U.S. ARMY

DEVCOM ARMY RESEARCH LABORATORY

THE ARMY'S TECHNOLOGY FORECASTING PROGRAM – AN INNOVATIVE ENABLER TO ARMY MODERNIZATION & TRANSFORMATION TOP - LEVEL OVERVIEW

DEVCOM ARL Technology Forecasting Office

10/22/2024

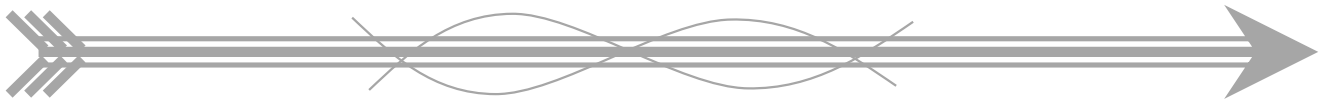
2 OCTOBER 2024

BOTTOM-LINE UP-FRONT

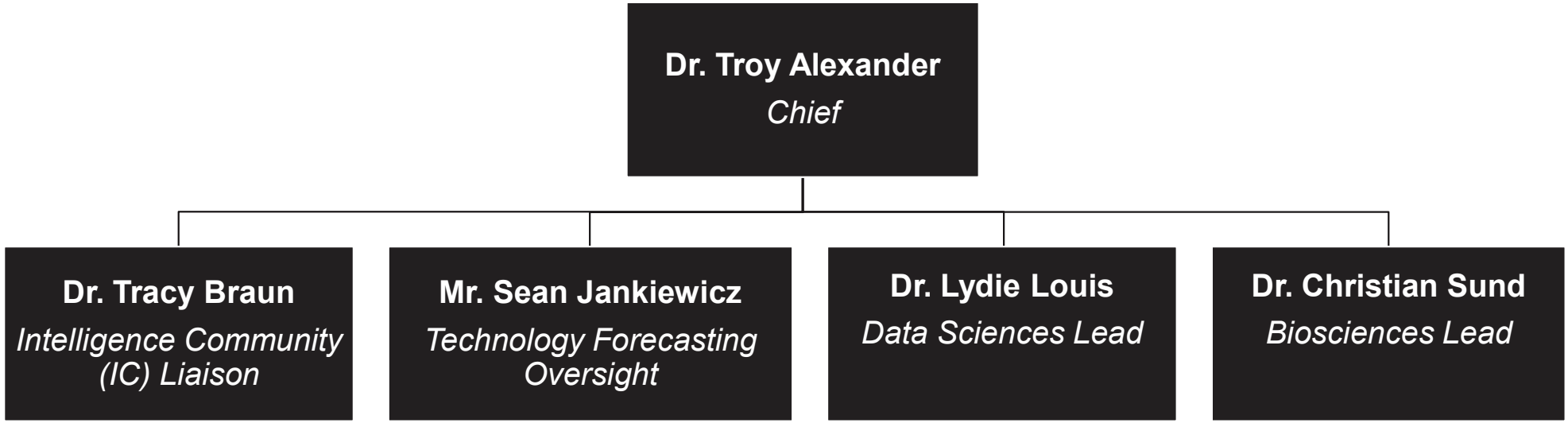
The DEVCOM ARL Technology Forecasting Office was stood-up in 2019 to support Army modernization through provision of timely, scientifically-grounded, and objective long-term technology forecasts

Since its origination, the office has developed multiple innovative methodologies to facilitate technology forecasting product realization, with the goal of helping to inform Army Senior-leader S&T decisions

The DEVCOM ARL Technology Forecasting Office, working in coordination with NGIC, develops high-order technology forecasting products to contextualize and support Army S&T decisions, anchored to anticipated S&T advances and pacing threat nation S&T directions



TECHNOLOGY FORECASTING OFFICE PERSONNEL



TFO MISSION: Provide timely, scientifically grounded, objective technology forecasts to the Army Modernization Enterprise to enable high impact warfighting capabilities

TFO VISION: The Army's primary provider of long-range, high consequence technology forecasts

HON Christine Wormuth,
25TH Secretary of the Army
AUSA Opening Ceremony,
10 October 2022

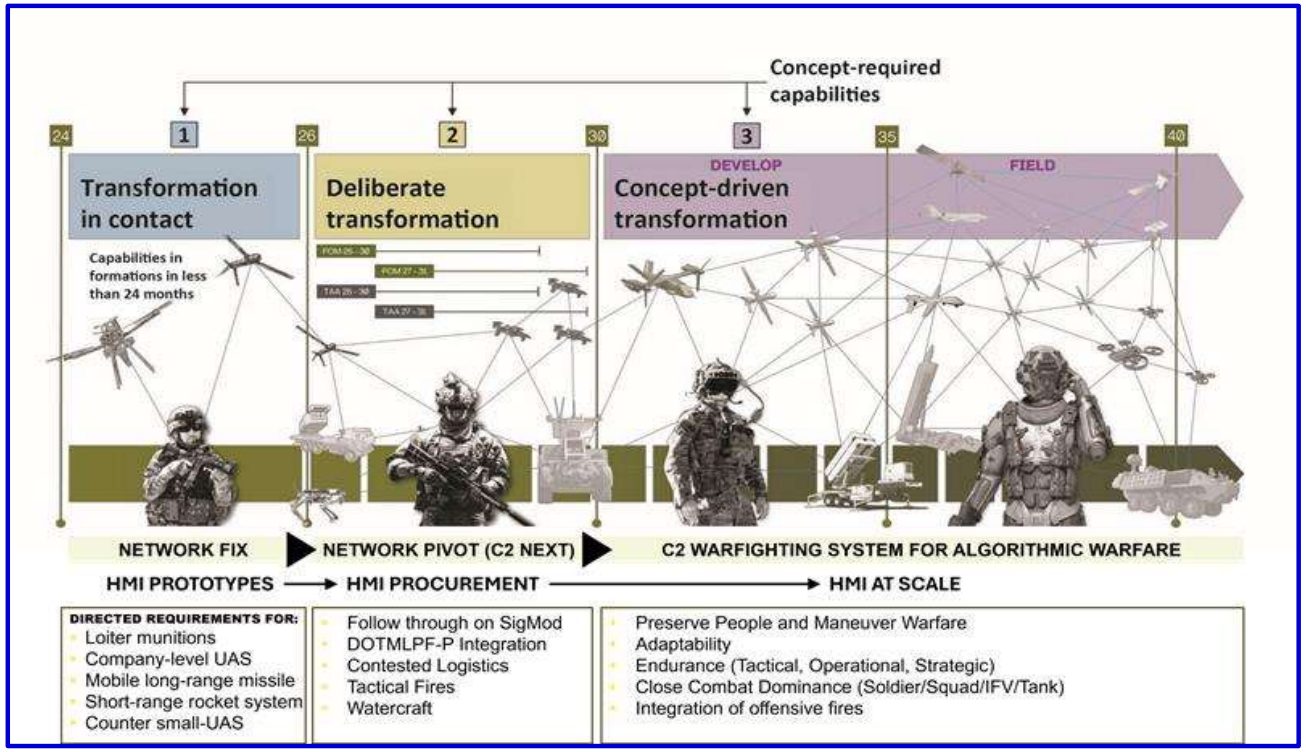
***"We will need to take the long view to* determine what foundational *investments* are needed *today* so that we are *ready tomorrow*."**

SCIENCE AND TECHNOLOGY TO ENABLE CONTINUOUS TRANSFORMATION FOR THE ARMY

GEN James Rainey
Army Futures Command, CG

First Principles (S&T) for Continuous Transformation

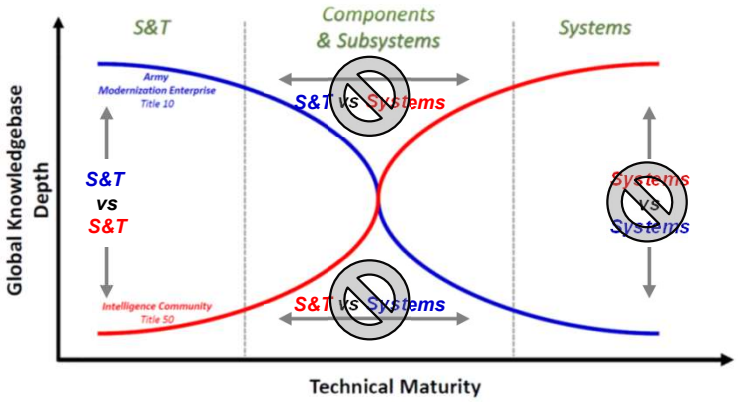
- Threat Driven.
- Focuses on specific technology for disciplined innovation and broad adoption.
- Divests of legacy systems to create assets for investment in new technology.



