, Navigation and Timing beyond GPS
- Cyber

Science and Technological Convergence. Although 90% of the technology development will occur in the very fragmented, uncontrolled private sector,[107] there is still a need to view robotics, artificial intelligence and autonomy as a holistic, seamless system. Technology convergence was a recurring theme among Mad Scientists. They projected that we will alter our fundamental thinking about science because of the "exponential convergence" of key technologies including …[108]

… Nanoscience and nanotechnology
… Biotechnology and Biomedicine
… Information Technology
… Cognitive Science and Neuroscience
… Quantum Science

This convergence of technologies is already leading to revolutionary achievements with respect to sensing, data acquisition and retrieval, and computer processing hardware. These advances in turn enable machine learning to include reinforcement learning and artificial intelligence. They also facilitate advances in hardware and materials, 3D printing, robotics and autonomy, and open-sourced and reproducible computer code. Exponential convergence will generate "extremely complex futures" that include capability "building blocks" that afford strategic advantage to those who recognize and leverage them.[109]

Co-evolution. Clearly humans and these technologies are destined to co-evolve. Humans will be augmented in many ways: physically, via exoskeletons, perceptionally, via direct sensor inputs, genetically, via AI-enabled gene-editing technologies such as CRISPR, and cognitively via AI "COGs" and "Cogni-ceuticals."[110] Human reality will be a "blended" one in which physical and digital environments, media and interactions are woven together in a seamless integration of the virtual and the physical.[111] [112] As daunting – and worrisome – as these technological developments might seem, there will be an equally daunting challenge in the co-evolution between man and machine: the co-evolution of trust.

Brave New World?

"Billionaire entrepreneur Elon Musk on Thursday confirmed plans for his newest company, called Neuralink Corp. … a startup that aims to merge computers with brains so humans could one day engage in "consensual telepathy". …Neuralink aims to implant tiny brain electrodes that first would be used to fight brain conditions but later help humanity avoid subjugation at the hands of intelligent machines.

Mr. Musk has spoken out about the dangers of being left behind by the advancements of artificial intelligence. "The pace of progress in this direction matters a lot … We don't want to develop digital superintelligence too far before being able to do a merged brain-computer interface."

Mr. Musk's comments come a day after Facebook Inc. announced similar ambitions. "What if you could type directly from your brain?" asked Regina Dugan, who runs Facebook's secretive hardware division Building 8, during a keynote address at the company's F8 developer conference Wednesday. Facebook job postings show the company is looking to hire engineers to work on "brain-computer interface" technology.

Rolfe Winkler, Wall Street Journal
20 April 2017

Trusted man-machine collaboration will require validation of system competence, a process that will take our legacy test and verification procedures far beyond their current limitations. Humans will expect autonomy to be nonetheless "directable," and will expect autonomous systems to be able to explain the logic for their behavior, regardless of the complexity of the deep neural networks that motivate it. These technologies in turn must be able to adapt to user abilities and preferences, and attain some level of human awareness (e.g., cognitive, physiological, emotional state, situational knowledge, intent recognition).[113]

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III *VISUALIZE*: Solution Approaches that address the Characteristics of the Future Operational Environment

Five potential solution approaches emerged as dominant themes throughout the Conference as Mad Scientists discussed how the technologies of robotics, artificial intelligence and autonomy might address the characteristics of the emerging Future Operational Environment (FOE).

Visualize: Solution Approaches to the Emerging Operational Environment

- **… Manned-Unmanned Teaming (MUM-T)**
- **… Asymmetric Awareness & Decision**
- **… Swarming**
- **… Intelligent Networks for the Internet of Battle Things**
- **… Autonomous Sustainment**

Overview: the Characteristics of the Future Operational Environment

The characteristics of the emerging operational environment can be summarized as follows: [114]

Contested in all Domains. Competitors contest all domains, neither accepting nor assuming sanctuary in any part of the land, air, sea, space, and cyberspace. Complex and lethal engagements permeate the battlespace from the deep seabed to geosynchronous orbit. Land, sea, air and space platforms encounter long range precision munitions, highly accurate guided missiles, lasers and microwave weaponry, stealthy and agile swarming robotic systems, and continuous probing of cyber systems. This contest extends to both control and use of the entire electromagnetic spectrum. Domain competition includes ongoing measures to degrade the effectiveness of AI, battle management, and firmware targeted even down to chipset level in any platform or weapon. This lethal exchange is not only characteristic within each domain, but also between them: the range and precision of sensors and weapons allows routine cross-domain engagement.

Unprecedented Speed. The momentum of human interaction unfolds at unprecedented speed. The speed of many engagements – laser systems, hypersonic weapons, cyber-attacks -- far exceeds the reaction ability of normal humans. Significant battle processes are highly automated and supervised by cognitively augmented humans and man-machine “centaur” teams. Modern manufacturing accelerates the rate of capability development so that by 2050, forces must have a very dynamic capacity to adapt and integrate capabilities, both materially and cognitively.

WMD Proliferation. Military planning must account for nuclear weapons, fissile materials, and chemical weapons, as well as novel and very dangerous biological weapons derived from revolutionary advances in commercial biotechnology. WMD proliferation is destabilizing as WMD “haves” coerce the “have-nots.” Several states have not only secured WMD forces for rudimentary deterrent effect, but have achieved credible and diverse retaliatory strike capabilities. Daunting in its own right, nuclear proliferation complicates conventional operations: dual-purpose platforms and command links pose serious escalation risk and complicate engagement decisions.

Complex Terrain the Norm. Urban environments sprawl horizontally, vertically and socially, posing both challenges and opportunities. Land forces must operate in these areas for sustained periods – and now view such operations as the default expectation, vice the exception. Some resort to the 'control by devastation' urban techniques of previous decades; others seek very precise, low collateral damage combat. Cities have massive resources that can be directed for war, such as computer controlled machine shops, 3D manufacturing facilities, small scale chip foundries, and a dense array of consumer electronics, wireless nodes, and commercial and private fiber networks. There is a premium on the ability to separate combatants from non-combatants in dense urban environments; forces employ sophisticated human and cultural mapping, biometric assessment and tagging at long range, and the ability to understand and selectively control city services and utilities.

Hybrid Combatants. Competitors combine regular and irregular forces, paramilitaries, terrorists, criminals and others to threaten strikes, raids, insurrection, information operations or outright invasion when possible or advantageous. States integrate manipulation of economic, financial, and political institutions to coerce, destabilize and unbalance target states and societies around the world. These hybrid operations are even more successful when they are augmented by conventional and WMD- escalation strategies that deter or dissuade targets -- and their would-be partners.

Solution Approaches and the SciTech Crowdsourcing Exercise

During the conference, participants described multiple solution approaches to address these future Operational Environment characteristics. The SciTech Crowdsourcing exercise further augmented the "future menu" of possible solutions. Throughout the two week event, SciTech Futures Crowdsourcing participants developed, refined, and prioritized nearly 140 distinct ideas related to robotics, AI, and autonomy. These are cataloged at Appendix B: SciTech Crowd-Sourcing Insights of this report, as well as a description of the methodology and outcomes of this event.

Each of the ideas developed and prioritized during the SciTech Crowdsourcing exercise were aligned to the five solution approaches in this section (MUM-T, Asymmetric Awareness and Decision, Swarming, Intelligent Networks for the Internet Battle of Things, and Autonomous Sustainment), as well as the year the idea could be expected to be achieved given the pace of technological change or other constraints, and are found in the relevant sections below.

Manned Unmanned Teaming (MUM-T)

MUM-T is the synchronized employment of Soldiers, manned and unmanned air and ground vehicles, robotics, and sensors to achieve enhanced situational understanding, greater lethality, and improved survivability. The concept of MUM-T is to combine the inherent strengths of manned and unmanned platforms to produce synergy and overmatch with asymmetric advantages.[115]

On highly lethal battlefields *contested in all domains*, MUM-T redistributes risk away from our most valuable and irreplaceable asset: our Soldiers. As *WMD proliferation* increases the likelihood of “dirty” battlefield zones, MUM-T will enable access and assessment throughout the battlespace. In *complex terrain* environments, sensors and shooters linked through MUM-T decrease the likelihood and impact of surprise. MUM-T will enable speed of movement, particularly for transportation assets in dangerous environments such as high-threat road conditions or high-speed nap-of-the-earth (NOE) flight. MUM-T has potential application against the complete range of *hybrid combatants*.

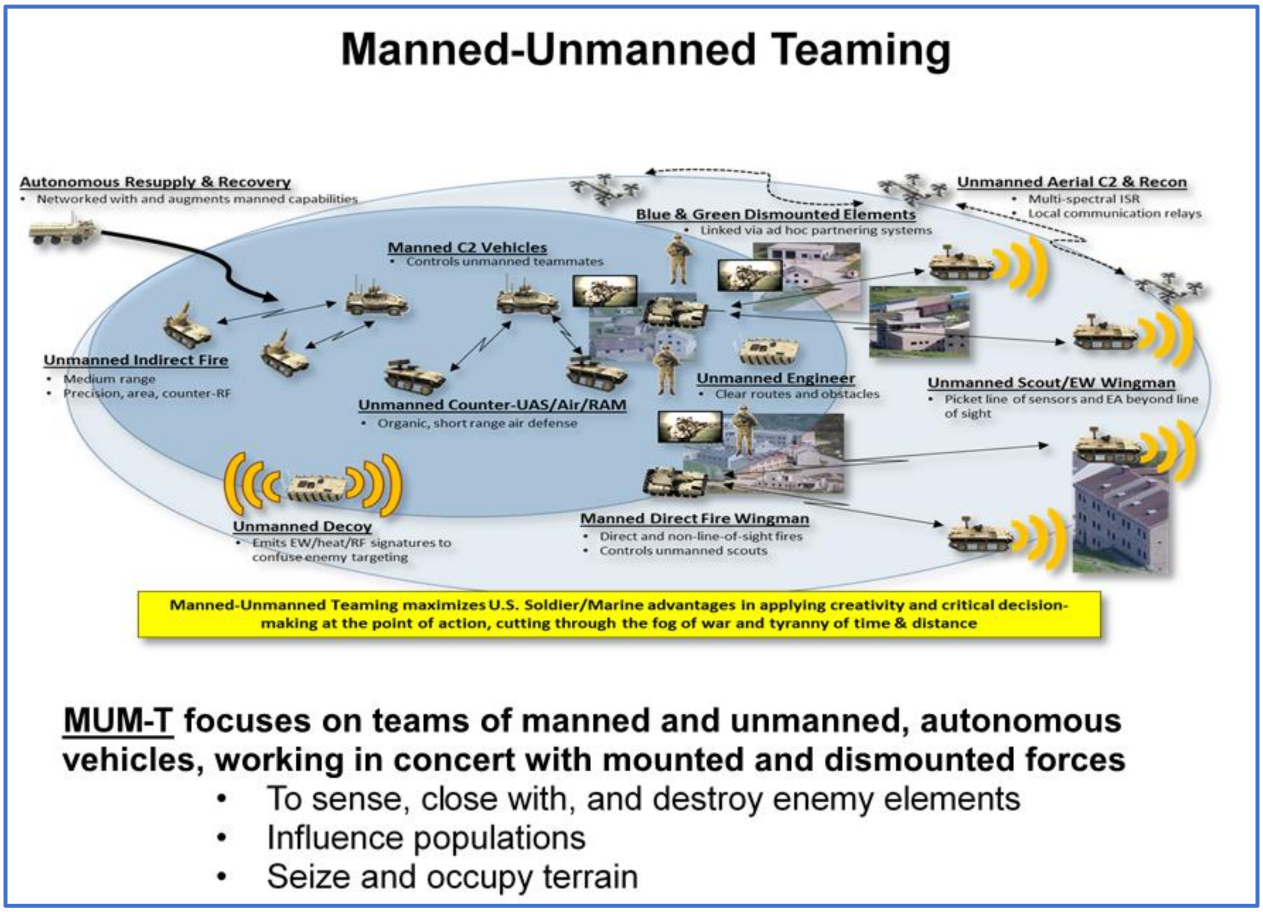


FIG III-1: Fountain Presentation
Mad Scientist Conference Day One

MUM-T Crowdsourcing Observations. Solutions associated with the MUM-T approach accounted for some 13% (19 of 139) of the total ideas developed during the crowdsourcing exercise. Of these, four ideas were represented in the “top 30” ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Man vs.*

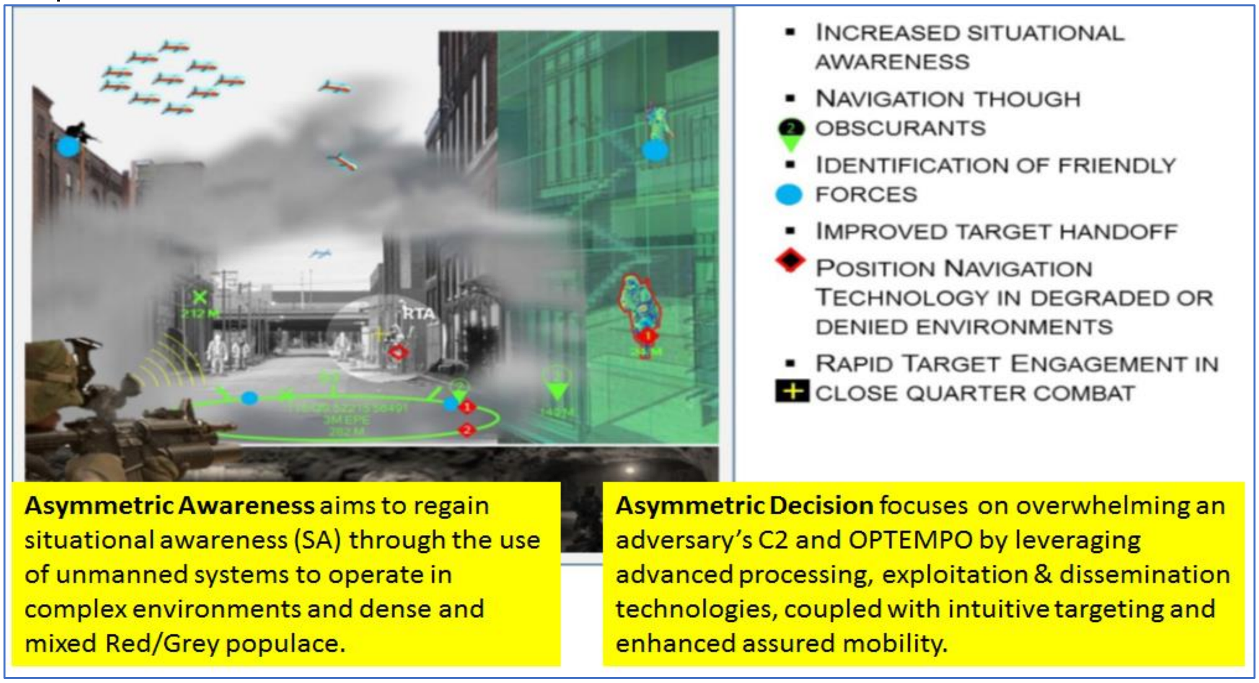
Machine: Human, AI, and Robotic Employment Optimization was the second highest-rated idea in the entire exercise. This idea envisions a DOD enterprise-wide approaches to evaluating the relative merits of human labor vice machine labor within the DoD. This idea promises a structured method to leverage the disruptive effect of robotics, AI, and autonomy and apply MUM-T and machine labor in an optimal way. It was imagined to be available to the force by exercise participants by 2020.

The full set of MUM-T crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Manned Unmanned Teaming: Idea Name**
2020	Man vs. Machine: Human, AI, and Robotic Employment Optimization**
2020	Sort Robotic Wearables: Autonomous Tourniquet
2020	Autonomous Mine Removal
2025	Mobile Protected Firepower
2025	Cyber Manifesto
2025	AWACS 3.0 Distributed Robotic Battle Management
2025	Appliqué Autonomy Kits
2025	AI-Assist for Combat Medic
2030	Walking Combat Vehicles
2030	Robotic Wingman**
2030	Combat Engineer Bots**
2030	Combat Robot Ethos
2035	Telecommuting to War**
2035	Second Skin
2035	Backup Brain
2040	Human Accessible Robot/AI Off Switch
2040	Remote Operated Assault Robots
2040	Enhanced Others
2045	Insect Man

Asymmetric Awareness and Decision (AA&D)

Asymmetric Awareness and Decision (AA&D) applies robotics, artificial intelligence, and autonomous systems to regain and maintain situational awareness in complex environments and overwhelm an adversary's command and control operational tempo.[116]



AA&D can extend Situational Awareness across *multiple contested domains*, and to lower echelons of C2 in the land force. AA&D is sorely needed to cope with the *unprecedented speed* of unfolding events on future battlefields. Although prediction is never possible, *WMD proliferation* and the increased potential of the use of CBRNE weapons will put a premium on the best possible indicators and warning.[117] With *complex domains the no*rm, advanced visualization techniques will be necessary to make sense of the large and rapid streams of data.[118] In the face *of hybrid combatants*, asymmetric awareness and decision must leverage complex and multi-dimensional streams of input. "Patterns of life," for example, are also in the cyber domain.[119]

Asymmetric Awareness and Decision Crowdsourcing Observations. Solutions associated with the AA&D approach represented the single most popular category for ideas during the exercise, accounting for nearly 24% (33 of 139) of the total set. Eight of these ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Machine Augmentation to Staff Functions* was the fourth highest-rated idea in the entire exercise. This idea described the application of deep learning and AI to optimize thousands of courses of action, from logistics, to personnel, intelligence, and operations fed from thousands of sensor and ISR fsources. This idea would allow staffs to operate within adversary decision cycles and allow the Army to seize and retain the initiative during operations. This idea was imagined to be available to the force by exercise participants by 2025.

The full set of AA&D crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Asymmetric Awareness and Decision: Idea Name**
2020	Multi-Layer Multi-Spectral Lens Protection**
2020	Real News Aggregator
2020	A.I Assisted Searchable Portable Military Library Laptop
2020	Pocket Augmented Reality Real-Time Training
2025	Adversaries Simulating Us
2025	Autonomous Sensor Defeat
2025	Heads-Up Glasses, Dash, and Desk Displays
2025	Pocket Interactive Doctrine, Training, and Policies
2025	Anti-Autonomy Sensor Disruptors
2025	Military/Law Enforcement Rehearsals
2025	Kinetic Courier / Kinetic Jammer
2025	Multi-Mode Laser Designator
2025	Machine Augmentation to Staff Functions**
2025	Robotic Subterranean Operations
2025	AI Robotic Information Warriors
2025	Adaptive Hyperspectral Algorithm for Camouflage Detection
2025	Recon-by-Wire**
2030	Chatbot: AI Resurrected Clones of Great Thinkers
2030	EW Applied to Human Perception
2030	Cybernetic Super-Sniffers
2030	Misinformation Disintegrator
2030	Anti-Pattern Recognition Camo**
2030	Mesh Networks as Alternate Internet**
2030	Recon Round**
2030	Genetic Algorithms for Optimizing Team Composition
2030	Rent-an-Avatar Booth
2030	Counter-AI Operations Field Manual**
2035	Second Skin
2035	21st Century Non-Kinetic, Multidomain Training for All Troops
2035	TOC in a Box
2035	Ever-Present Commander – Rules of Engagement Authority
2040	DigiPatton**
2045	Ultra-Fast Battlefield

Swarming

> **"Today, platforms rule the battlefield. In time, however, the large, the complex, and the few will have to yield to the small and the many. Systems composed of millions of sensors, emitters, microbots and mini projectiles, will, in concert, be able to detect, track, target, and land a weapon on any military object large enough to carry a human. The advantage of the small and the many will not occur overnight everywhere; tipping points will occur at different times in various arenas. They will be visible only in retrospect."**
>
> M. Libicki (1996)
> The Mesh and the Net:
> Speculations on Armed Conflicts
> in an Age of Free Silicon

Swarms leverage autonomy, robotics and artificial intelligence to generate "global behavior with local rules" for multiple entities – either homogeneous or heterogeneous teams. Collective behaviors emerge because of simple rules at the individual level that lead to complex aggregate behavior. No individual in the swarm "knows" the solution, but collectively, the swarm converges on an optimal path or solution.[120] Swarming leverages distributed awareness from multiple sources; the multiplicity of the sources enhances learning.[121] Swarm entities are typically expendable and have limited broadcast and computing power; a swarm system can survive loss of several platforms but still perform.[122]

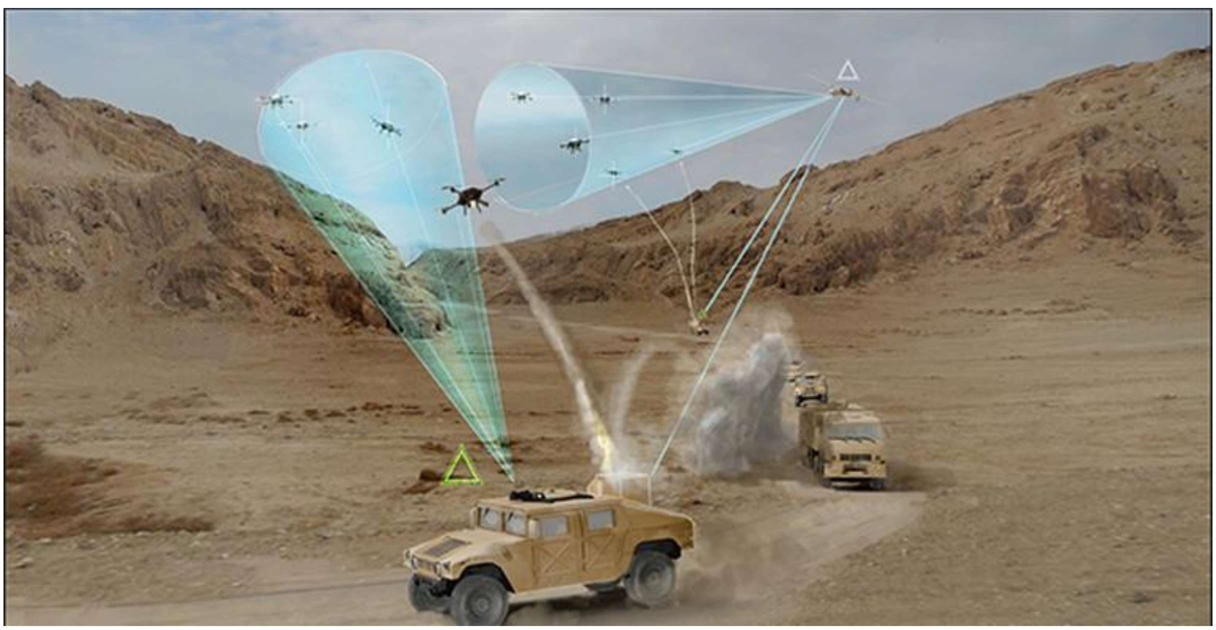


FIG III-3: Autonomous UAS Swarming

Swarm tactics, techniques and procedures are feasible in *all domains.* Swarm techniques will be one manifestation of the *unprecedented speed* of future operations as multiple entities overwhelm linear, sequential decision processes.

"Swarm Intelligence"[123] will search Big Data and seek to make sense of highly *complex environments*. The difficulty of dealing with overwhelming attacks of "the small, the smart and the many" may lead some competitors to leverage large scale area suppression weapons, including weapons of mass destruction (WMD.) VNSA components of *hybrid adversaries* frequently leverage swarm C2 techniques to generate collective behavior without the use of interdictable / interruptible global C2.

Swarming Crowdsourcing Observations. Swarming-related ideas accounted for 8% (12 of 139) of the total set. Two of these ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Ten Cent Defeat* was the 14th highest-rated idea in the entire exercise. This idea described the ability of all robots and autonomous systems to not "fail spectacularly" when confronted with primitive, low-cost defeat mechanisms, adapt, and recover functionality. The idea would apply a range of technologies and approaches to ensure that some percentage of a robotic fleet would remain operational even when confronted with novel countermeasures. This idea imagined to be available to the force by exercise participants by 2020.

The full set of Swarming crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Swarming: Idea Name**
2020	Ten-Cent Defeat**
2025	Virtual Minefield
2025	Drone Swarms
2025	Mothership/UCAV Delivery Carrier
2030	Nano-AI Vaccines**
2035	AI Prototype Platform Design
2035	Autonomous Infrastructure Repair and Maintenance
2035	Swarming Attack Nano-Bots
2035	Permanent Protective Drone Swarms
2035	Nanobot/Microbot Tracing Sensors
2040	Sleeper Drones
2045	Attack of the Clones

Intelligent Networks for the "Internet of Battle Things (IoBT)"

Intelligent Networks are distributed, interconnected entities that have goals, sense their environment, identify constraints and threats, and plan and execute adaptive actions through the leverage of autonomy, artificial intelligence and robotics.[124] The Internet of Battle Things is not a straightforward extension of the "Internet of Things," because the Internet of Battle Things must deal with the adversarial nature of the environment to include …

… Kinetic attack

… Directed Energy
… Electronic Attacks
… RF Channel Jamming
… Destruction of fiber channels
… Destruction or debilitation of power sources
… Electronic Eavesdropping
… Cyber Malware

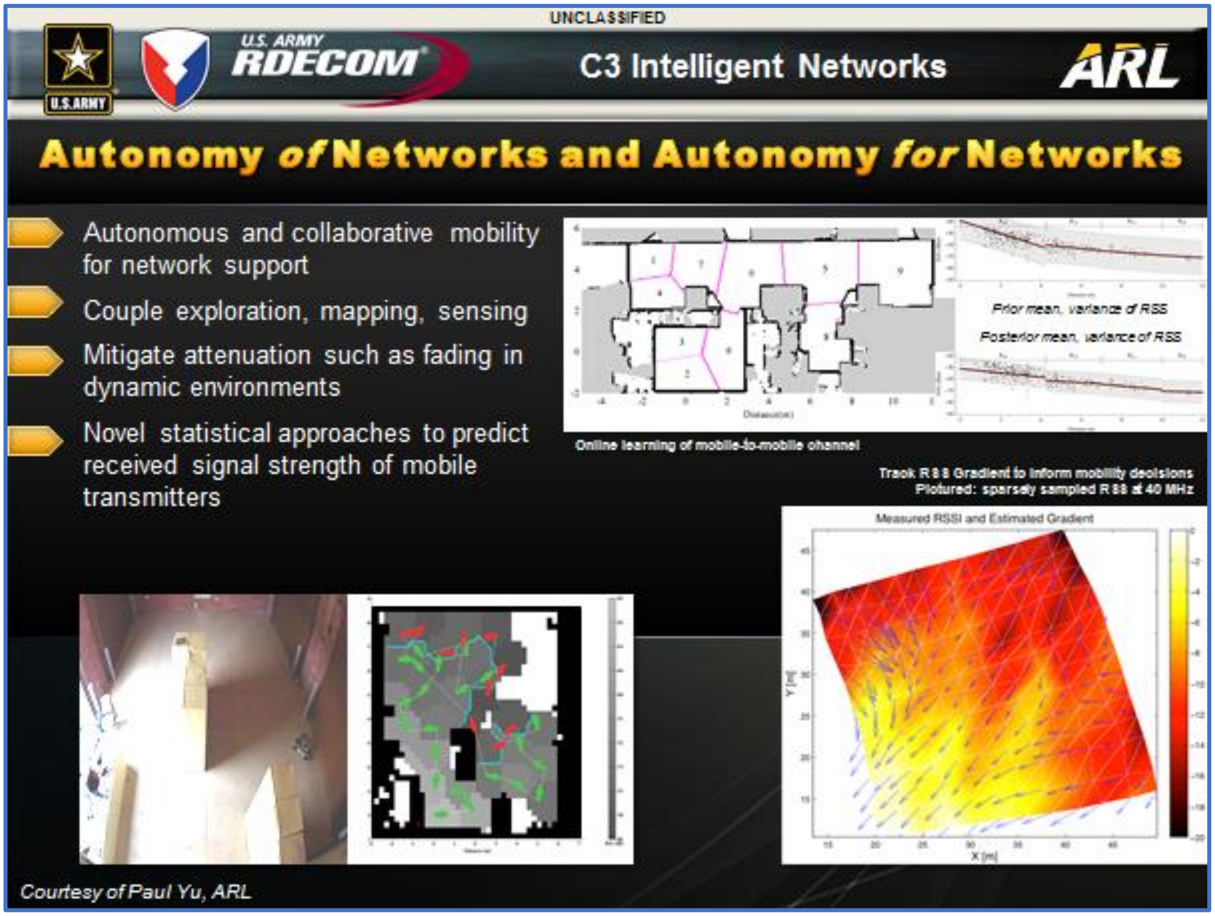


FIG III-4: Kott Presentation
Mad Scientist Presentation Day Two

Intelligent Network applications in the emerging operational environment may include networks of intelligent munitions passing data to defeat highly lethal adversary domain defenses. High speed flight through highly cluttered, *complex environments* enabled by dynamic, self-forming networks. We will see battles between networks of intelligent munitions, and intelligent munitions might come sooner than intelligent platforms.[125] Combatants will leverage the millions of devices embedded in megacities to sense and deceive, and autonomous cyber agents in defense of mobile tactical networks will leverage intelligent networks.