"The Army will provide Joint Force Commanders with the absolute ability to dominate the land domain"

ACCURATE TECHNOLOGY FORECASTING

- **Key Distinguishing Features**
  - **Leverages both Title 10 and Title 50 authorities**
    - **Intelligence-informed (I^2) estimates** – assesses threats as a foundation to develop S&T estimates
    - **Facilitates simultaneous assessment of both blue and red (future) technology developments**



- **Joint Force-focused, Army-centric**
- **Scientifically-based projections**
- **Utilizes diverse projection methods to build time-mosaicked forecasts**

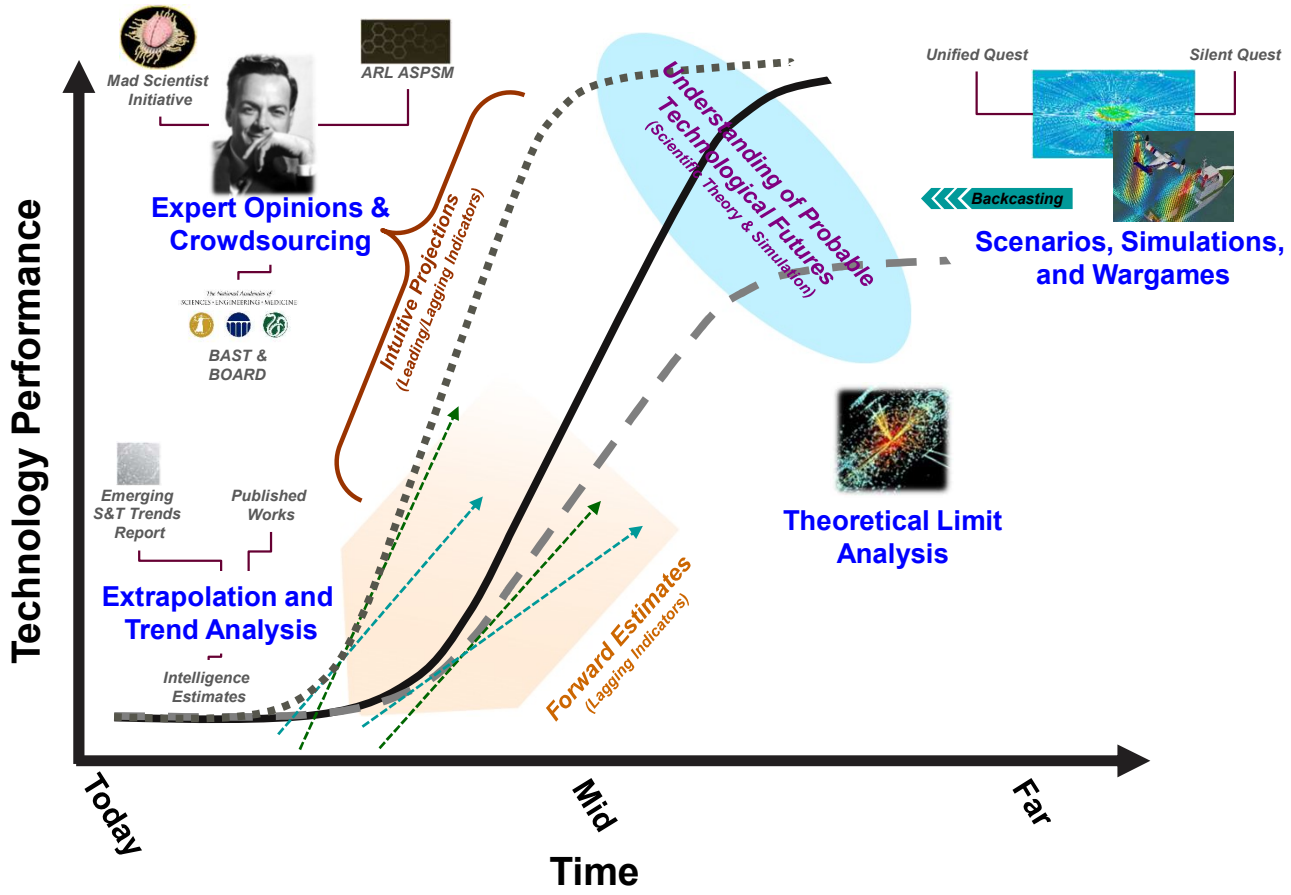
TECHNOLOGY FORECASTING BENEFITS FOR THE ARMY

	TECHNOLOGY FORECASTING	CURRENT STATUS
TECHNICAL SUPERIORITY	**Mitigates technical surprise**	'Technical Surprise' occurs as much as 70% of the time
S&T PROGRAM FORMULATION GUIDANCE	**Helps to steer towards preferred S&T outcomes**	May be at parity or overmatched in some situations
PARALLEL S&T PLANNING	**Supports identification of required future enabling or ancillary technologies**	Not currently done in a comprehensive manner
SUPPLY CHAIN	**Provides insight into probable future supply chain needs**	Not currently done in a comprehensive manner

FUNDAMENTAL TECHNOLOGY FORECASTING ASSUMPTIONS

1. The ***Nature of War*** will not change – it will continue to be primarily a human endeavor
2. Fundamental changes in the ***Character of War*** will progressively emerge
3. The Army will operate in joint, multi-domain, high-intensity environments to achieve its mission
4. Government investment and S&T activities are critical to continued innovation and invention
5. The nation's land power dominance will continue to rely on significant S&T advances that ensure the maneuver force's competitive advantage
6. Technology will continue to mature through a logistic (sigmoidal) progression
7. Technology performance is proportional to technology adoption

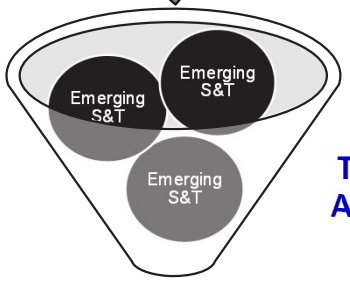
TECHNOLOGY FORECASTING METHODS



TECHNOLOGY FORECASTING OFFICE
HOLISTIC TECHNOLOGY FORECASTING FRAMEWORK

Horizon Scan

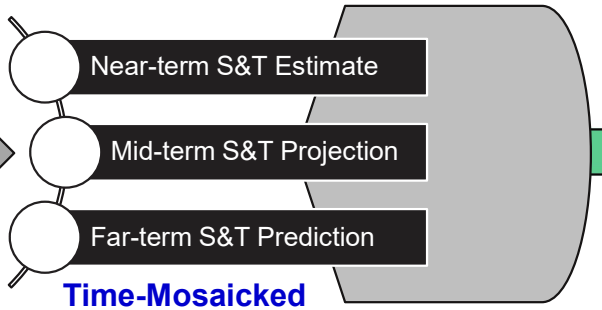
Broad-based assessment of emerging S&T fields/developments