Intelligent Networks for the Internet Battle of Things Crowdsourcing Observations. Intelligent Network-related ideas accounted for 13% (18 of 139) of the total set. Three of these ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Smart Dust* was the third highest-rated idea in the exercise. This idea described radio-frequency identification (RFID) transmitters the size of a human hair with unique number strings for tracking purposes which are deployed in varying amounts for discrete or mass surveillance. The idea would provide a new range of ISR capabilities to the force to track and monitor targets remotely and with high quality data. This idea imagined to be available to the force by exercise participants by 2030.

The full set of Intelligent Networks crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Intelligent Networks for the Internet of Battle Things: Idea Name**
2020	AI-Enhanced Network Gate-keepers**
2020	AI Research Assistants
2020	Multi-Function Weapons
2020	Report Writer: Customizable AI Research Tool
2020	Robotic Programmers, Inc.
2025	Plug and Play Military Robotics Vehicles
2025	Corrupted R&D Simulation Software
2025	Kit to Control Captured Enemy Equipment
2025	Disrupter Bots for Crowd-Sourced Online Studies
2025	Algorithms to Approximate Human Judgments
2030	Teams of Small Robots to Move Casualties to Safety
2030	Anti-Machine Pathogens
2030	Smart Dust**
2030	AI Overrun Protection
2030	Neuronet
2030	Internet of (Hostile) Things
2030	Networked Autonomous Infrastructure Sabotage Battalion
2035	Machine Learning Pathologies**

Autonomous Sustainment

Autonomous Sustainment is a multi-modal approach that will leverage autonomy, artificial intelligence and robotics to increase sustainment distribution, throughput and efficiency.

Use of autonomous additive manufacturing can reduce forward sustainment demand and minimize exposure to contested commons in the maritime and aerospace domains. In a Future Operating Environment *contested in all domains*, autonomous (or leader-follower) convoy delivery of supplies through areas of *high threat*, conventional or *hybrid*. Autonomous Sustainment can leverage additive manufacturing and the resources of highly complex environments such as large distributed urban areas to minimize forward throughput and accommodate the unprecedented *speed of operations* and associated logistic demands. Robotic delivery systems can also negotiate highly contaminated areas generated by the use of *Weapons of Mass Destruction*.

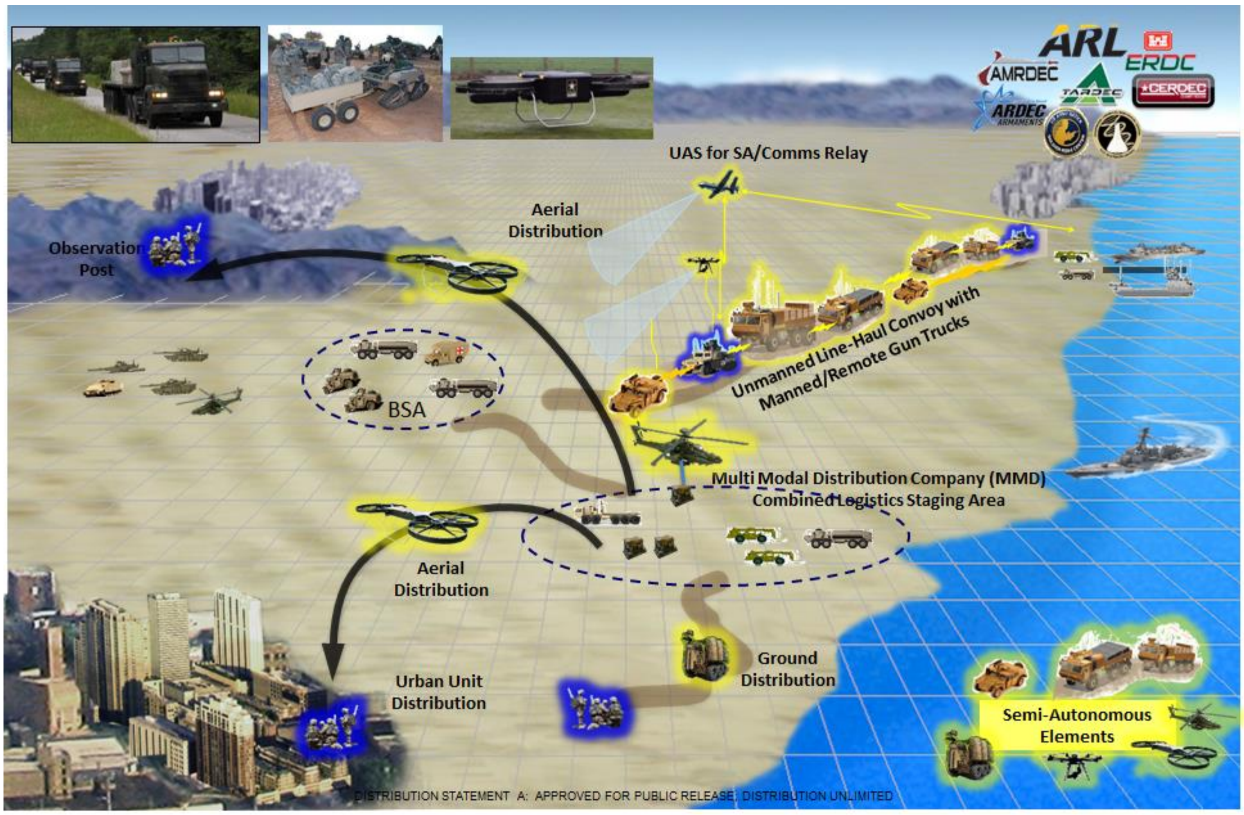


FIG III-6

FIG III-5: Sadowski Presentation
Mad Scientist Presentation Day One

Autonomous Sustainment Crowdsourcing Observations. Autonomous Sustainment-related ideas accounted for 8% (12 of 139) of the total set. Four of these ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Motorpool Bots* was the 11th highest-rated idea in the exercise. This idea described need to develop a capability to repair and maintain robots in the future. Robots may significantly enhance PMCS as well as perform repairs and system upgrades. Once they master the controlled environment, these systems could then be outfitted with cross-country terrain mobility systems so they can follow units into the field, repairing and recovering damaged system even under direct or indirect fire.

The idea would allow robots to undertake dirty, dull, and dangerous repair tasks for the Army. This idea imagined to be available to the force by exercise participants by 2030.

The full set of Autonomous Sustainment crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Autonomous Sustainment: Idea Name**
2025	3D Printing for Maintenance Parts
2025	Additive Manufacturing Sustainment Brigades**
2025	Hoarder Drone
2025	Fabship Aircraft**
2025	Six Sigma Army Total Design and Maintenance
2025	Robotic CASEVAC**
2030	AI Based New Product Development
2030	Motorpool Bots**
2035	Walking Emergency or Construction Vehicles
2035	Integrated Electrical Logistics
2045	Autonomous Space Miners
2045	BN/BDE Experimentation and Upgrade Officer

IV *DESCRIBE*: the Competitions of Multi-Domain Warfare

Overview: the Competitions of Multi-Domain Warfare

The interaction of multiple great powers – similarly equipped with emerging robotic, AI, and autonomous technologies and simultaneously trying to address the strategic and operational challenges of the future operational environment – will drive a fundamental change in the character of warfare, a change characterized as a series of competitions.[126]

The simultaneous and interactive competitions of *finders* vs *hiders* and *strikers* vs *shielders* will generate a battlespace of unprecedented lethality. Combatants will struggle – and aggressively innovate – to generate *survivable close engagement* in the face of formidable adversary *range* and *lethality*. The advantages of *connection*, *aggregation* and *centralization* will trade against equally compelling motivations for *disconnection*, *disaggregation*, and *decentralization* – with the probable result of a widely distributed, non-contiguous battlespace. In such a battlespace, at least between peer competitors in the land domain, the *defense* will be relatively advantaged over the *offense*.

Emerging capabilities in robotics, autonomy and artificial intelligence will present future combat developers with interesting trade-offs between *planning* versus *reaction*, and *judgement* versus *autonomy*. Competitors will have daunting *escalation* capabilities, making escalation advantage a prominent feature of future force design, doctrine and policy. The extended range and precision of land based systems will extend their effects more routinely and more effectively into the other domains, so that legacy combined arms synergy now extends across multiple *domains*. Similarly, there will be widespread recognition that conflict is a competition, not only across every domain in the physical dimension, but also across the cognitive and moral *dimensions*.

Describe: The Competitions of Multi-Domain Warfare …

- **… *Finders*** vs ***Hiders***
- **… *Strikers*** vs ***Shielders***
- **… *Range & Lethality*** vs ***Close Engagement & Survivability***
- **… *Disconnection / Disaggregation / Decentralization***
  vs ***Connection / Aggregation / Centralization***
- ***Offense*** vs ***Defense***
- ***Planning & Judgement*** vs ***Reaction & Autonomy***
- ***Escalation*** vs ***De-Escalation***
- ***Domain*** vs ***Domain***
- ***Dimension*** vs ***Dimension***

Finders vs *Hiders*

In the emerging competition between finders and hiders, manned-unmanned teaming (MUM-T) of Soldiers, platforms and sensors (*finders*) will extend the reach, ubiquity, and safety of *finders,* extending their capabilities into complex and lethal environments. Asymmetric Awareness and Decision (AA&D), enabled by AI-based signal processing and big data techniques, will be applied to make sense of the plethora of sensor information. On the other side of this competition, *hiders* will leverage inexpensive, autonomous robots as decoys. Robotics, autonomy and artificial intelligence will enable the dispersion of capabilities across disaggregated entities – disrupting and concealing their expected capability signatures. Both sides of this competition will leverage intelligent networks that will autonomously maneuver to minimize risk of intercept. Intelligent, autonomous EW assets will collect, assess and react to new waveforms "real time." Swarming – enabled by autonomy and AI – will serve as a maneuver technique for both *hiders* and *finders.* On highly distributed and non-contiguous battlespace, MUM-T can deploy sensors in depth, generate effects in depth, and execute supporting actions that significantly expand a formation's area of influence.[127]

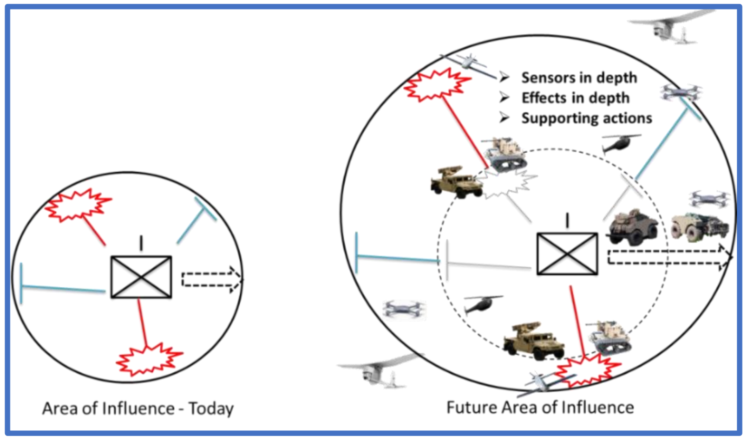


FIG IV-1: Sadowski Presentation
Mad Scientist Conference Day One

Strikers vs *Shielders*

The finder-hider competition is fundamental because of the simultaneous maturation – and proliferation – of the precision *strike* regime. The type of precision formerly reserved for high end aero-space assets is extending to all domains and at every echelon of engagement, including the individual Soldier. Combatants – including many non-state entities – leverage multiple manifestations of precision strike: kinetic weapons, hyper-kinetic weapons, directed energy, EMS, and cyber. Peer competitors cannot long endure the application of such strike effects, particularly when directed by robust find capabilities. Successful combatants devise *shields*: joint, combined arms endeavors that target opposing finders, their linkages to strikers, or the strikers themselves. For every manifestation of striker, there is a shielder counterpart: intercept missiles, railguns, lasers, jamming. Robotics, AI and autonomy will play a key role in the future competition between *strikers* and *shielders*.

The simultaneous and interactive competitions of *finders* vs *hiders* and *strikers* vs *shielders* will generate a battlespace of unprecedented lethality. MUM-T will mitigate the risk of movement through this lethal battlespace. *Strikers* will employ swarming solutions to overwhelm and defeat *shielders* -- potentially at significant cost advantage. Strike munitions connected via intelligent networks will collaborate to assess and defeat sophisticated shield systems (See FIG IV-2).[128] *Shielders* will employ autonomous AI to generate Asymmetric Awareness & Decision (AA&D) and the speed of decision needed to identify striker threats and allocate response resources. Autonomous Sustainment will be needed to restore the inevitable losses associated with the *striker* vs *shielder* competition.

FIG IV-2: Kott Presentation
Mad Scientist Conference Day Two

Range & Lethality vs Close Engagement & Survivability

Combatants in future *striker-shielder* competitions will leverage *range* and *lethality* to penetrate and overwhelm a shield – or, conversely – shield against strikers. A complementary approach is *close engagement*. Close engagement disintegrates integrated defenses, causing concealed forces to unmask and uncover, exposing them to the finder and striker dynamic. The challenge is the approach. *Close engagement* forces need superior range and lethality in the close fight, but they also need *survivability*: the protection (and mobility) that allows them to maneuver through denied areas to close with and defeat the highly lethal assets securing the adversary shield. Thus ensues the competition between *range and lethality* vs *survivability and close engagement*:

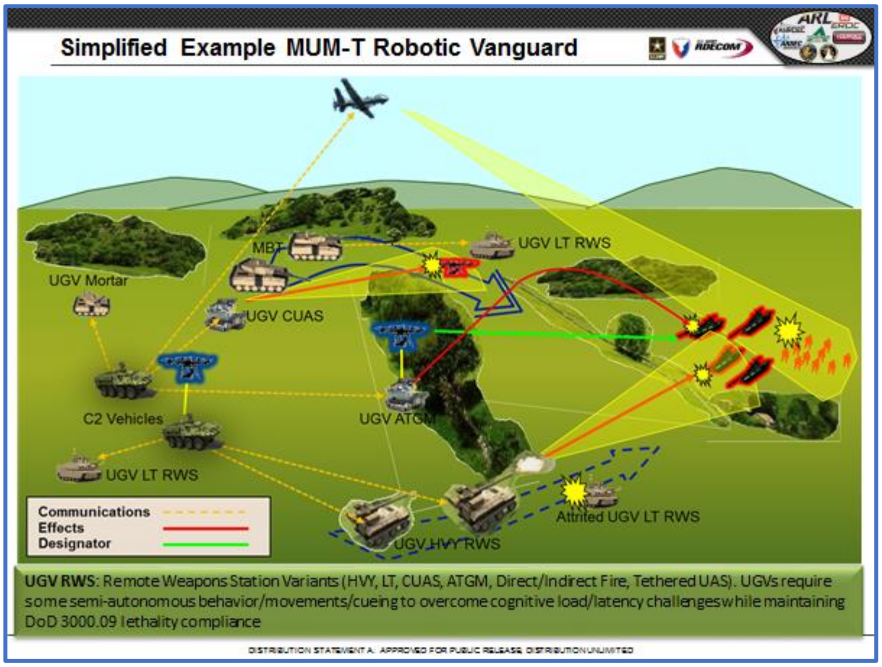


FIG IV-3: Sadowski Presentation
Mad Scientist Conference Day One

MUM-T of disaggregated armored platforms allows land forces to close with the enemy across zones of very high lethality – at reduced risk to Soldiers (FIG IV-3). Intelligent networks exacerbate lethality by extending the range of sensors (*finders*) and the precision of weapons (*strikers*). Asymmetric Awareness and Decision (AA&D) leverages AI to counter enemy IADS (Integrated Air Defense Systems) by enabling "boundary effect air mobility": high speed, very low nap of the earth flight. Cyber agents across Intelligent Networks extend the range and impact of effects in the cyber domain, with significant cross-domain impact that reduces the exposure to highly lethal effects in the physical dimension. Robotics, AI and autonomy enable the flexible and high-production manufacturing techniques that make possible the generation of new applications of "mass" via swarms of relatively inexpensive autonomous weapons that can negotiate lethal zones to close with and destroy their targets. These same capabilities enable Autonomous Sustainment and the generation of mass needed to withstand high attrition conflicts.