Critical Technology Assessment

Identification of S&T areas with the highest potential to impact and influence Army operational capabilities into the deep future

Promising S&T Areas



Time-Mosaicked Technology Forecasting Method

Novel, time-based approach to prediction and projection of high-importance Army S&T areas

All Army 30-Day Sprint

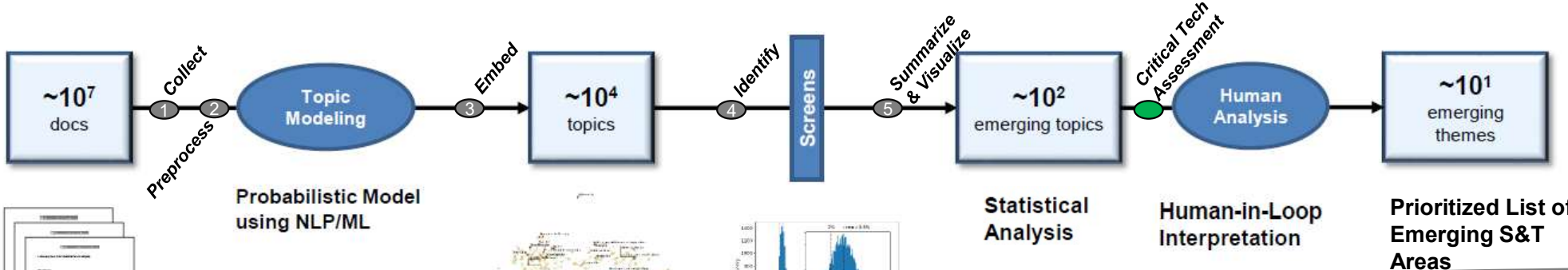
TFO Chief
TFO APRA Lead
ARL SME
DEVCOM Ctr SME
NGIC/IC SME
*75TH IC SME**

Long-range Technology Forecast

FACILITATED OUTCOMES

- ***Establish broad-based S&T baseline relative to the pacing threats***
- ***Help to identify new opportunities that guide initiation of new S&T efforts across DEVCOM Enterprise and the AME***
- ***Help to identify new Army Priority Research Areas (APRAs) and APRAs after next***
- ***Help to inform high-consequence Army S&T decisions – to shape S&T PPBE***
  - *BLUE Placemats that compliment AMIE*
  - *RED-BLUE Long-term Parity/Overmatch Assessment*
- ***Support strategic-level understanding of S&T implications on the Future OE***

HORIZON SCANNING AND PRIORITIZATION FRAMEWORK



SUMMARIZE AND VISUALIZE
Trends are summarized using a combination of **automated and expert-driven analytics**. Output can include topic summaries, keywords, geographic distributions, author networks, and many other insights.

EMBED
Documents are transformed into **fixed-length feature vectors**, giving each document a unique "fingerprint". Similar documents will be geometrically closer together in "feature space".

COLLECT
Documents and metadata on identified technology domains are gathered from **open-source databases**. Collection can be automated through APIs and done via custom import of text files, Excel workbooks, etc.

PREPROCESS
Text and metadata are preprocessed and formatted into a **common document template**. Preprocessing focuses on cleaning up text, normalizing names, fetching geolocation data, etc.

IDENTIFY
Feature vectors are fed into a graph-based **clustering algorithm** that identifies the fastest-growing trends. The algorithm also finds the most important documents for each trend.

BluePath Labs
www.bluepathlabs.com

ARMY CRITICAL TECHNOLOGY ASSESSMENT METHODOLOGY

Critical Technologies – *S&T areas with the highest potential to impact and influence Army operational capabilities into the deep future. Typically characterized by high uniqueness, superior disruptive potential, and significant probability to enable Army operational overmatch*

Three-stage selection approach

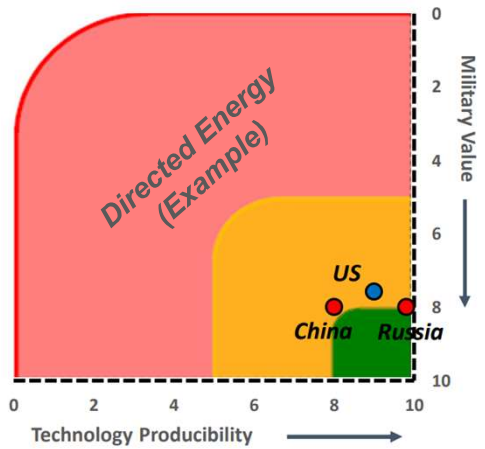
- Straight forward (dichotomous) pre-selection protocol, based on four criteria
- Scorecard to quantitatively appraise each technology
  - Technology Producibility – *4 category comparative valuation, based on technical strengths and scalability*
  - Military Value – *4 category comparative valuation, based on expected technology impacts on Army operational capabilities*
- Evaluative assessment of technologies in different micro-Operational Environments, across time-horizon
  - Comparative valuation of expected national-level performance
  - Based on Porter's Diamond and Five Forces Models

Knowledge Visualization Dashboard

- Displays data in an easily interpreted format
- Provides simultaneous display of relevant information for U.S. and competing nations

Develop a Critical Technology Assessment Methodology to help inform Army resource prioritization for S&T investments

- Guide Blue Capability Development
- Better Understand Red-threat Capabilities
- Inform technology protection strategies



S&T PRIORITIES ACROSS THE DEPARTMENT

USD(R&E)
$1.6B, FY23

Seed Areas of Emerging Opportunity
- *Biotechnology*
- *Quantum Science*
- *Future Generation Wireless Technology (FutureG)*
- *Advanced Materials*

Effective Adoption Areas
- ***Trusted AI and Autonomy***
- *Integrated Network Systems-of-Systems*
- *Microelectronics*
- *Space Technology*
- *Renewable Energy Generation and Storage*
- *Advanced Computing and Software*
- *Human-Machine Interfaces*

Defense-specific Areas
- *Directed Energy*
- *Hypersonics*
- *Integrated Sensing and Cyber*

Army
$2.7B, FY23

- *Additive Manufacturing*
- ***Artificial Intelligence***
- ***Autonomy***
- *Disruptive Energetics*
- *Hypersonic Flight*
- *Materials-by-Design*
- *Quantum*
- *RF Electronic Materials*
- *Synthetic Biology*
- *Human Sciences**

Navy
$2.6B, FY23

The Small, The Agile, and The Many
- *Attritable Platforms*
- ***Autonomy***

Decision Superiority
- *Analytics*
- ***Artificial Intelligence***

Point Defense
- *Directed Energy*
- *Missiles*
- *Small Projectiles*

Air Force
$3.15B, FY23

Global Persistent Awareness
- *Distributed, multimodal sensing*
- *Microelectronics, photonics, and materials*

Resilient Information Sharing
- *Alternative navigation*
- *Quantum Science*
- *Human-Machine Interfaces*

Rapid, Effective Decision Making
- ***Artificial Intelligence***
- ***Autonomous Electronic and cyberwarfare agents***

Complexity, Unpredictability, and Mass
- *Agile and additive manufacturing*
- ***Collaborative autonomy and swarming***

Speed and Reach of Disruption and Lethality
- *Hypersonic Flight*
- *Directed energy*

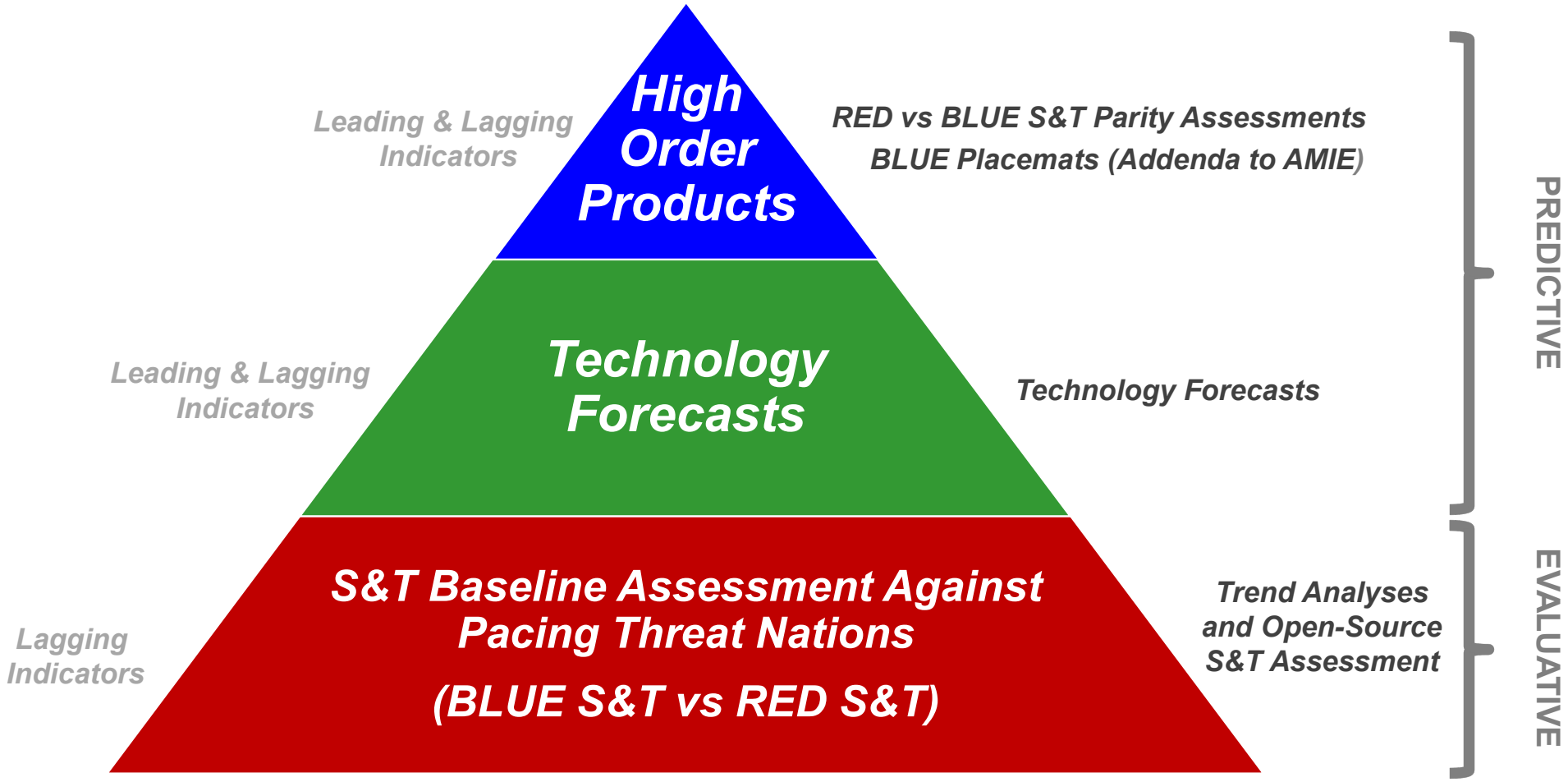
DARPA
$4.1B, FY23

AFC
"1" + "4" + "1"

The Future Operational Environment (FOE) describes not just the threat from potential adversaries, but also critical global trends across many different fields, and how those trends intersect to create both challenges and opportunities.

-GEN James E. Rainey
AFC Commanding General
13 January 2023

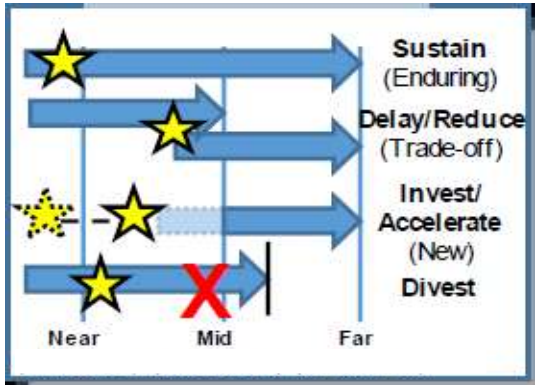
TECHNOLOGY FORECASTING OFFICE PRODUCT TYPES



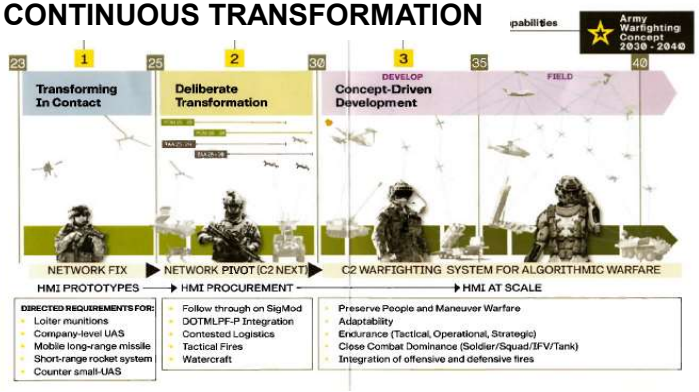
TECHNOLOGY FORECASTING TO SUPPORT ARMY MODERNIZATION AND CONTINUOUS TRANSFORMATION

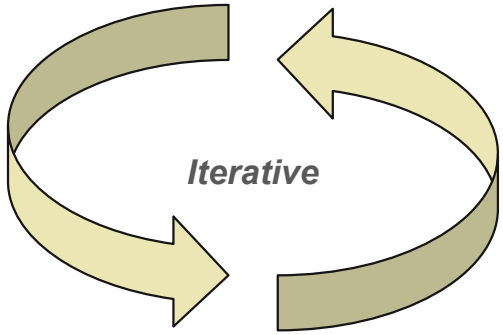
DEVCOM ARMY RESEARCH LABORATORY

ARMY MODERNIZATION FRAMEWORK



CONTINUOUS TRANSFORMATION



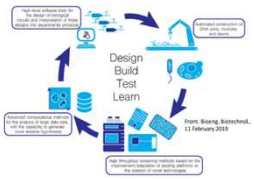


Technology Forecasting can be ....

Confirmative *– "Directed Energy"*

Guiding/Corrective *– "AI and Autonomy"*

Formulative *– "Synthetic Biology"*



TOP FIVE AREAS OF CONCERN

A. **Autonomy** – *Manned-Unmanned Teaming (MUM-T)*
   - *Armed UAV swarms demonstrated in 2019 by Chinese company*

B. **Disruptive Energetics**
   - *Russian-Chinese collaboration has led to demonstrated increase in CL-20 explosive capacity*

C. **Human Sciences** – *Human Performance Enhancement*
   - *Russia has deployed 300,000 exoskeleton systems – used in Syria; an updated version (Sotnik) will be deployed in 2025*
   - *As of 2018, China ranked #2 in world based on publications in Synthetic Biology*

D. **Hypersonic Flight**
   - In 2018, Avangard (Russia) successfully hit a target 6,000 km away, traveling up to Mach 20 speeds

E. **Quantum**
   - In 2017, China successfully entangled photons at two ground stations 1203 km apart, via Micius satellite

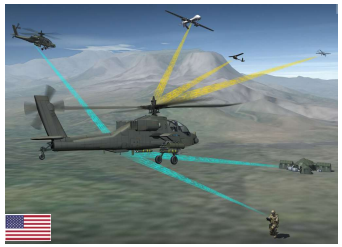
Prepared July-2022

(U) HUMAN AGENT TEAMING / MANNED-UNMANNED TEAMING

(U) OVERVIEW

(U) Human Agent Teaming (HAT) aka Manned-Unmanned Teaming (MUM-T) refers to collaboration between humans and autonomous systems. This goes beyond traditional teleoperation interfaces, encompassing a host of techniques for communication and partnership between people and unmanned systems. This includes speech control, gesture recognition, AI modeling of human intent, and emotion recognition, among others. HAT operations combine the strengths of each platform to increase situational awareness, allowing the armed forces to conduct operations that include combat support and intelligence, surveillance, and reconnaissance (ISR) missions. The U.S. Army is making HAT an established part of its tactics, techniques, and procedures (TTPs) and is likely to maintain a lead over major emerging competitors, at least over the next five years.