Disconnection / Disaggregation / Decentralization vs *Connection / Aggregation / Centralization*

In the future operating environment, consolidation of forces enhances their connectivity, aggregation, and control. Such consolidation reinforces the strength of the shield and ability to mass effects. On the other hand, such consolidation poses extreme risk and there is a countervailing impetus to *disconnect* – to the extent possible -- from global sensing networks, *disaggregate* formations, and accept significantly *decentralized* control. In this competition, robotics, artificial intelligence and autonomy may mitigate the difficult trades between control and risk.

Disaggregation, for example, will demand flexible, scalable force structures that can accommodate joint and combined capabilities decentralized to extremely low levels. As formations disaggregate and disperse across non-contiguous battlespace, a very diverse set of joint and combined arms capabilities will migrate to lower levels. Leaders and staffs of super-enabled small units will need to leverage AI, robotics and autonomy to generate the Asymmetric Awareness and Decision (AA&D) needed to generate joint and combined arms synergy at increased levels of scale and complexity, but at lower echelons of command and control. MUM-T may apply new manufacturing advances and autonomy and afford command posts that are self-driving, fully connected server farms – and fully mobile.

The non-contiguous future battlespace will pose two particular challenges: the contest to communicate and the struggle to sustain. Intelligent Networks will adapt to attempts to interdict communications.

FIG IV-4: Kott Presentation
Mad Scientist Conference Day Two

Autonomous Sustainment enables resupply on a distributed, non-contiguous, and very lethal battlefield. The same advanced manufacturing techniques that enable Autonomous Sustainment also enables reduction demands by fabricating MTOE parts and small arms munitions in theater. They may also reduce evacuation requirements because of their ability to engineer human organs and synthetic fluids. Advanced manufacturing techniques may be able to produce tracked and wheeled vehicles with equivalent protection and capabilities at weight reductions ranging from 50% to 90%, reducing logistic demands for distributed, dispersed formations.[129]

Offense vs Defense

Offense vs *Defense* is a timeless competition, the outcome reflecting the strategic and technical conditions peculiar to each era. In the emerging operational environment, conditions favor the defense. With peer competitors robustly – but equally -- equipped with *finders* and *strikers*, the combatant who moves – particularly over extended strategic and operational distances -- is disadvantaged. A defensive stance favors the development of more robust *shields* with robust passive sensors (finders), and offers the advantage of hardened, redundant locations in the *lethality* vs *survivability* contest.

This inherent defense advantage will reward competitors who can generate strategic surprise and present unprepared adversaries with a "fait accompli." Asymmetric Awareness and Decision (AA&D) may detect very subtle indicators and warning to aid in the anticipation of preemptive attacks and the prevention of such strategic surprise. Closing with the enemy will be the tactical challenge of the era; MUM-T will limit losses as forces move across highly lethal defensive zones. Swarms will be employed to overwhelm and saturate defenses at decisive points. Intelligent Networks will "learn" real time and reconfigure during operations and even during engagements. Adversaries will pursue forward presence in potential regions of conflict, particularly a forward presence that support a prepared operational defense and its consequent advantages. As these forward positions weather initial attacks, Autonomous Sustainment will serve to extend their endurance until reinforced by follow on forces.

> **"10 years from now if the first person through a breach isn't a robot, shame on us"**
>
> Robert Work

Planning & Judgment vs Reaction & Autonomy

The duel for initiative is inherent to the nature of war, but this duel has a unique character in the emerging operational environment. Operational tools will work at extraordinary speed and reach, and not infrequently precipitate unexpected consequences. The planning paradox in the offense is that rapid execution depends on very careful planning and condition setting, particularly in the cyber domain. On the defense, however, faced with bewilderingly short reaction windows, many combatants will resort to automated – and increasingly autonomous – decision processes.

Taking human beings "out of loop" poses potential advantages versus competitors unwilling or unable to automate key decision processes. Automation will extend beyond platforms to decision making itself.[130] Asymmetric Awareness and Decision (AA&D) will apply AI and decision aids to enable sub-millisecond decision for allocation of information assets and direction of kinetic attacks across all domains.[131] This coordination will extend across many automated decision-making entities, most of it without human knowledge or intervention.[132] Distributed, autonomous cyber agents working across intelligent networks will exercise a vast preponderance of the decision-making for defensive cyber.

Escalation vs *De-Escalation*

Means of violence will be readily available to a wide range of actors in the future operating environment, and on unprecedented scales. Many competitors will have Weapons of Mass Destruction (WMD) and incorporate their routine use into doctrine and policy. Conventional and cyber capabilities are so potent, moreover, that they can generate effects on the scale of Weapons of Mass Destruction (WMD). The competition between violence *escalation* and *de-escalation* will be central to stability, deterrence, and strategic success. Robotics, AI and autonomy technologies will afford numerous solution approaches that facilitate transition up and down the *escalation* / *de-escalation* ladder.

MUM-T solutions will enable forces greater access to inhospitable CBRNE environments. There will be a premium on pre-empting escalation to the employment of WMD, so Asymmetric Awareness and Decision (AA&D) capabilities will enhance the ability to capture early indicators and warning. Automated Sustainment to enable sustained operations in such environments even when necessary to traverse highly contaminated zones. Intelligent Networks reconfigure to ensure communications in spite of large scale infrastructure disruption due to EMP or area kinetic effects (thermobarics).

Domain vs *Domain*

The competitions of future warfare will extend and intensify in new domains, particularly space and cyberspace. Each domain will be fiercely contested, and between great powers assured dominance or even lasting advantage in any domain will prove elusive. As the tools of warfare extend their physical capability to both *find* and *strike*, armies will not constrain their planning and operations merely to the land domain. Each domain's unique physics will constrain platforms and techniques, but the highest art of combined arms warfare will be to generate effects from one domain against another: leveraging their relative advantages and mitigating their innate vulnerabilities. In this environment, effective joint synergy will not be a bonus, it will be table stakes for survival.

Robotics and autonomous systems will extend the reach of legacy systems and extend effects from one domain into another. Because of risks across multiple domains, robotics, AI and autonomy are applied to disaggregate and decentralize key capabilities (e.g., nuclear C2) while retaining control and function.[133] The complexities of generating multi-domain synergy across multiple domains impose daunting cognitive loading on leaders to simultaneously accommodate the range of maritime functions, the speed of air / space / cyber operations, and the tactical complexity of land warfare.[134] Asymmetric Awareness and Decision (AA&D) helps understand, visualize, describe and direct action across multiple domains.

Dimension vs Dimension

Future conflict will be a competition, not only across every domain in the physical *dimension*, but also the cognitive *dimension*, and even the moral *dimension* of belief and values. Adversaries – equally enabled by ubiquitous sensors, big data techniques, responsive space satellites and robust social media access – will enjoy competitive levels of situational awareness. Information will be weaponized, directly through cyber techniques or implicitly through social media techniques.[135] There will be a recognized premium for understanding and appreciation of the belief systems that motivate actors in the moral dimension of conflict.

Robotics, artificial intelligence, and autonomy will enhance the significance of the cognitive dimension of conflict, and extend the cognitive *dimension's* impact on the *physical dimension*. The impact of these technologies, however, is so extensive that it also tests the moral dimension of conflict: the dimension of our values and beliefs. Between future competitors, a severe **asymmetry of ethics** may emerge with respect to the limits of allowable human performance enhancement, permissible levels of control for artificial intelligence and autonomous systems, delegation of authorities for cyber attacks, the legitimacy of terror tactics, and a willingness to put noncombatants at risk through WMD use -- or use of conventional means with equivalent impact.

"Meanwhile, developments in robotics and artificial intelligence will render large groups of armed humans less and less important in warfare. Already, the United States is turning to robots and drones to accomplish tasks that just decades ago required humans. We use robots to disarm bombs and check for threats inside buildings; we use drones to monitor substantial swaths of territory, vacuum up electronic communications, and fire missiles at designated targets. Already, military robots and drones are getting smaller, stealthier, hardier, and smarter; within a decade or two (at most), the United States or some other state will develop robots, drones, or other weapons systems capable of operating autonomously in circumstances too challenging for humans to handle …

… perhaps we shouldn't be too quick to celebrate the end of war. Fewer piles of corpses is a good thing, but war's diminishing brutality may also diminish political inhibitions, tempting the powerful to employ their bloodless new mechanisms for coercion and control more frequently and more indiscriminately, with fewer legal and political safeguards. The less bloody wars of the future may spread more insidiously and invisibly, enabling ever-more Orwellian forms of political control — and because they barely resemble traditional wars, they may be that much more difficult to discern and regulate."

Rosa Brooks "Can There Be War Without Soldiers?"

Mad Scientists observed that nothing in the current laws of war mandate human decision-making vice machine decision-making. The laws of armed conflict cover effects on the battlefield (e.g., proportionality, discrimination, precautions in attack). If a machine can be used in a manner that meets these criteria, then it can be used lawfully. However, one important asymmetry between people and machines under the laws of war is that machines are not legal agents. Humans are bound by the laws of war; robots / autonomous systems are not combatants.[136]

V *DIRECT*: the Drivers of Outcome

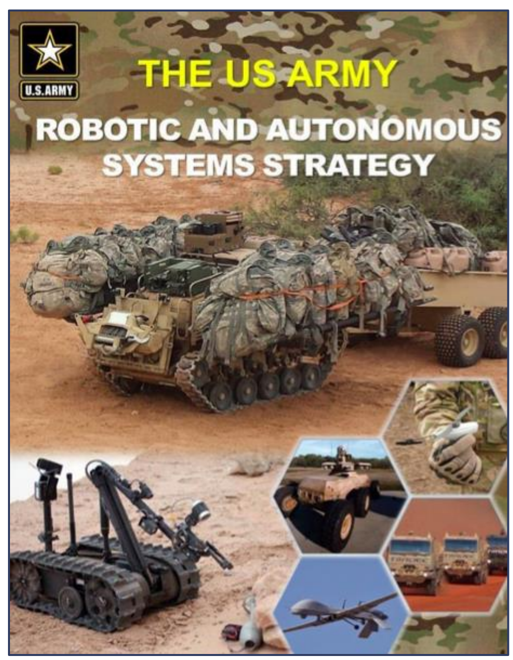
As future competitors leverage the technologies of robotics, artificial intelligence, and autonomy to wage the competitions that will characterize future warfare, success will accrue to those most effective in the institutional contests that are already underway and will shape the outcomes of the future. Those contests will include strategies and policy, concepts, innovation and adaptation, combinations and learning.

> ***Direct: The Drivers of Outcome …***
> **… Strategy & Policy**
> **… Concepts**
> **… Innovation & Adaptation**
> **… Combinations**
> **… Learning**

Strategies & Policy

Third Offset Strategy. DoD is already focused on the potential of these technologies. In November 2014, then–Secretary of Defense Chuck Hagel announced a new Defense Innovation Initiative, which included the Third Offset Strategy. The initiative sought to maintain U.S. military superiority over capable adversaries through the development of novel capabilities and concepts. Prior Secretary of Defense Ashton Carter built on Hagel's vision of the Third Offset Strategy, and Deputy Secretary of Defense Bob Work, has championed numerous small bets on advanced capability research projects featuring robotics, artificial intelligence, and autonomous technologies.[137]

US Army Robotics & Autonomous Systems (RAS) Strategy. The US Army has also been active in exploring the potential of these technologies, and published a Robotics & Autonomous Systems (RAS) Strategy in 2016. Dr Robert Sadowski, Army Chief Roboticist and Chair of the RDECOM Robotics Community of Practice summarized this strategy in some detail for the Mad Scientist Conference. The RAS Strategy established five priorities as follows:



- Increased Situational Awareness
- Lighten Soldier's Physical and Cognitive Workloads
- Sustain the Force with increased distribution, throughput and efficiency
- Facilitate Movement and Maneuver
- Protect the Force

The RAS priorities are phased over time as shown at FIG V-1.