(U) CURRENT STATE OF THE ART



(U) Multi-platform communication for enhanced situational awareness

(U) Testing Prototype Remote Vehicle (Army)

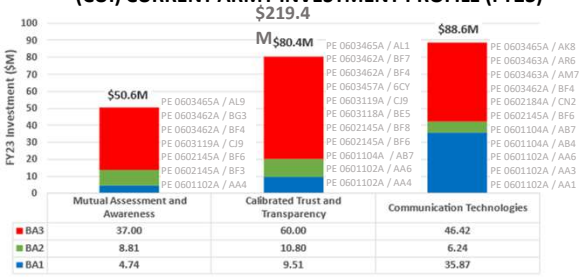
(U) EOD operating an explosive sensing robot

(U) Peer and near-peer adversaries are investing heavily in autonomous systems; however, there is very little emphasis on HAT. While the U.S. sees great potential in HAT for Battlefield Operations, China and Russia are focusing more on full autonomy and swarming technology. In 2020, Russia and China set world records by simultaneously flying 2,200 and 3,051 UAVs, respectively. Russia has operationally employed semi-autonomous UAVs in Syria and loitering munitions in Ukraine. China has pushed itself to the forefront of the self-driving industry, offering robotaxi rides in major cities. In 2022, China launched the world's first crewless drone carrier that uses AI to navigate autonomously in open water.

(U) Chinese Drone "Mothership"
(U) Fully autonomous ship that can deploy dozens of UAVs, SOFREP, JUN 2022

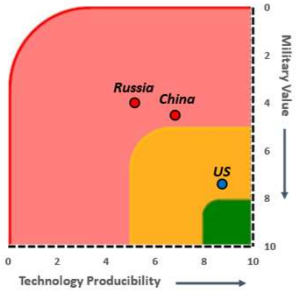
(U) Russian Semi-Autonomous Drones
(U) Launch of Orlan-10 UAVs, Vostok Exercise 2018

(CUI) CURRENT ARMY INVESTMENT PROFILE (FY23)



	Mutual Assessment and Awareness	Calibrated Trust and Transparency	Communication Technologies
BA3	37.00	60.00	46.42
BA2	8.81	10.80	6.24
BA1	4.74	9.51	35.87

(U) BENCHMARK OF U.S. AND NEAR-PEER S&T EFFORTS



(U) Russia and China are behind the U.S. in the development and implementation of HAT technologies. China and Russia likely intend to "leapfrog" HAT and focus on fielding fully autonomous systems. U.S. is making heavy investments in tech that supports teaming operations between manned and unmanned air/ground platforms. HAT is likely going to play a significant role in all future U.S. military operations. China and Russia are making significant technical strides in fully autonomous S&T.

(U) LEADING U.S. RESEARCHERS

(U) Mutual Assessment and Awareness

Bilge Mutlu	*University of Wisconsin-Madison*
Sergey Levine	*University of California, Berkeley*
Brian Scassellati	*Yale University*
Daniel Szafir	*University of Colorado, Boulder*

(U) Calibrated Trust and Transparency

Anca D. Dragan	*University of California, Berkeley*
Guy Hoffman	*Cornell University*
Daniel Szafir	*University of Colorado, Boulder*
Tathagata Chakraborti	*IBM*

(U) Communication Technologies

Anca D. Dragan	*University of California, Berkeley*
James Kennedy	*Plymouth State University*
Guy Hoffman	*Cornell University*
Mac Schwager	*Stanford University*

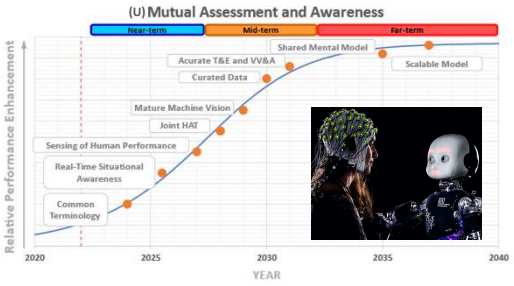
(CUI) S&T ACCELERATION OPPORTUNITIES

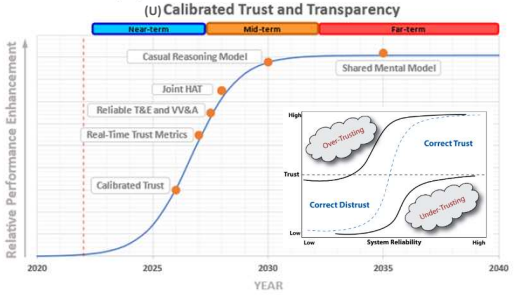
(CUI) Pursue Explainable AI and ML algorithms to optimize HAT modeling, processing, prioritization, multi-modal communication and control

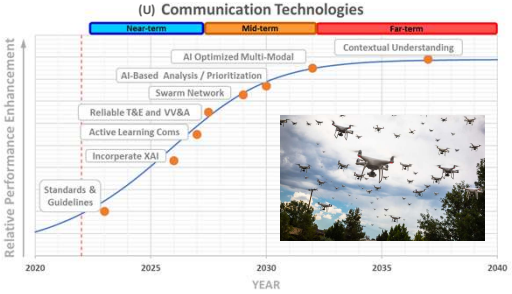
(CUI) Develop adaptive shared mental models for all aspects of HAT

(CUI) Develop community wide T&E infrastructure and nomenclature to include standards, metrics, and guidelines

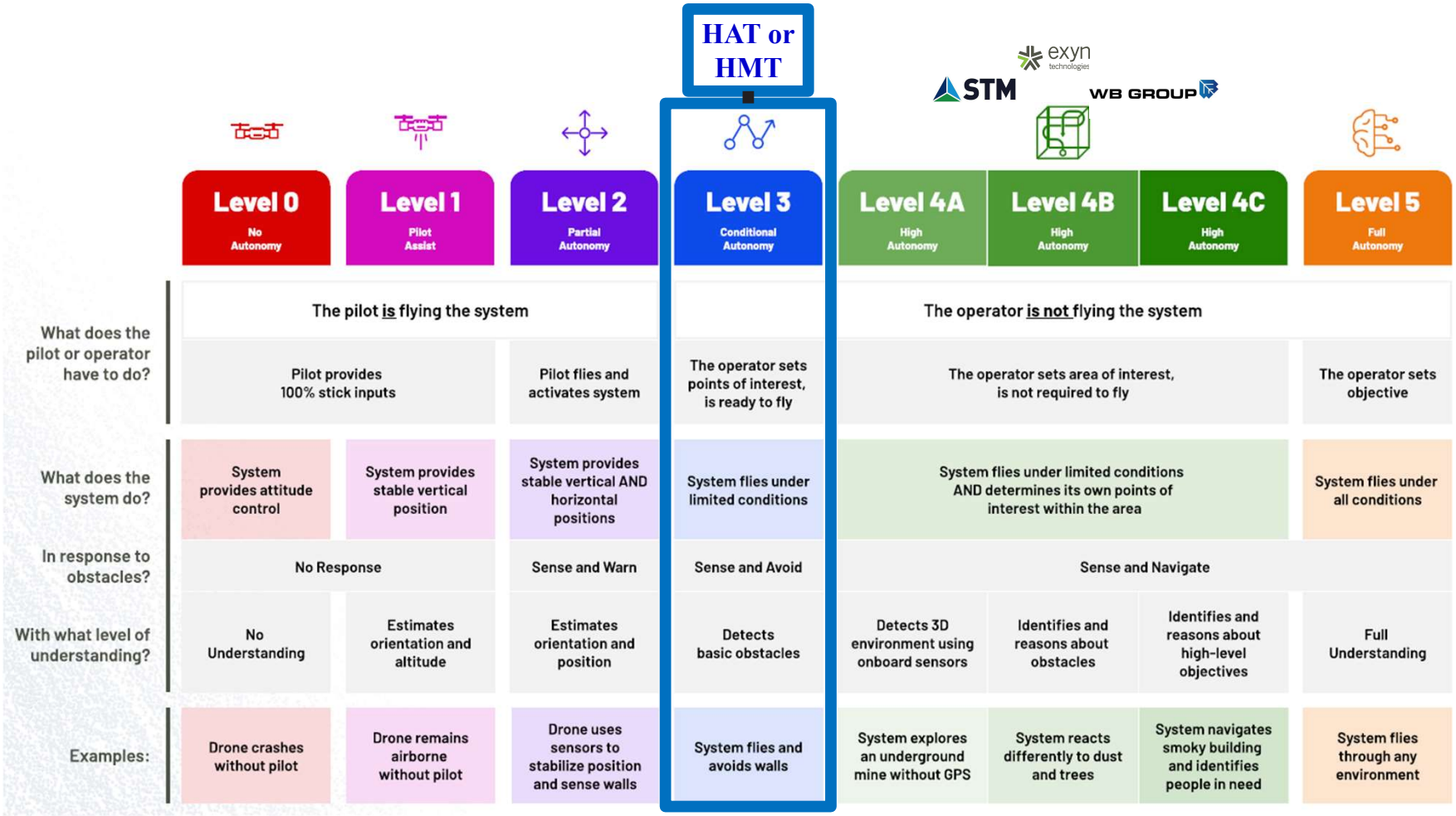
(U) ANTICIPATED S&T ADVANCES







UNMANNED AERIAL SYSTEM (UAS) AUTONOMY SCALE



COMMERCIALLY-AVAILABLE HIGH-AUTONOMY (LEVEL 4) UAV EXAMPLARS

- **Turkish company that markets high-autonomy UAVs for defense**
- **STM markets a line of "Tactical Mini UAV Systems"**
  - Kargu-2® – Autonomous Attack VTOL UAV/tactically proven in Libya (UN report)
  - Alpagu™ – Autonomous tube launched, fixed wing loitering platform
  - Boyga® – Autonomous Combat VTOL UAS with 81mm mortar drop capability
- **Modular command and control capabilities**
  - Kerkes – Makes autonomous platform operational in GPS-denied/RF-denied environments
  - Bumin – Enables rotary & fixed wing platforms to execute mission as swarm

Kargu-2
30 min mission duration
3 km MSL,ceiling

Alpagu
10 min mission duration
400 ft AGL, ceiling

Boyga
35 min mission duration
2 km MSL,ceiling

- **Philadelphia-based company that markets high-autonomy UAVs for mine exploration and mapping**
- **Marketed as *"pilotless drone that navigates complex environments"***
- **Key Features**
  - Operates in GPS-denied environments
  - Minimal Comms requirements
  - Obstacle avoidance
  - VTOL

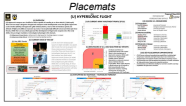
ExynAero
18 min mission duration

- **Polish company that markets high-autonomy fixed-wing, loitering UAV for defense**
- **WARMATE is marketed as *"a lightweight airframe with the ability to perform various missions"***
- **Key Features**
  - Fully autonomous attack mode, with video tracking of targets
  - Interchangeable warheads – high explosive (HE), thermobaric, training
  - Swarm-capable

Warmate
60 min mission duration
3 km MSL,ceiling

TECHNOLOGY FORECASTING PRODUCT DISSEMINATION ACROSS THE ARMY MODERNIZATION ENTERPRISE

RED-BLUE Army Technology Parity Assessment – Disruptive Energetics
CLASSIFIED


BLUE S&T Placemats

RED-BLUE Army Technology Parity Assessment in Synthetic Biology [2022]
CLASSIFIED

BLUE Placemats of Emergent, High-Consequence S&T Areas [2022]


Near-term Trend Analyses

Compendium of Army Priority Research Area Near-term Trend Analyses [2021]

Critical Technology Assessment Methodology **Development and Implementation [2020]**


Critical Technology Assessment Methodology

Directed Energy (DE) Technology Forecast (2019-2060) [2019]


Directed Energy Technology Forecast

Time-Mosaicked Technology Forecasting Methodology **Development and Implementation [2019]**

Tier III
- DEVCOM ARL Director
- DEVCOM ARL BoD
- DEVCOM ARL Workforce
- DEVCOM ARL Security Office

Tier II
- Forward Elements
- DEVCOM Commanding General (C1)
- DEVCOM Commanding General (B2)
- DEVCOM EtCG
- DEVCOM G2
- DEVCOM AC
- DEVCOM S&TI
- DEVCOM CBC

Tier I
- AFC Commanding General (R4)
- AFOSR
- AFC Commanding General (M4)
- White House Office of Science and Technology Policy
- Congress/ HASC
- AFC-DoIS
- ASA(ALT)-DASA(R&T)
- NGIC
- OSD
- Intelligence COI
- AFC DCG-A&S (T3)
- AFC TRAC
- 75TH Innovation Command
- TRADOC G2

RECOGNITION

TFO MISSION: Provide timely, scientifically grounded, objective technology forecasts to the Army Modernization Enterprise to enable high impact warfighting capabilities

As DEVCOM's Commanding General, Brown leads a world-class team of science and technology experts fully focused on empowering the future American Soldier with ***advanced Army capabilities*** made possible by ***cutting-edge technology forecasting***, research and development.

MG Edmond 'Miles' Brown, Former DEVCOM CG
AFC Chief of Staff
Excerpt from DEVCOM CG's Bio (Rev 09.21)

*"...a big piece of this **future operating environment** is tech forecasting. There is a **tech forecasting cell at the Army Research Lab**, not only from a U.S. Tech base but worldwide which looks at where the investments are being made and **where we are going to be in technology in 10 to 15 years**."*

GEN Mike Murray, 1st AFC CG (Ret.)
The National Interest,
15 June 2020

Troy, This is ***the best*** [technology forecasting] method that we have seen, ***anywhere across the government***. We thought that it was possible, but you have shown that it works!

Dr. Greg Hebner, PhD
Assistant Director for Intelligence Programs
White House-Office of Science and Technology Policy
Personal Communication – 6 September 2022