Near Term Priorities: Until 2020	Mid Term Priorities: 2021-2030	Far Term Priorities: Beyond 2030
"ADAPT NEAR"	"EVOLVE MID"	"INNOVATE FAR"
Increase situational awareness for dismounted forces at lower echelons	**Increase situational awareness advanced, smaller RAS and swarming**	**Increase situational awareness with persistent reconnaissance from swarming systems**
Improve sustainment with automated ground resupply	**Improve sustainment with fully automated convoy operations**	**Improve sustainment with autonomous aerial cargo delivery**
Facilitate movement with improved route clearance	**Improve maneuver with unmanned combat vehicles and advanced payloads**	**Facilitate maneuver with advancements to unmanned combat vehicles**
Protect the Force with EOD RAS platform and payload improvements		

FIG V-1: RAS Priorities by Phase[138]

The RAS Strategy Implementation Framework includes 3 Lines of Effort (LOE) as described below at FIG V-2.[139]

LOE 1: Envision the Future

- Validate potential formational constructs through soldier in the loop simulation via Early Synthetic Prototyping (ESP) and User Wargaming
- Explore different platforms/employment: purpose built/appliqué/optionally manned, lethality/survivability/mobility mix, levels of supervision and degraded comms effects
- Leverage Soldier Innovation Workshops to generate new concepts from Soldiers
- Generate future CONOPS and requirements documents

LOE 2: Develop RAS Capability

- In Theater Ground / Aerial Autonomous Resupply
- Initial Virtual RAS Proving Ground
- Initial Teaming Behaviors w/ Combat Formations
- Soldier / Crew Deployed ISE
- Open Autonomy Software Architecture

LOE 3: Sustain Integrated Campaign of Learning

- Work with TRADOC Centers of Excellence to deliberately conduct operational experiments with RAS platforms to embed the User Community in the technology development process.
- Determine the utility of RAS platforms through relevant operational assessment to both drive future CONOPS/TTPs/Requirements as well as feedback information to RAS technology development (Gaps/Use Cases)
- Leverage RAS ICDT management structure to layout battle rhythm of M&S through COE Battle Labs coupled with hardware experimentation

FIG V-2

Introducing robotics technologies into the formation is fundamentally new for the Army and requires concurrent technology development, operational experimentation and CONOPS development in order to maximize the capability offered by autonomous systems.[140]

Policy Ethics. The ethical issues underscoring policy decisions are not as straightforward as simply "Should we build a Terminator?" There will be a plethora of subtle operational issues to be confronted in system design and operation.[141] Mad Scientists explored several of these. If we have a loitering munition or an unmanned vehicle that is operating in a communications-denied environment, how much autonomy do we want to give it to attack emerging targets of opportunity? How much prior information do we expect military commanders to have about specific targets for attack? How much specificity about target selection can they delegate to a machine? If we have an unmanned vehicle in a communications-denied environment and it is attacked, do we want it to use force to defend itself? What about preemptively?[142]

The ethical issues associated with these technologies are global. Over 60 non-governmental organizations -- part of a "Campaign to Stop Killer Robots" -- have called for a legally-binding treaty banning autonomous weapons. Over 3,000 AI and robotics experts signed a letter in 2015 calling for a ban on "offensive autonomous weapons beyond meaningful human control." For the past three years, nations have discussed autonomous weapons in the United Nations Convention on Certain Conventional Weapons; discussions may move to a more formal Group of Governmental Experts next year, but there is currently no momentum towards a treaty. Only a handful of states (and no major powers) have said they support a ban.[143]

> **"One of the places that we spend a great deal of time is determining whether or not the tools we are developing absolve humans of the decision to inflict violence on the enemy. And that is a fairly bright line that we're not willing to cross. … it is entirely possible that as we work our way through this process of bringing enabling technologies into the Department, that we could get dangerously close to that line. And we owe it to ourselves and to the people we serve to keep it a very bright line."**
>
> GEN Paul Selva, VCJCS (Aug 2016?)

Mad Scientists were generally in agreement that the key decision is: *what role do we want humans to play in use-of-force decisions*? If we could automate everything, what decisions would we still want humans to retain, and why?[144] The Army is currently committed to systems that are not totally autonomous: Soldiers will always be involved to address lethal decisions.[145] The future ethical challenges for the Army – and for the Nation – will emerge when we contend, for vital national interests, with peer competitors who have chosen to not symmetrically self-constrain.

Concepts

An operational concept is an image of combat: a concise visualization that portrays the operational challenges of adversaries and their capabilities, and the scenario by which they will be defeated. Since the most effective operational concepts incorporate the dominant socio-economic and technical trends of their time, we can expect future concepts to feature solutions that leverage robotics, artificial intelligence and autonomy. The Joint Community, in fact, developed the Joint Concept for Robotic and Autonomous Systems (JCRAS) in 2016 to describe a joint vision of future robotic and autonomous systems in use by 2035. Significantly, the JCRAS admits a unique focus on capability *development* vice capability *employment*, and states a primary purpose to "guide … comprehensive development across the Joint Force."[146]

The JCRAS presents a vision wherein, by 2035, the Joint Force will employ integrated Human-RAS teams in a wide variety of combinations to expand the Joint Force commander's options. This concept envisions a future Joint Force that capitalizes on technological advances to embed highly-capable and interconnected RAS into every echelon and formation. It projects RAS evolution from tools for basic tasks into team members capable of coordinating and collaborating across domains and Services. RAS will play a central role in performing and supporting an extensive array of complex mission sets across the range of military operations.[147]

> **"In May 1940, the Allied and German Armies squared off in what was expected to be an extended campaign for the conquest of France. Six weeks later, the victorious German Army marched down the Champs-Elysees in Paris. How was it that the Germans, with fewer tanks, fewer trucks, fewer troops, less artillery and access to roughly equivalent technologies, managed to accomplish such a remarkable feat? While leadership, luck, and a host of other factors were at play, the decisive factor was the remarkable way in which a few German inter-war military thinkers envisioned and developed a new way of warfare, known to the Allies as the blitzkrieg. German doctrine successfully integrated current technologies in aircraft, radios, and tanks into a coherent and integrated way of fighting and then applied it to great effect. The result was amplified because the Germans fought an enemy that in many cases failed to account for the possibilities enabled by the new combination of these technologies.**
>
> **We are now on the cusp of a similar revolution in warfare with the opportunity to integrate several current and near term technologies into our concept of how we will conduct military operations in the not-to-distant future. The winner of the next conflict will not likely be determined primarily by the state of their technologies, but by how well a nation's military thinkers conceptualize future warfare in an integrated manner and then apply robotic systems, or warbots, appropriately to our way of fighting."**
>
> Brian M. Michelson, "The Coming Warbot Revolution" (6 Mar 2017)

It is not clear that the Army will need to publish a developmental concept at its own level; the JCRAS may suffice for that purpose. The representative "solution approaches" presented earlier (MUM-T, Asymmetric Awareness and Decision, Intelligent Networks, Swarming, and Autonomous Sustainment are likely candidates for incorporation into broader concepts, doctrine, or tactics, techniques and procedures (TTP).

Robotics, artificial intelligence and autonomy may also significantly reinforce legacy concepts and doctrine. Mission Command, for example, is often cited as a foundational concept for "Centaur Teaming:"

"… the U.S. Army's concept of mission command gives it a decisive advantage on the battlefield without even the expectation of perfect control over every soldier and vehicle. While absolute autonomy is correctly viewed as unacceptable, if we are to see the full benefits of warbots, we already have the mission command framework and can adapt it to the new forms of interaction that will emerge between manned and unmanned systems."[148]

Innovation & Adaptation

Mad Scientists consistently stated that robotics, artificial intelligence and autonomy technologies enable previously infeasible solution approaches and therefore may change the character of warfare itself. Because these technologies will be broadly available to most future combatants, the contest of innovation and adaptation between those combatants will be a key driver of future outcomes.

Scope and Flow of Innovation. Mad Scientists asserted that innovation and adaptation must comprehensively and simultaneously explore solution approaches from the conceptual to the platform / sub-system level. Innovation and adaptation will not only mitigate battlefield vulnerabilities and enable exciting new capabilities, it also offers the potential for significant cost reductions in manufacturability and sustainment. Robotics, autonomy and artificial Intelligence can improve the performance of legacy platforms and will probably first be applied for incremental improvements to current capabilities.[149]

Unlike for previous defense-related technology waves, the flow of technology – particularly for Third Offset technologies such as robotics, artificial intelligence and autonomy -- is predominantly *from* the commercial sector *to* defense. Therefore most of these technologies have a "dual-use" nature that makes them widely accessible to both emerging great powers and non-state entities.[150] Think tank studies such as the CNAS report "Future Foundry: A New Strategic Approach to Military-Technical Advantage" have recommended "optionality strategies" in which DoD evaluates a diverse array of technologies in light of a greater volume of high- and low-end threats. Focusing initially on prototype design and limited production, the government can delay full production until threats become more defined – and capabilities verified.[151] Future advanced manufacturing capabilities might enable such surge production.

"… the velocity and volume of 21st Century technological advancement in the commercial sector — from renewable energy sources to nanotechnology, to the vast and profound integration of communication and information technology, or wildly disruptive processes like 3-D manufacturing — have rendered the Pentagon a net importer of technology vs. the vaunted exporter it had been for most of its existence. Left unmanaged, the inability of the Pentagon to quickly acquire and adapt a wider range of technology will yield a dominant focus on incremental improvements to existing systems at best and will block military superiority at worst … … The Pentagon's modernization strategy relies heavily on networked-enabled and autonomous learning systems, cloud computing, robotics, and the state-of-the-art in cybersecurity. Yet, there is no identified path to acquire some of the world's most exciting commercial technology."

William Lynn and Sean O'Keefe,
C4ISRNET, 1 May 2017

Asserting that commercial technology can address 15 percent of the US defense market requirements, the same study recommends contracted “Commercial Systems Adapters” missioned to continuously search – worldwide – for commercial technology with promising defense applications that might be adapted or integrated for military purposes.[152]

Manufacturability. In an operational environment featuring peer technical competitors, these technologies enable the manufacturability that may provide the decisive competitive edge: the ability to build the things we need once we know we need them – very fast, efficiently and with high reliability.[153] Manufacturability will transition from an approach that must choose between customization or high volume, contend with disconnected supply chain, produce single function products, and test early state prototypes before full production. Future manufacturing will evolve to customization at any volume, a fully integrated supply chain, multi-functional products, and production at any scale.[154] One of the most important applications of the machine learning dimension of artificial intelligence will be its application to the “Industry 4.0’s Manufacturing Revolution.[155] “Machines that can Learn” can inform “Machines that can Make”, enabling solution approaches such as remanufacturing weapons based on the outcome of the previous engagement.[156]

The Innovation Race. With widespread recognition that the race to innovate and adapt is a contest with many competitors ranging from emerging great powers to super-empowered individuals, there was a widespread recognition among Mad Scientists of “The Need for Speed.” Echoing the words of Mad Scientist Dr James Canton, Dr Alexander Kott stated:

> “Much is possible today so what are we waiting for? If we wait, our adversaries will not wait and the future may be coming towards us when we least expect it. The future will come at us much faster than we want. Better to disrupt ourselves than be disrupted by adversaries.”[157]

FIG V-3: Kott Presentation
Mad Scientist Conference Day 2

From a military perspective, innovation without acquisition will not be relevant, and our legacy acquisition systems are routinely identified as strategic handicaps. There are widespread recommendations to move away from “high quality” acquisition strategies that frequently fail after decades of investment, to a “good enough” approach that aims to “fail early and fix early.” $100 million field tests where “failure is not an option” are problematic.[158] Good enough acquisition strategies could readily leverage machine learning, robotics and autonomy for iterative yet efficient prototyping and production.

Mad Scientists noted that developmental approaches for this technology are predominantly "open source." Due to the vast amount of available open research and the rate at which it is published, progress in development and fielding of these technologies is increasingly "a numbers game," particularly in the fields of machine learning and artificial intelligence. Competitors need lots of science, technology, engineering and mathematics (STEM) skills to explore the huge space of low-hanging fruit.[159] The innovation race is also a STEM race, but the gap between the United States and its competitors with respect to STEM skills continues to close.

> **"The United States still offers the world's largest supply of scientists and engineers, but countries in East and Southeast Asia – most notably China – have "been catching up," the National Science Board said in its annual "Science and Engineering Indicators" report, made public Thursday afternoon.**
>
> **America's lead is "distinct but decreasing," the board said. China, it pointed out, "almost tripled its number [of researchers and science and engineering workers] since the mid-1990s."**
>
> **Meanwhile, from 2003 to 2012, China's high-tech manufacturing sector grew fivefold, an increase that tripled its contributions to global high-tech manufacturing from 8 percent of the market to 24 percent in just nine years."**
>
> US News and World Report. Feb 6, 2014

Innovation and adaptation is enabled by a set of developmental standards and frameworks that are widely adapted across DoD and the Army and serve as developmental speed enablers. Mad Scientists presented several, including:

Autonomous Ground Vehicle Reference Architecture Software Standard. The AGVRA software architecture is constructed to enable a modular approach to upgrade and acquire autonomous system behaviors for military ground systems. The AGVRA bases military autonomous software on the world largest open-source framework and development community to maximize opportunities for innovation across industry, academia and the government.[160] Subsequent spirals will increase the level of modularity of the software, adding more interfaces and enabling greater competition at lower behavioral levels.[161]

Robotic Operating System (ROS) is a collection of software frameworks for robot software development providing operating system-like functionality on a node-cluster format. ROS is open source and used by the majority of robotics developers in industry and academia. The Army is adapting ROS to be the baseline software development framework for future autonomous behaviors by creating ROS-Military (ROS-M) for military specific applications.

Robotic Technology Kernel Library. The RTK Library is a government developed, ROS-based autonomy software application library that creates a reusable foundation of autonomous platform behaviors that can be applied across multiple mission roles and systems.[162]

Unmanned Ground Vehicle Interoperability Profile (IoP). PEO CS&CSS funds TARDEC to maintain and develop their IOP which defines software messaging & hardware interfaces between major subsystems of unmanned ground systems utilizing existing standards.[163]

These developmental, open source standards are both speed enablers but also potential points of vulnerability that illuminate design and control architectures to potential "fast followers" and hackers. Internal encryption will be an important requirement for the security of future systems.

As we enter the early stages of a global innovation economy, the biggest global risk factor is not innovating fast enough.[164] In the words of Mad Scientist Dr. James Canton, there are new rules: "*Disrupt yourself before you get disrupted*."[165]

FIG V-4: Canton Presentation
Mad Scientist Conference Day 2

Combinations

Warfare has always been the art of combinations; throughout history combinations are a significant driver of conflict because outcomes belong to the competitor most imaginative and effective in presenting his adversary those combinations that pose complex, multiple dilemmas. At the national level this entails effective integration of all the elements of power: diplomatic, informational, military and economic. At the operational level the art of combining diverse capabilities in multiple domains generates joint and combined arms synergy. This set of technologies – robotics, artificial intelligence, and autonomy – is a classic example of the power of combinations. They are not only routinely applied interdependently; they have vastly enhanced potential in combination with each other as well as with legacy or emerging technologies.

Mad Scientists explored both the potential and challenges of these combinations. There is a particularly challenging combination challenge in the interaction between man and machine. Man-machine combinations that are particularly challenging include …[166]

… a human sensing using sensors of autonomous system, while controlling it via augmented reality (remotely);
… a human controlling a swarm or group of robots;
… a human overseeing autonomous control of entire fleets;
… a human specifying high-level objectives and automated agents enacting those objectives.

Solving such challenges will entail significant conceptual and technical advances – and may still leave us with some persistent dilemmas:

Inferior Interfaces. Currently the interfaces between humans and machines are relatively immature and not optimized for either component of the man-machine team. Mad Scientists pointed to requirements for progress in natural language processing and "explainable AI:" explanation of AI decision.[167] DARPA has initiated a program ("Explainable Artificial Intelligence") to address this need.[168] [169]

Infinite Situations. There will be a bewildering and virtually limitless set of complex and uncertain environments that can not possibly all be accounted for in design. Man-machine combinations will need strategies to effectively – and very quickly – transfer the appropriate learning to address new situations.[170]

System Integration. The solutions for sensing, perceiving, detecting, identifying, classifying, planning for, deciding, and responding to a very diverse and dynamic set of threats – in a very complex environment – will be innately complex. The integration challenges will be daunting.[171]

Human Unpredictability. The human component of the man-machine team is innately unpredictable – and increasingly, so is the artificial intelligence component.[172]

AI Unexplainability. Paradoxically, the application of these increased technical capabilities may actually *decrease* our ability to predict and control outcomes.[173]

Learning

A Campaign of Learning for Robotics, Artificial Intelligence and Autonomy. Because of the broad range of enabling technologies and sciences for robotics, artificial intelligence and autonomy, Mad Scientists recommended a comprehensive campaign of learning across a wide range of topics as shown below in FIG V-5.[174] [175] [176]

Manned – Unmanned Teaming	Asymmetric Awareness & Decision	Machine Learning and Artificial Intelligence	Swarming
○ Unmanned Ground Vehicles ○ Unmanned Air Vehicles ○ Robust Communications ○ Reliable/assured PNT ○ Man-machine interface	○ The Big-Data Storage and Architectures ○ Analytic Algorithms ○ Augmented Reality Situational Awareness and Targeting ○ Small Unit Leader Precision Targeting ○ Integrated Sensor Architectures	○ Unsupervised learning, generative modeling ○ Reinforcement learning for decision-making ○ Multi-task networks, transfer learning	○ Sensing and Perception ○ Navigation ○ Communications Architectures ○ Autonomous Behaviors ○ Human Factors

○ Lethality ○ Platform Protection ○ Manned Vehicles ○ Cyber resiliency	○ 3D Enriched Urban Terrain Visualization ○ Advanced Training and Simulation Technologies ○ Wearable Devices ○ Soldier Enhancement and Optimization	○ Multi-source fusion and distributed sensing ○ Human performance	○ Trust and Dynamic Team Formation ○ Heterogeneous Teams
FIG V-5 Technology Enablers for the Campaign of Learning			

In addition to the broad array of enabling technologies in FIG V-5, Mad Scientists asserted that the Campaign of Learning would be well served by basic research in areas to include:

- Life Sciences
- Material science
- Nanotechnology
- Biotechnology
- Information Science
- Quantum Science
- Socio-cultural Behavioral Sciences
- Human Performance Augmentation

Learning to Learn. Researchers are discovering techniques that enable AI software to "learn" … *how to write AI software*. "Learning to learn" developmental approaches may significantly reduce the typically huge volumes of data needed to 'learn' a specific task by inference from solutions already developed for similar – but distinct – problems. Such techniques may accelerate the development and fielding of the AI capabilities that enable our most advanced robotic and autonomous systems.[177]

> **"Google Brain's researchers describe using 800 high-powered graphics processors to power software that came up with designs for image recognition systems rivaling the best designed by humans"**
>
> Tom Simonite "AI Software Learns to Make AI Software" MIT Tech Review

Experimentation. In a future characterized by technological peer competitors, experimentation will be increasingly important. Mad Scientist Dr Sadowski offered that:

> "Successful implementation of RAS will not predominantly be a hardware race… whose robot shoots farther or better… to make these platforms truly members of the combined arms team will require user experimentation to refine/guide S&T developmental paths and enable the user to employ innovative CONOPS"[178]

Observing that artificial intelligence frequently succeeds when applied to a specific space of objects and behaviors; Mad Scientist Dr Kott recommended more experimentation, especially early in the development process. He advised that initial objectives can be simple: "Don't make the tech do everything the prior capability can. Try single things, later, combine things if you can / must."[179]

Crowd-sourcing. Institutions in all domains, including the U.S. Government, are increasingly turning to crowd-sourcing as a learning technique, and this Mad Scientist event was notable for its inclusion of this technique in the SciTech Crowd-sourcing Exercise.[180] This crowd-sourcing exercise was essentially a game, and Mad Scientists noted that ...

> "The superior human strategies stem from the mind's ability to capture the essence of a problem. Quantum concepts may seem less bizarre to people in a game than they do in other contexts, because it is an environment in which they expect rules to be broken."[181]

> There is a notion that expertise is narrow but we see the power of crowd sourcing. When you create open doors for people to showcase their work and introduce it into official channels it is powerful and enduring.[182]

Results of the SciTech Futures Crowd-sourcing exercise are described at Appendix B.

The "Art" of Learning. Mad Scientist August Cole argued compellingly that artists – particularly fiction writers -- are a strategically underutilized asset for future foresight.[183] The artistic creation of an idea often precedes the reality of novel ways of fighting.[184] The ability to think creatively and holistically is critical: the most catastrophic failures are the failures of imagination. We need to reach the young, we need to reach out internationally, and we need to reach out to those not usually heard. Cole advocated ""FICINT:" an intelligence process that monitors fictional writing. He asserted that fiction will be increasingly important for combat developers because the pace of events will otherwise outpace us. "How do you get to deep thinking? Creating the science fiction world allows you to do that."[185]

TRADOC has several calls for papers, including a science fiction "Warfare in 2035" and "Visualizing Multidomain Battle to assist in this deep thinking and provide current-future contrast necessary for effective future learning.

The following extract from the Atlantic Council's "Art of the Future" illustrates the power of fiction for imagining and envisioning the future.

The Death of Homer

> "Captain Stacy Doss felt the urge to yell to Homer, to ask him if he was OK. But that was stupid, because he was dead, and that made it highly unlikely that he would answer. Homer wasn't his real name, just a funny nickname for her favorite platoon leader. She had lost contact with him a few hours ago. He was brave, resourceful, and probably killed by an enemy warbot. And here she was, a Captain in the United States Army, sitting north of Manila, feeling the sense of guilt only commanders know after a battle. Call it the weight of command. Maybe she missed something, perhaps she could have done better. As the commander of Alpha Company, 1st Battalion, 15th Infantry Regiment, she needed to find him to pay her respects, for closure. It was what commanders did …

… Stacy finally found him, or what was left of him. He was the first one she had seen when she arrived in the unit two weeks ago. Being young and new to war, she had thought it would be cute to write Homer on the side of his hull to personalize him a bit. It seemed like a shame that the supply system knew Homer, and those like him, simply as an M316 Heavy Offensive Multi-Role Robot, or "HOMRR" for short.

She shed no tears, but had a very strange sense of guilt that she was the one who had sent him into a fight that he did not survive. He had fought bravely, courageously, and autonomously. The correct term was no longer KIA, or "killed in action," but rather DIA, or "Destroyed in Action." She had to remind herself that Homer was a robot and that had he and those like him been manned fighting vehicles, many more Soldiers would have died not only in this battle, but also in this war."[186]

(Image by Alex Brady: Laser Tank @ http://artoffuturewarfare.org/2017/02/warbot-1-0-the-death-of-homer/)

VI Conclusion

There is indeed the potential that developments in robotics, artificial intelligence and autonomy will precipitate the "Cambrian Explosion" described at this report's introduction. Efforts such as this Mad Scientist project are essential to appreciate the scope, depth, and impacts of these transformative capabilities and the innovative approaches they will enable. To the extent that we can advance that appreciation, we mitigate the risk that this 'Cambrian Explosion' becomes our 'Cambrian Conundrum.'

To that end this project has sought to *understand* the fundamental trends propelling these technologies from both a friendly and threat perspective, to include an appreciation of their speed, scope, and convergence. Building on that understanding with the insight of the Mad Scientists, we can *visualize* five principal solution approaches that leverage these technologies to address the emerging characteristics of the Future Operating Environment. We can further *describe* how solution approaches such as MUM-T, Asymmetric Awareness and Decision, Swarming, Intelligent Networks and Autonomous Sustainment can be applied to the competitions that will characterize future warfare. The outcome of those future competitions will be the consequence of how we currently *direct* the drivers of outcome: strategy and policy, concepts, innovation and adaptation, combinations, and learning.

Mad Scientists noted the wisdom generated by predecessors who also peered into an ambiguous future. Mad Scientist Dr. Gary Ackerman cited Thomas C. Schelling:

> "The danger is not that we shall read the signals and indicators with too little skill; the danger is in a poverty of expectations – a routine obsession with a few dangers that may be familiar rather than likely.... The planner should think in subtler and more variegated terms and allow for a wider range of contingencies."[187]

The challenge, as our CSA has reminded us, is to be "not too wrong." Along those lines Mad Scientist Dr. Augustus Fountain cited Wick Murray's Adaptation in War:[188]

> "Those military organizations that display imagination and a willingness to think through the changes that occur in the tactical, operational, and strategic levels in peacetime have in nearly every case been those that have shown a willingness and ability to adapt and alter their prewar assumptions and preparations to reality."[189]

In his closing remarks to the Mad Scientists, TRADOC G2 Tom Greco cited "Disrupt yourself before you are disrupted" as "the quote of the day."[190] Both Schelling and Murray would approve. So would Dr Roper, Director of the Strategic Capabilities Office:

> **"Our challenges and opportunities are great. Our challenges because they require a new playbook, but our opportunities because creating [a new playbook] is leveraging some of our nation's greatest strengths -- ingenuity, technology and ... our unparalleled operators. I like our chances.**[191]

End Notes

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Appendix A: Workshop Design & Sources

Appendix A-1: Workshop Agenda

Mad Scientist 2017:
Robotics, Artificial Intelligence & Autonomy:
Visioning Multi Domain Battle in 2030-2050
7-8 March 2017
Georgia Tech Research Institute

Agenda Day 1: 7 March 2017

0800-0830 Registration

0830-0835 *Administrative Remarks*
Mr. Lee Grubbs, TRADOC

0835-0845 *Technology Wargaming*
Mr. Aaron Chan, ASA(ALT)

0845-0910 *Welcome Remarks*
LTG Kevin W. Mangum, DCG TRADOC

0910-0930 *Opening Remarks*
Dr Steve Cross, Executive Vice President for Research, Georgia Institute of Technology

0930-0950 Dr. Augustus Fountain
Deputy Chief Scientist, Office of the Deputy Assistant Secretary of the Army (Research & Technology)

0950-1010 Dr. Robert Sadowski
Robotics Senior Research Scientist Research, Technology and Integration Director at U.S. Army TARDEC, U.S. Army Chief Roboticist

1010-1040 **Break**

1040-1140 *Machine learning and artificial intelligence for sensor processing and perception*
Dr. Zsolt Kira, Branch Chief of Advanced Machine Learning Analytics Group, Robotics and Autonomous Systems Division at the GTRI

1140-1240 *AI and Machine Learning/Translation*
Dr. Jaime Carbonell, University Professor and Allan Newell Professor of Computer Science at Carnegie Mellon

1240-1345 **Lunch Break & Robot 'Petting Zoo'**

1345-1445 *The Competitive Edge of Manufacturability*
Brynt Parmeter, NetFlex

1445-1545 *Death of the White Paper: How sci-fi stories, video games and film help us understand and prepare for Future conflict*
August Cole, nonresident Senior Fellow at the Brent Scowcroft Center on International Security at the Atlantic Council and Director of The Art of the Future Project

1545-1645 *Unmanned Aerial Vehicle Swarms*
Dr. Charles Pippin, Senior Research Scientist in the Aerospace, Transportation and Advanced Systems (ATAS) Laboratory at GTRI

1645-1745 *Arsenal of the Mind*
Juliane Gallina, Director, Cognitive Solutions for National Security (North America) IBM WATSON

1745-1800 *Closing Remarks*
MG Robert M. Dyess Jr., U.S Army, Deputy Director ARCIC

Agenda Day 2: 8 March 2017

0800-0830 Welcome Remarks
Mr. Thomas Greco, TRADOC G2

0830-0930 *Convergence of Future Technology*
Dr. James Canton, CEO and Chairman of the Institute for Global Futures

0930-1030 *Robotics and Human/Robot Interaction*
Dr. Magnus Egerstedt, Executive Director for the Institute for Robotics and Intelligent Machines at the Georgia Institute of Technology

1030-1100 **Break**

1100-1200 *Robotics and Sensors*
Dr. Nahid Sidki, Executive Director of Robotics R&D, SRI International

1200-1300 **Lunch Break**

1300-1400 *Unmanned and Autonomous systems*
Paul Scharre, Senior Fellow and Director of the Future Warfare Initiative at the Center for New American Security

1400-1500 *Non-State actors and their uses of emerging technologies*
Dr. Gary Ackerman, University of Maryland, National Consortium for the Study of Terrorism and Responses to Terrorism

1500-1600 *The Network is the Robot*
Dr. Alexander Kott, Chief, Network Science Division, Computational and Information Sciences Directorate, US Army Research Laboratory

1600-1700 *Artificial Intelligence and Machine Learning: Potential Applications in Defense Today and Tomorrow*
Louis Mazziotta, Armament Research, Development, and Engineering Center

1700-1730 *Closing Remarks*

Appendix A-2: Conference Presenters

(IN ALPHABETICAL ORDER BY LAST NAME)

Dr. Gary Ackerman, *University of Maryland, National Consortium for the Study of Terrorism and Responses to Terrorism* (Day 2)

Dr. James Canton, *CEO and Chairman of the Institute for Global Futures* (Day 2)

Dr. Jaime Carbonell, *University Professor and Allan Newell Professor of Computer Science at Carnegie Mellon* (Day 1)

Aaron Chan, Office of the ASA(ALT) (Day 1)

August Cole, *nonresident Senior Fellow at the Brent Scowcroft Center on International Security at the Atlantic Council and Director of The Art of the Future Project* (Day 1)

Dr Steve Cross, *Executive Vice President for Research, Georgia Institute of Technology* (Day 1)

MG Robert M. Dyess Jr., *U.S Army, Deputy Director ARCIC* (Day 1)

Dr. Magnus Egerstedt, *Executive Director for the Institute for Robotics and Intelligent Machines at the Georgia Institute of Technology* (Day 2)

Dr. Augustus Fountain, *Deputy Chief Scientist, Office of the Deputy Assistant Secretary of the Army (Research & Technology)* (Day 1)

Juliane Gallina, *Director, Cognitive Solutions for National Security (North America) IBM WATSON* (Day 1)

Mr. Thomas Greco, *TRADOC G2* (Day 1&2)

Dr. Zsolt Kira, *Branch Chief of Advanced Machine Learning Analytics Group, Robotics and Autonomous Systems Division at the GTRI* (Day 1)

Dr. Alexander Kott, *Chief, Network Science Division, Computational and Information Sciences Directorate, US Army Research Laboratory*

LTG Kevin W. Mangum, *DCG TRADOC* (Day 1)

Louis Mazziotta, *Armament Research, Development, and Engineering Center*

Brynt Parmeter, *NetFlex* (Day 1)

Dr. Charles Pippin, *Senior Research Scientist in the Aerospace, Transportation and Advanced Systems (ATAS) Laboratory at GTRI* (Day 1)

Dr. Robert Sadowski, *Robotics Senior Research Scientist Research, Technology and Integration Director at U.S. Army TARDEC, U.S. Army Chief Roboticist* (Day 1)

Paul Scharre, *Senior Fellow and Director of the Future Warfare Initiative at the Center for New American Security* (Day 2)

Dr. Nahid Sidki, *Executive Director of Robotics R&D, SRI International* (Day 2)

Appendix A-3: Conference Presentations

(IN ORDER OF PRESENTATION)