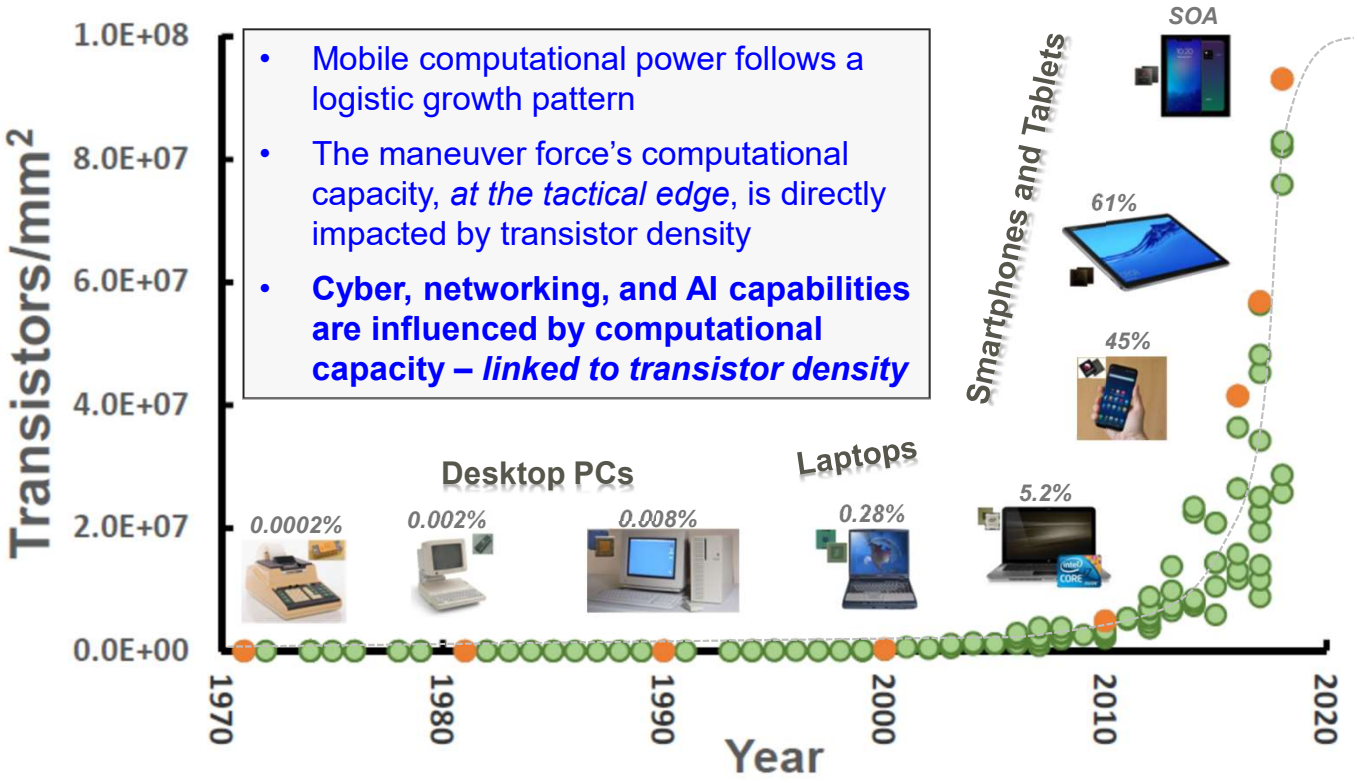
*Alexander recognized as **Distinguished Visitor** for AFOSR Spring Review*

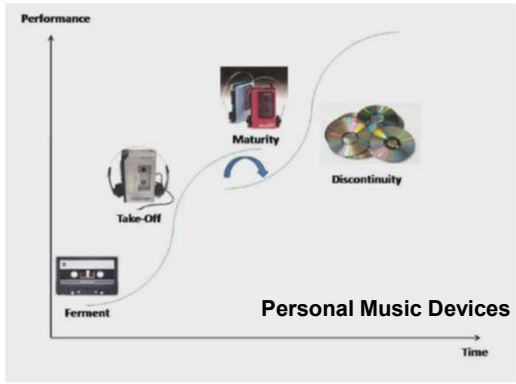
TFO invited to provide tech forecasting insights and implementation of TMTF

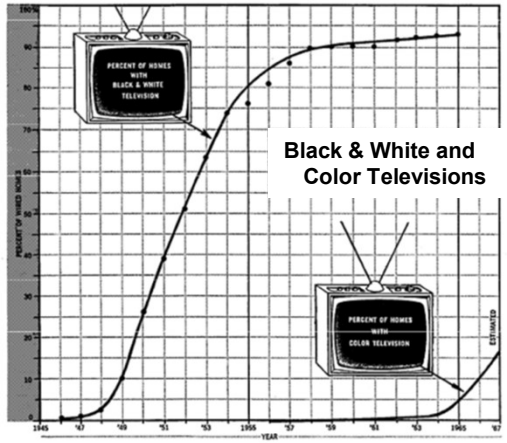
BACKUP

NON-LINEAR TECHNOLOGY MATURATION

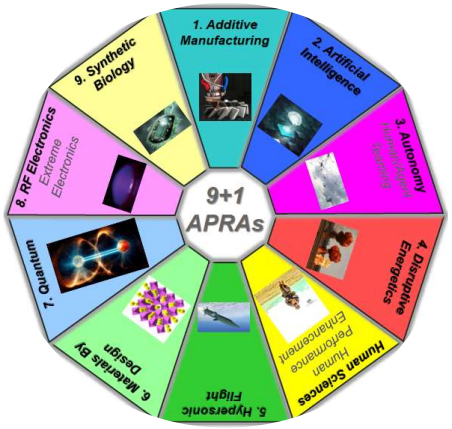
- Mobile computational power follows a logistic growth pattern
- The maneuver force's computational capacity, *at the tactical edge*, is directly impacted by transistor density
- **Cyber, networking, and AI capabilities are influenced by computational capacity – *linked to transistor density***



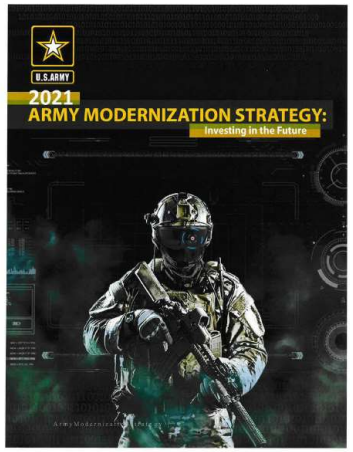




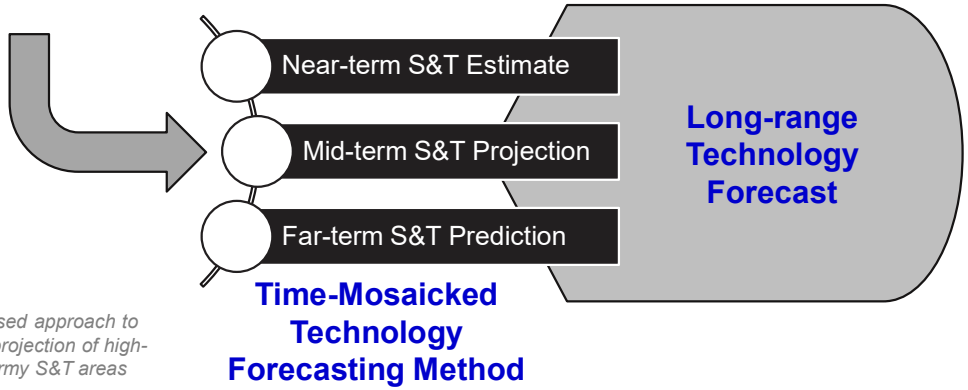
TECHNOLOGY FORECASTING OFFICE
HOLISTIC TECHNOLOGY FORECASTING APPROACH



1. Additive Manufacturing
2. Artificial Intelligence
3. Autonomy
4. Disruptive Energetics
   Human Sciences
5. Hypersonic Flight
6. Materials by Design
7. Quantum
8. RF Electronic Materials
9. Synthetic Biology