DAY ONE, 7 March 2017

Welcome Remarks
Mr. Lee Grubbs, TRADOC

Technology Wargaming
Mr. Aaron Chan, ASA(ALT)

Welcome Remarks
LTG Kevin W. Mangum, DCG TRADOC

Opening Remarks
Dr. Steve Cross, Executive Vice President for Research, Georgia Institute of Technology

Introductory Remarks
Dr. Augustus Fountain, Deputy Chief Scientist, Office of the Deputy Assistant Secretary of the Army (Research & Technology)

Army Robotics Technology, Research, and Integration
Dr. Robert Sadowski, Robotics Senior Research Scientist Research, Technology and Integration Director at U.S. Army TARDEC, U.S. Army Chief Roboticist

Machine Learning and Artificial Intelligence for Sensor Processing and Perception
Dr. Zsolt Kira, Branch Chief of Advanced Machine Learning Analytics Group, Robotics and Autonomous Systems Division at the GTRI

AI and Machine Learning/Translation
Dr. Jaime Carbonell, University Professor and Allan Newell Professor of Computer Science at Carnegie Mellon

The Competitive Edge of Manufacturability
Brynt Parmeter, NetFlex

Death of the White Paper
August Cole, nonresident Senior Fellow at the Brent Scowcroft Center on International Security at the Atlantic Council and Director of The Art of the Future Project

Unmanned Aerial Vehicle Swarms
Dr. Charles Pippin, Senior Research Scientist in the Aerospace, Transportation and Advanced Systems (ATAS) Laboratory at GTRI

Arsenal of the Mind

Juliane Gallina, Director, Cognitive Solutions for National Security (North America) IBM WATSON

Closing Remarks

MG Robert M. Dyess Jr., U.S Army, Deputy Director ARCIC

DAY TWO, 8 March 2017

Welcome Remarks

Mr. Thomas Greco, TRADOC G2

Convergence of Future Technology

Dr. James Canton, CEO and Chairman of the Institute for Global Futures

Robotics and Human/Robot Interaction

Dr. Magnus Egerstedt, Executive Director for the Institute for Robotics and Intelligent Machines at the Georgia Institute of Technology

Robotics and Sensors

Dr. Nahid Sidki, Executive Director of Robotics R&D, SRI International

Unmanned and Autonomous Systems

Paul Scharre, Senior Fellow and Director of the Future Warfare Initiative at the Center f or New American Security

Non-State Actors and their Uses of Emerging Technologies

Dr. Gary Ackerman, University of Maryland, National Consortium for the Study of Terrorism and Responses to Terrorism

The Network is the Robot

Dr. Alexander Kott, Chief, Network Science Division, Computational and Information Sciences Directorate, US Army Research Laboratory

Artificial Intelligence and Machine Learning: Potential Applications in Defense Today and Tomorrow

Louis Mazziotta, Armament Research, Development, and Engineering Center

Closing Remarks

Mr. Thomas Greco, TRADOC

Appendix B: SciTech Crowd-Sourcing Insights

SciTech Crowdsourcing Exercise Design

From 6-19 March, 2017, Office of the Deputy Assistant Secretary of the Army (Research & Technology) in partnership with the U.S. Army Training and Doctrine Command's (TRADOC) Mad Scientist Initiative partnered in a SciTech Futures online crowdsourced exercise.

> **"*Crowdsourcing* is the practice of obtaining information or input into a task or project by enlisting the services of a large number of people, either paid or unpaid, typically via the internet."**
>
> The term crowdsourcing was popularized in a 2004 book by James Surowieki called "The Wisdom of Crowds." In it, he described an experiment in 1906 by Francis Galton in which over 800 people asked to judge the weight of an Ox. The average guess was very close to the actual weight. In the internet age, the ability of a great many to collaborate and refine a single idea has allowed crowdsourcing to become a powerful tool for online prediction markets and if well designed, high quality forecasts that are better on average than individual expert opinion.

This exercise consisted of three basic parts. The ***Imaginarium*** was a virtual space in which online participants could post ideas and brainstorm issues related to robotics, AI and autonomous systems. The ***Workshop*** was a place in which promising ideas – as decided by exercise participants – could be sharpened and refined collaboratively. The third part of crowdsourcing exercise was the ***Marketplace***. In it, participants invested virtual currency in promising ideas.

Each registered exercise participant was given a fixed, non-transferrable amount of virtual currency each day and could place that money in ideas they believed held the most promise. Participants could evaluate ideas based on individual criteria found on each idea page, which included:

- A description of the idea.
- Description of special characteristics that make each idea new or different.
- Implications of the idea.
- Top improvements to the idea by other collaborators.
- Time frame when the idea will make a difference.
- Who will benefit most from the idea, for example, the Army, society, adversaries, etc.

The SciTech Futures Crowdsourcing Exercise web site is at: https://scitechfutures.com/ex6/.

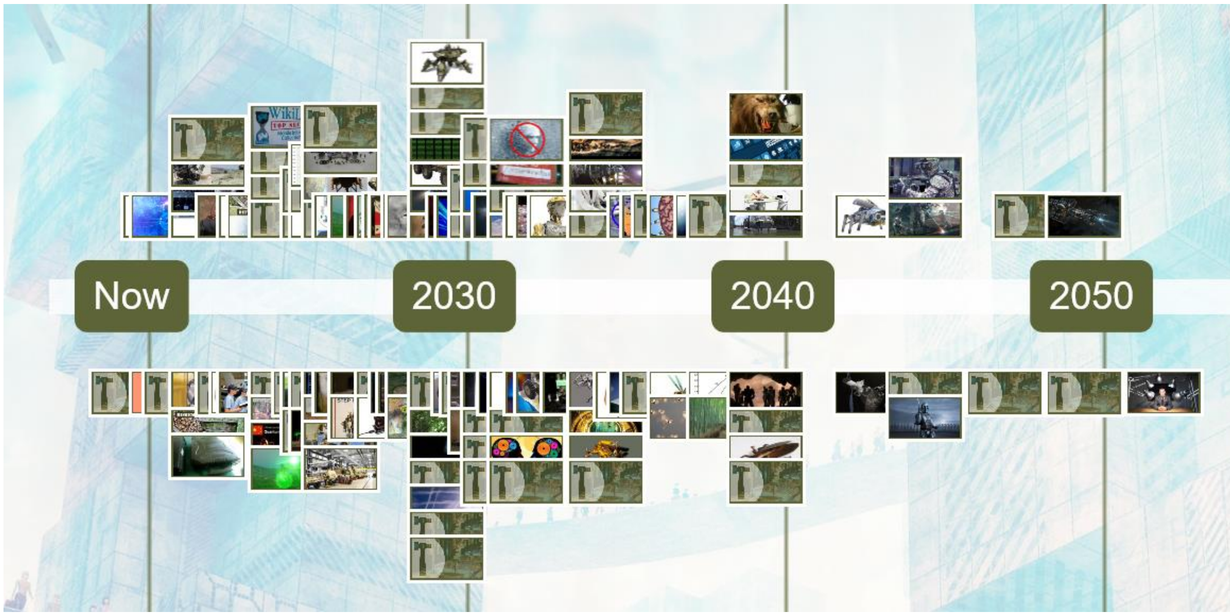
Leading Crowdsourced-Developed Ideas

The nearly two-week exercise resulted in 139 distinct, “investible” ideas within the ***Marketplace.*** Crowdsource exercise participants invested in 134 of the 139 ideas that transitioned to the marketplace. The average investment in any particular idea was $9500. The top thirty ideas by amount of investment dollars over the course of the exercise were as follows:

Rank	Idea Name	Amount Invested	Year Achieved
1	Exponential Human Intelligence	$67,000	2045
2	Man vs. Machine – Enterprise Level Approach	$55,000	2020
3	Smart Dust	$41,000	2030
4	Machine Augmentation to Staff Functions	$33,000	2025
5	Crowd-Source Game Environment	$30,500	2020
6	Recon-By Wire	$28,000	2025
7	EMP Protection Inc.	$25,500	2035
8	Robotics/AI/Cyber Geneva Convention	$23,000	2030
9	Machine Learning Pathologies	$21,500	2035
10	AI Planetary Colonization	$21,000	2050
11	Motorpool Bots	$20,500	2030
12	AI-Enhanced Network Gatekeepers	$19,000	2020
13	DigiPatton	$18,000	2040
14	Ten-Cent Defeat	$17,500	2020
15	Robotic CASEVAC	$17,000	2025
16	Mesh Networks as Alternate Internet	$16,500	2030
17	Combat Engineer Bots	$16,000	2030
18	Combating Space Junk	$15,500	2035
19	Additive Manufacturing Sustainment Brigades	$15,000	2025
20 (tie)	Follow Me!	$14,500	2030
20 (tie)	Nano-AI Vaccinations	$14,500	2030
22 (tie)	Go Medieval	$14,000	2025
22 (tie)	Potential Replacements for Honey Bees	$14,000	2040
22 (tie)	Soft Robotics for Triage	$14,000	2030
25 (tie)	Robotic Wingman	$13,500	2030
25 (tie)	FC-48 Fabship Aircraft	$13,500	2025
27	Telecommuting to War	$13,000	2035
28	Robo Lingo	$12,500	2030
29 (tie)	Multi-Layer Multi-Spectral Lens Protection	$12,000	2020
29 (tie)	Anti-Pattern Recognition Camo	$12,000	2030
29 (tie)	Counter-AI Operations Field Manual	$12,000	2030
29 (tie)	Mr. Trashwheel for Space	$12,000	2040
30	Recon Round	$11,500	2030

Marketplace Ideas by OE Solution Approach

Each of the ideas were judged by participants as to the most likely year they would be achieved or have an effect. These judgements were averaged, and the graphic below provides and overall picture of the "spread" of when individual ideas would most likely be available. Most ideas clustered in the 2030 time frame.



After completion of the exercise, the research team collected each marketplace ideas and arranged them by year according to the Operating Environment solution elements in Section III of this technical report. These are:

- Manned-Unmanned Teaming
- Asymmetric Awareness and Decision
- Swarming
- Intelligent Networks for the Internet of Battle Things
- Autonomous Sustainment

Post exercise analysis arranged each of the ideas by relevance to the OE thematic areas by the time they were expected to be available. "Top 30" ideas within each area were marked by red double asterisks (**).

Several highly ranked ideas within the top 30 (for example, Exponential Human Intelligence, Robotics/AI/Cyber Geneva Convention or Exponential Human Intelligence) could not be easily categorized or were irrelevant to the OE solution elements, and are not found in the solution element/crowdsourced idea tables.

MUM-T Crowdsourcing Observations. MUM-T-related ideas accounted for some 13% (19 of 139) of the total ideas developed during the crowdsourcing exercise. Of these, four ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Man vs. Machine: Human, AI, and Robotic Employment Optimization* was the second highest-rated idea in the entire exercise. This idea envisions a DOD enterprise-wide approaches to evaluating the relative merits of human labor vice machine labor within the DoD. This idea promises a structured method to leverage the disruptive effect of robotics, AI, and autonomy and apply MUM-T and machine labor in an optimal way. It was imagined to be available to the force by exercise participants by 2020.

The full set of MUM-T crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Manned Unmanned Teaming: Idea Name**
2020	Man vs. Machine: Human, AI, and Robotic Employment Optimization**
2020	Sort Robotic Wearables: Autonomous Tourniquet
2020	Autonomous Mine Removal
2025	Mobile Protected Firepower
2025	Cyber Manifesto
2025	AWACS 3.0 Distributed Robotic Battle Management
2025	Appliqué Autonomy Kits
2025	AI-Assist for Combat Medic
2030	Walking Combat Vehicles
2030	Robotic Wingman**
2030	Combat Engineer Bots**
2030	Combat Robot Ethos
2035	Telecommuting to War**
2035	Second Skin
2035	Backup Brain
2040	Human Accessible Robot/AI Off Switch
2040	Remote Operated Assault Robots
2040	Enhanced Others
2045	Insect Man

Asymmetric Awareness and Decision Crowdsourcing Observations. AA&D – related ideas represented the single most popular category for ideas during the exercise, accounting for nearly 24% (33 of 139) of the total set. Eight of these ideas were represented in the “top 30” ideas relevant to the Army in the future (marked with ** in the table). The top idea, Machine Augmentation to Staff Functions was the fourth highest-rated idea in the entire exercise. This idea described the application of deep learning and AI to optimize thousands of course of action, from logistics, to personnel, intelligence, and operations fed from thousands of sensor and ISR feeds. This idea would allow staffs to operate within adversary decision cycles and allow the Army to seize and retain the initiative during operations. This idea was imagined to be available to the force by exercise participants by 2025.

The full set of AA&D crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Asymmetric Awareness and Decision: Idea Name**
2020	Multi-Layer Multi-Spectral Lens Protection**
2020	Real News Aggregator
2020	A.I Assisted Searchable Portable Military Library Laptop
2020	Pocket Augmented Reality Real-Time Training
2025	Adversaries Simulating Us
2025	Autonomous Sensor Defeat
2025	Heads-Up Glasses, Dash, and Desk Displays
2025	Pocket Interactive Doctrine, Training, and Policies
2025	Anti-Autonomy Sensor Disruptors
2025	Military/Law Enforcement Rehearsals
2025	Kinetic Courier / Kinetic Jammer
2025	Multi-Mode Laser Designator
2025	Machine Augmentation to Staff Functions**
2025	Robotic Subterranean Operations
2025	AI Robotic Information Warriors
2025	Adaptive Hyperspectral Algorithm for Camouflage Detection
2025	Recon-by-Wire**
2030	Chatbot: AI Resurrected Clones of Great Thinkers
2030	EW Applied to Human Perception
2030	Cybernetic Super-Sniffers
2030	Misinformation Disintegrator
2030	Anti-Pattern Recognition Camo**
2030	Mesh Networks as Alternate Internet**
2030	Recon Round**
2030	Genetic Algorithms for Optimizing Team Composition
2030	Rent-an-Avatar Booth
2030	Counter-AI Operations Field Manual**
2035	Second Skin
2035	21st Century Non-Kinetic, Multidomain Training for All Troops
2035	TOC in a Box
2035	Ever-Present Commander – Rules of Engagement Authority
2040	DigiPatton**
2045	Ultra-Fast Battlefield

Swarming Crowdsourcing Observations. Swarming-related ideas accounted for 8% (12 of 139) of the total set. Two of these ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Ten Cent Defeat* was the 14th highest-rated idea in the entire exercise. This idea described the ability of all robots and autonomous systems to not "fail spectacularly" when confronted with primitive, low-cost defeat mechanisms, adapt, and recover functionality. The idea would apply a range of technologies and approaches to ensure that some percentage of a robotic fleet would remain operational even when confronted with novel countermeasures. This idea imagined to be available to the force by exercise participants by 2020.

The full set of Swarming crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Swarming: Idea Name**
2020	Ten-Cent Defeat**
2025	Virtual Minefield
2025	Drone Swarms
2025	Mothership/UCAV Delivery Carrier
2030	Nano-AI Vaccines**
2035	AI Prototype Platform Design
2035	Autonomous Infrastructure Repair and Maintenance
2035	Swarming Attack Nano-Bots
2035	Permanent Protective Drone Swarms
2035	Nanobot/Microbot Tracing Sensors
2040	Sleeper Drones
2045	Attack of the Clones

Intelligent Networks for the Internet Battle of Things Crowdsourcing Observations. Intelligent network-related ideas accounted for 13% (18 of 139) of the total set. Three of these ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Smart Dust* was the third highest-rated idea in the exercise. This idea described radio-frequency identification (RFID) transmitters the size of a human hair with unique number strings for tracking purposes which are deployed in varying amounts for discrete or mass surveillance. The idea would provide a new range of ISR capabilities to the force to track and monitor targets remotely and with high quality data. This idea imagined to be available to the force by exercise participants by 2030.

The full set of Intelligent Networks crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Intelligent Networks for the Internet of Battle Things: Idea Name**
2020	AI-Enhanced Network Gate-keepers**
2020	AI Research Assistants
2020	Multi-Function Weapons
2020	Report Writer: Customizable AI Research Tool
2020	Robotic Programmers, Inc.
2025	Plug and Play Military Robotics Vehicles
2025	Corrupted R&D Simulation Software
2025	Kit to Control Captured Enemy Equipment
2025	Disrupter Bots for Crowd-Sourced Online Studies
2025	Algorithms to Approximate Human Judgments
2030	Teams of Small Robots to Move Casualties to Safety
2030	Anti-Machine Pathogens
2030	Smart Dust**
2030	AI Overrun Protection
2030	Neuronet
2030	Internet of (Hostile) Things
2030	Networked Autonomous Infrastructure Sabotage Battalion
2035	Machine Learning Pathologies**

Autonomous Sustainment Crowdsourcing Observations. Autonomous Sustainment-related ideas accounted for 8% (12 of 139) of the total set. Four of these ideas were represented in the "top 30" ideas relevant to the Army in the future (marked with ** in the table). The top idea, *Motorpool Bots* was the 11th highest-rated idea in the exercise. This idea described need to develop a capability to repair and maintain robots in the future. Robots may significantly enhance PMCS as well as perform repairs and system upgrades. Once they master the controlled environment, these systems could then be outfitted with cross-country terrain mobility systems so they can follow units into the field, repairing and recovering damaged system even under direct or indirect fire. The idea would allow robots to undertake dirty, dull, and dangerous repair tasks for the Army. This idea imagined to be available to the force by exercise participants by 2030.

The full set of Autonomous Sustainment crowdsourced ideas are as follows:

Mad Scientist SciTech Futures Crowd-Sourcing Exercise	
Year Achieved	**Autonomous Sustainment: Idea Name**
2025	3D Printing for Maintenance Parts

2025	Additive Manufacturing Sustainment Brigades**
2025	Hoarder Drone
2025	Fabship Aircraft**
2025	Six Sigma Army Total Design and Maintenance
2025	Robotic CASEVAC**
2030	AI Based New Product Development
2030	Motorpool Bots**
2035	Walking Emergency or Construction Vehicles
2035	Integrated Electrical Logistics
2045	Autonomous Space Miners
2045	BN/BDE Experimentation and Upgrade Officer

Appendix C: Collection and Assessment Methodology

This appendix describes the collection, organization, and assessment of data, information, and knowledge for the ***Mad Scientist 2017 Conference: Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050***, including associated papers, speaker notes, conference discussions, and observations derived from participants in a parallel crowd sourced wargame (known as the *SciTech Futures Exercise*). Our overall approach to data collection and analysis is captured in Figure 1 below.

Collection and Assessment Topic	Description
Background	What is the situation being studied?
Purpose	Why is this study being conducted?
Key Tasks	What tasks must be accomplished, and who will do them?
End State and Deliverables	What will this effort produce? What is the deadline for the project?
Scope	What are the limits of this collection effort? Who will be involved?
Concept	What is the scale of effort and what areas must be examined? Who will conduct the study? What is the time frame for the study?
Research Questions	What are the issues to be examined? What questions must be asked to examine those issues? Optionally, hypothesize what you are trying to confirm or deny.
Key Personnel and Organizations	Who can answer these questions? Develop a list of key personnel to be interviewed.
Methodology	How will the study be organized? How will various teams interface?
Reference Material	What will be the primary documents of reference? How will they be applied in the study?
Data Collection Procedures	What quantitative and qualitative data must be collected, and how and when?
Data Management Procedures	How will collected data be managed? Who will have access to the data and at what stages of collection and analysis? Who has release authority? What are the classification procedures?

Figure 1: Overall Approach to Data Collection and Assessment

Background

On 7-8 March, United States Army TRADOC G2 conducted Mad Scientist 2017 Conference: *Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050* in partnership with the Georgia Tech Research Institute. This event explored the Army's robotics, AI, and autonomy requirements for multi-domain battle in the 2035-2050 period. This conference is part of a larger United States Army TRADOC *Mad Scientist Series* in support of the overall *Army Campaign of Learning*.

Purpose

The *Mad Scientist 2017 Conference: Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050* was designed to support the broader Army Mad Scientist initiative goals to continuously adapt, innovate, and allow for broader engagement in problem solving within the far future of armed conflict. This conference explored two broad themes related to the application of robotics, AI, and autonomous systems in future warfare. These were:

- How will AI and robotics change the relationship between humans and warfare?
- How could AI, robotics, and autonomous systems enable the United States military and its adversaries in multi-domain warfare?

This collection and assessment methodology describes how the analysis team collected and assessed the event data to provide observations and insights captured in the Quicklook and Technical Reports.

Key Tasks

Key tasks for this collection and assessment effort were derived from the Robotics, AI, and Autonomy Information Paper and the GTRI/Mad Scientist Primer briefing and included:

- Prepare for the *Robotics, AI, and Autonomy Conference* by developing a collection and assessment protocol (due 6 March 2017).
- Develop an analytic method to produce a Technical Report (due 6 March 2017).
- Observe briefings and panel discussions during the event, collect detailed notes on conference proceedings, and gather and organize the results of each phase of the conference.
- Collect and assess ongoing activities and responses within the SciTech Futures Exercise.
- Assess the results of the *Robotics, AI, and Autonomy Conference.*
- Generate a Quicklook Report providing initial insights for the TRADOC G2 AAR process (due 7 April 2017)
- Produce a Technical Report with the results of the *Robotics, AI, and Autonomy Conference* that further refines our understanding of these issues to effectively support regional, global, joint and Army Operations in Multi-Domain Battle, 2030-2050, as well as those capabilities a potential adversary may employ.
- Deliver a Technical Report within no later than 19 May 2017)
- Support HQ TRADOC analytical team, by collecting notes and developing observations and insights during the event and from live stream questions and comments and providing consolidated insights to forward TRADOC G-2 personnel at event, to aid in updates and briefings to senior U.S. Army personnel.

End State and Deliverables

The observations and insights generated in accordance with this collection and assessment methodology enabled the delivery of key insights for senior Army leaders to support the assessment of technical challenges and potential solutions related to the use of robotics, AI, and autonomy in the context of Multi Domain Battle. This analytic report is intended to assist in TRADOC G-2s understanding of these issues out to 2050. This report provides provide additional focus on how AI and robotics may change the relationship between humans and warfare. Insights are also designed to support the Army campaign of learning, contributing to an improved understanding of conflict and the character of war in the future operating environment.

All observations and insights were collected, refined, and presented in a Quicklook Report (delivered 7 April 2017) and a Technical Report (delivered 19 May 2017) that provide initial and refined observations and insights consolidating relevant data from the conference presentations, SciTech Futures Exercise, and other associated data.

The findings of the Technical Report address five potential solution areas which emerged as dominant themes during the conference. These included Manned-Unmanned Teaming, Asymmetric Awareness and Decision, Swarming, Intelligent Networks for the Internet of Battle Things, and Autonomous Sustainment. Section III of the Technical Report provides a view of potential robotics, AI, and autonomy solutions within each of these themes.

Additionally, the Technical Report arranges ideas developed during the SciTech Futures Exercise along these five themes. Each idea is arranged according to the year that participants believed that the solution might be available to the Army. A full accounting of the ideas uncovered during the exercise are found at appendix B of this report.

Observations and insights were further explored in terms of how they may impact nine "Competitions of Multi-Domain Warfare" derived from a draft study "The Operational Environment, 2035-2050: The Emerging Character of Warfare." These competitions include:

- Finders vs Hiders
- Strikers vs Shielders
- Range & Lethality vs Close Engagement & Survivability
- Disconnection / Disaggregation / Decentralization vs Connection / Aggregation / Centralization
- Offense vs Defense
- Planning & Judgement vs Reaction & Autonomy
- Escalation vs De-Escalation
- Domain vs Domain
- Dimension vs Dimension

Scope

This collection and assessment methodology describes how the team captured and refined the data, information, and knowledge developed for and during the March 2017 *Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050 Conference*, as well as robotics, AI, and autonomy-related policies and strategies as well as relevant studies that explore the nature of these advanced technologies as well as their impact on the future of warfare.

Concept

The concept to collect and assess information generated over the course of the *Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050 Conference* included the following elements:

- Conduct a survey of studies, reports, or concepts related to robotics, AI, and autonomy.
- Develop analytic structure for Technical Report that relates to Army S&T lines of effort.
- Collect notes from the assessment team captured over the course of the *Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050* using a structured set of information elements related to each of the research questions (see **Research Questions** and **Methodology** below)
- Observe SciTech Futures Exercise research questions, discussions, and outputs and integrate observations into Quicklook and Technical Reports.
- Assess the results of the *Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050 Conference*, and write an initial insights ("Quicklook) report by 7 April 2017.
- Write a Technical Report with the results of the conference, with specific recommendations to the impact of these capabilities (both U.S. and adversary) on Multi-Domain Battle.
- Complete and delivery Technical Report by 19 May, 2017.

Research Questions

This research effort was guided by seven research questions that focused note-taking, continuous analysis, and observations and insights development. These questions included:

1. What roles will AI/machine learning have in the planning, preparing, and execution of combat operations in a multi-domain conflict?

2. How will robotics and autonomy change the roles of Soldiers and Leaders in future combat?

3. How will AI/machine learning help Leaders visualize combat operations ongoing across all domains?

4. What are the ethical considerations and vulnerabilities of using or not using autonomous systems in lethal operations?
5. What are the possibilities for human machine interface that will allow Leaders to offload mental and physical responsibilities?
6. How could adversaries gain tactical and operational advantages over U.S. military forces using AI and autonomous devices?
7. What other trends will be greatly impacted – accelerated or amplified – with the explosion of AI and autonomy in society and war?

Key Personnel

The analytic effort was undertaken by Mr. David Fastabend, and Mr. Jeff Becker. This effort also relies on close collaboration with others key partners in the broader effort throughout the analytic effort, including:

- Overall study integration and senior leader support: Mr. Tom Schmidt, TRADOC G2
- TRADOC G2 POC: Mr. Lee Grubbs, TRADOC G2
- SciTech Futures Exercise Observations: Mr. Luke Shabro, TRADOC G2

Methodology

The methodology to assess data and information collected over the course of the *Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050 Conference* occured over the following four phases.

In **phase 1** (pre-conference preparation), the team conducted a comprehensive review of applicable literature, including prior Mad Scientist study reports, as well as reference material cited at Appendix C. The team began formulating the Quicklook and Final Report structures by examining the overarching themes and associated research questions, and developing a report structures that communicate key ideas such that they are easily relatable to Army S&T priorities (see Appendix A).

In **phase 2** (conference execution), two members of the research team (Fastabend; Becker) were located on-site and attend all Conference proceedings. The conference was designed around briefings by featured speakers explore issues or topics related to robotics, AI, and autonomous systems. Each was intended to spark discussion among conference participants about how these technologies and capabilities may evolve out to 2050 and the implications of these changes for the future of warfare – but particularly for the Army and Multi-Domain Battle.

The note-taking and observation development team conducted continuous assessment and synthesis of the proceedings. In order to capture conference presentations and discussion sufficient to address the research questions, the team took detailed notes and conducted continuous assessment based on the seven research questions outlined above. Note takers met meet each day immediately before and after conference sessions to share observations, and provided notes each day to Mr. Fastabend and Mr. Becker.

The team listened to each speaker presentation, and collected notes based on this method. As necessary, the team engaged with conference participants both during and after the conference to further refine and develop ideas. The team collected briefings for reference during phase 3 of the methodology. The team integrated any written materials from these panels and briefings as the foundation the Quicklook and Technical Report development and writing efforts as well.

In **phase 3** (Quicklook Report development) the team developed an initial synthesis of key findings related to the research questions. The Quicklook Report was organized according to several broad thematic areas, and focused on surfacing and refining important issues described during the *Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050 Conference* presentations and proceedings, as well as the SciTech Futures Exercise results. The exercise took place concurrently with and after the conference (from 6-19 March) and was monitored after the exercise was completed.

The team delivered a *2050 Robotics, Artificial Intelligence, and Autonomy in Multi-Domain Battle 2030-2050 Quicklook Briefing* in Microsoft Word format. It describe emerging themes in order to support AAR development for the wider TRADOC G2 effort.

In **phase 4** (Technical Report Construction) the team constructed a Technical Report keyed to inform overall TRADOC OE development and the Army Campaign of Learning. This report summarized key observations and insights from the event, the SciTech Futures Exercise, as well as implications of findings derived from the prior three phases of the study.

Reference Material

Primary reference material associated with the study is cited at Appendix D. The reference material list evolved throughout the study process and is provided as part of this final report.

Data Collection Procedures

The team conducted real-time collection management to ensure the collection of accurate and complete impressions of the event, and that notes are shared between both team members. Our analysts have documented notes from each panel and presentation of a summary sheet in Microsoft Word. Each set of notes was be collected, integrated, and stored on a Microsoft OneDrive shared file system in a Microsoft Word file. These summaries were also be shared and saved on two independent computers for continuity of operations.

The notes and analysis team held daily collaboration sessions to share key insights from the day's work and to begin to identify key and recurring themes. This disciplined and methodical cataloguing of summaries and other documents, coupled with the verbal discourse during the event enabled our team to analyze conference proceedings and develop observations and insights in a timely manner for the Quicklook Report, and comprehensively for the Technical Report.

Data Management Procedures

Data collected during the event was managed individually be the team members. The information was shared via Google Gmail and Microsoft OneDrive file structures. Only note and analysis team members have access to the data. Data release was managed by Mr. Fastabend, who will provide TRADOC G2 raw collected data and analytic materials at their request. This material is unclassified, but until publically released, is sensitive in nature. As such, it will not be shared except between the team members and between the team and TRADOC G2 authorities.

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