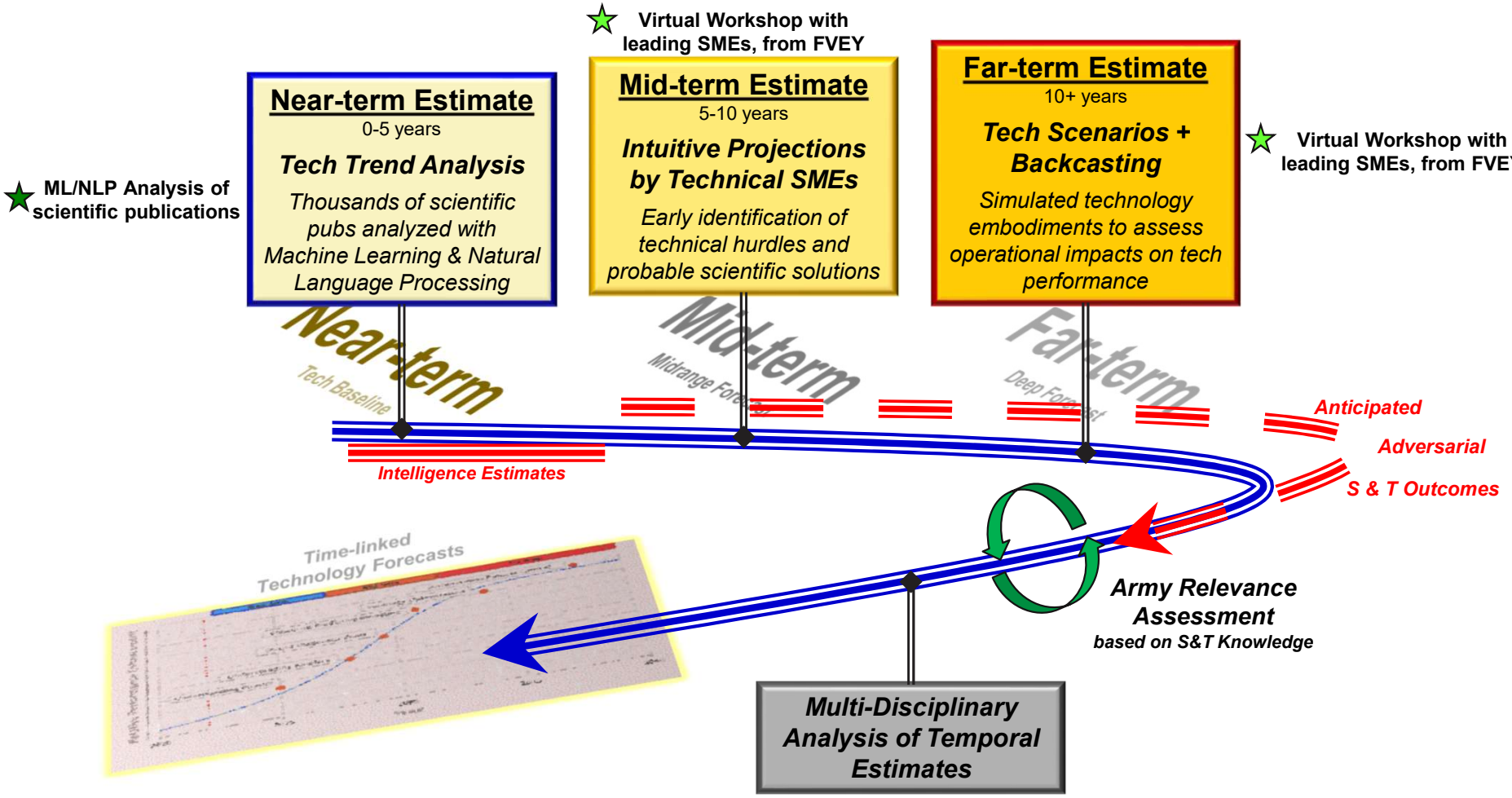


9 Army Priority Research Areas



Novel, time-based approach to prediction and projection of high-importance Army S&T areas

TIME-MOSAICKED TECHNOLOGY FORECASTING FRAMEWORK

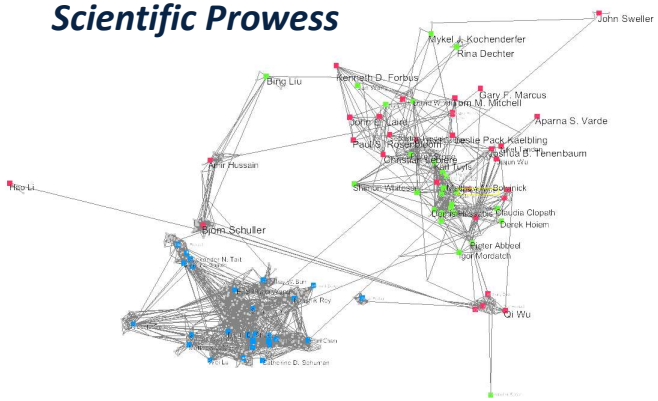


MID-TERM & FAR-TERM TECHNOLOGY FORECASTING VIRTUAL WORKSHOPS SUBJECT MATTER EXPERT (SME) SELECTION

Leverage VT-ARC's (an ARL PIA) scouting analytics methodology that combines quantitative and qualitative measures to identify diverse set of highly influential SMEs

- **~$20k per workshop (all virtual)**
- **Participation by invitation only**
- **3 Sessions over ~1.5 weeks**
- **All voluntary participation**
  - 30-35 Mid-term participants
  - 10-15 Far-term participants

Scientific Prowess



Community Leadership

- Conferences
- Professional Societies
- Journal Editors
- Industry Consortium
- Government Panels

Industry Players

PAST PARTICIPANTS IN TECHNOLOGY FORECASTING OFFICE WORKSHOPS

Dr. Mark J. Lewis is chief executive officer of the Purdue Applied Research Institute, the nonprofit applied research arm of Purdue with a particular focus on national security, economic security and food security for the United States. Lewis came to Purdue from his post as executive director of the National Defense Industrial Association's Emerging Technologies Institute, a nonpartisan think tank focused on technologies that are critical to the future of national defense. Before this position, Lewis was the director of defense for research and engineering in the Defense Department, overseeing technology modernization for the services and defense agencies, as well as the acting **deputy undersecretary of defense for research and engineering**. In that role, he was the Pentagon's senior-most scientist, managing a $17 billion budget that included the Defense Advanced Research Projects Agency, the Missile Defense Agency, the Defense Innovation Unit, the Space Development Agency, Federally Funded Research and Development Centers (FFRDC) and the Defense Department's basic and applied research portfolio.

Pamela Silver is the Adams Professor of Biochemistry and Systems Biology at Harvard Medical School and the Wyss Institute for Biologically Inspired Engineering. She received her BS in Chemistry and PhD in Biochemistry from the University of California. Her work has been recognized by an Established Investigator of the American Heart Association, a Research Scholar of the March of Dimes, an NSF Presidential Young Investigator Award, Claudia Adams Barr Investigator, an NIH MERIT award, the Philosophical Society Lecture, a Fellow of the Radcliffe Institute, and election to the American Academy of Arts and Sciences. She is among the **top global influencers in Synthetic Biology** and her work was named one of the **top 10 breakthroughs** by the World Economic Forum. She serves on the board of the Internationally Genetics Engineering Machines (iGEM) Competition and is member of the National Science Advisory Board for Biosecurity. She has led numerous projects for ARPA-E, iARPA and DARPA. She is the co-founder of several Biotech companies including most recently KulaBio and serves on numerous public and private advisory boards.

John E. Laird is the John L. Tishman Professor of Engineering at the University of Michigan, where he has been since 1986. He received his Ph.D. in Computer Science from Carnegie Mellon University in 1983. His current research focuses on cognitive architecture, integration of cognitive architecture with robotics, and interactive task learning. He is **one of the original developers of the SOAR (State, Operator And Result) cognitive architecture** and leads its continued evolution. SOAR has been used in many applications from AI classic problems to computer game AI, military training simulations, autonomous robotics, and health care applications. He is a founder and Chairman of the Board of Soar Technology, Inc. He is a founder and co-director of the non-profit Center for Integrated Cognition, a component of IQMRI. He is a fellow of the American Association for the Advancement of Science, Association for the Advancement of Artificial Intelligence, Cognitive Science Society, and Association for Computing Machinery. With Paul Rosenbloom, he was awarded the 2018 Herbert A. Simon Prize for Advances in Cognitive Systems.