AT THE HEART OF THE MISSION

NDIA 1919 100 2019

2019

ROBOTICS CAPABILITIES

CONFERENCE & EXHIBITION

Multi-Domain Operational Robotics

April 24 – 25 | Columbus, GA | NDIA.org/Robotics

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WHO WE ARE

The National Defense Industrial Association is the trusted leader in defense and national security associations. As a 501(c)(3) corporate and individual membership association, NDIA engages thoughtful and innovative leaders to exchange ideas, information, and capabilities that lead to the development of the best policies, practices, products, and technologies to ensure the safety and security of our nation. NDIA's membership embodies the full spectrum of corporate, government, academic, and individual stakeholders who form a vigorous, responsive, and collaborative community in support of defense and national security. NDIA is proud to celebrate 100 years in support of our warfighters and national security. The technology used by today's modern warfighter was unimaginable 100 years ago. In 1919, BG Benedict Crowell's vision of a collaborative team working at the intersection of science, industry, government and defense began what was to become the National Defense Industrial Association. For the past century, NDIA and its predecessor organizations have been at the heart of the mission by dedicating their time, expertise and energy to ensuring our warfighters have the best training, equipment and support. For more information visit **NDIA.org**

ROBOTICS DIVISION

WHO WE ARE

The Robotics Division focuses on security-related robotics technology. The group covers development, acquisition, application, integration and sustainment of unmanned ground systems to improve war fighters' capabilities and survivability — with an emphasis on underlying technologies that will yield integrated, interoperable unmanned systems to meet present and future operational requirements.

EVENT INFORMATION

WI-FI

Network: 2019 Robotics
Password: NDIA

SLI.DO

Join the conversation! Submit questions during the general session, visit **slido.com** and enter event code **ROBOTICS**, then click “join”.

LOCATION

Columbus Georgia Convention & Trade Center
801 Front Avenue
Columbus, GA 31901

ATTIRE

Civilian: Business
Military: Uniform of the day

SURVEY AND PARTICIPANT LIST

You’ll receive via email a survey and list of attendees (name and organization) after the conference. Please complete the survey, which helps make our event even more successful in the future.

EVENT CONTACT

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HARASSMENT STATEMENT

NDIA is committed to providing a professional environment free from physical, psychological and verbal harassment. NDIA will not tolerate harassment of any kind, including but not limited to harassment based on ethnicity, religion, disability, physical appearance, gender, or sexual orientation. This policy applies to all participants and attendees at NDIA conferences, meetings and events. Harassment includes offensive gestures and verbal comments, deliberate intimidation, stalking, following, inappropriate photography and recording, sustained disruption of talks or other events, inappropriate physical contact, and unwelcome attention. Participants requested to cease harassing behavior are expected to comply immediately, and failure will serve as grounds for revoking access to the NDIA event.

SCHEDULE AT A GLANCE

TUESDAY, APRIL 23

Registration
South Hall Lobby
12:00 – 5:00 pm

Welcome Reception Hosted by NAMC
Coca-Cola Space Science Center
6:00 – 9:00 pm

WEDNESDAY, APRIL 24

Registration
South Hall Lobby
7:00 am – 6:30 pm

Networking Breakfast
South Hall Lobby
7:00 – 8:00 am

General Session
Center Hall
8:00 am – 5:30 pm

Exhibit Hall Open
South Hall
9:00 am – 7:00 pm

Networking Lunch
South Hall
12:30 – 1:30 pm

Networking Reception in the Exhibit Hall
South Hall
5:30 – 7:00 pm

THURSDAY, APRIL 25

Networking Breakfast
South Hall Lobby
7:00 – 8:00 am

Technical Sessions
Center Hall and Room 211
8:00 am – 12:00 pm

Exhibit Hall Open
South Hall
9:00 am – 12:00 pm

TUESDAY, APRIL 23

12:00 – 5:00 pm

REGISTRATION
SOUTH HALL LOBBY

6:00 – 9:00 pm

WELCOME RECEPTION
Hosted by NAMC
COCA-COLA SPACE SCIENCE CENTER

WEDNESDAY, APRIL 24

7:00 am – 6:30 pm

REGISTRATION
SOUTH HALL LOBBY

7:00 – 8:00 am

NETWORKING BREAKFAST
SOUTH HALL LOBBY

8:00 – 8:15 am

OPENING REMARKS
CENTER HALL

LTC Matt Dooley, USA (Ret)
Chair, NDIA Robotics Division

MG James Boozer, USA (Ret)
Chief of Staff, National Defense Industrial Association

MG Gary Brito, USA
Commanding General, Maneuver Capability Development and Integration Directorate,
U.S. Army Futures Command, Ft. Benning

8:15 – 9:10 am

KEYNOTE: PREPARING FOR MULTI-DOMAIN OPERATIONS
CENTER HALL

LTG Eric Wesley, USA
Deputy Commanding General, Futures and Concepts Center, U.S. Army Futures Command

9:10 – 10:05 am

KEYNOTE: HELPING INDUSTRY UNDERSTAND THE ARMY'S EFFORT TO TRANSFORM ACQUISITIONS
CENTER HALL

Helen Greiner, SES
Army Highly Qualified Expert, Robotics, Autonomous Systems and Artificial Intelligence,
Assistant Secretary of the Army (Acquisition, Logistics and Technology)

9:00 am – 7:00 pm

EXHIBIT HALL OPEN
SOUTH HALL

10:05 –10:35 am

NETWORKING BREAK IN THE EXHIBIT HALL

SOUTH HALL

10:35 – 11:20 am

PURSUING ROBOTIC AUTONOMY THROUGH TRANSFORMATION

CENTER HALL

Paul Decker
Deputy Chief Roboticist
U.S. Army Combat Capability Development Command, Ground Vehicle Systems Center

LTC Stu Hatfield, USA (Ret)
Robotics Branch Chief, Force Development Directorate, Army G-8

11:20 am – 12:20 pm

ADVANCING AUTONOMY: INDUSTRY PERSPECTIVE

CENTER HALL

Ted Maciuba
Deputy Director, Robotics Requirements, Maneuver Capability Development and Integration Directorate, U.S. Army Futures Command
Moderator

Carl Conti
Technical Director, Spatial Integrated Systems

Jeff Schneider
Research Professor, Carnegie Mellon University

Buck Tanner
Program Director, Combat Vehicle Chief Engineer, BAE Systems

Mack Traynor
Chief Executive Officer, ReconRobotics

12:20 – 12:30 pm

AWARDS CEREMONY

CENTER HALL

12:30 – 1:30 pm

NETWORKING LUNCH IN THE EXHIBIT HALL

SOUTH HALL

1:30 – 2:30 pm

NEXT GENERATION COMBAT VEHICLE & ROBOTIC COMBAT VEHICLE UPDATES

CENTER HALL

LTC Stu Hatfield, USA (Ret)
Robotics Branch Chief, Force Development Directorate, Army G-8
Moderator

COL Warren Sponsler, USA
Deputy Director, Next Generation Combat Vehicle Cross-Functional Team, U.S. Army Futures Command

LTC Jon St. John, USA
Product Lead Robotic Combat Vehicle, Program Manager NGCV, PEO GCS

COL Kevin Vanyo, USA
Military Deputy, Combat Capabilities Development Command, Ground Vehicle Systems Center

2:30 – 3:15 pm

A CONSTELLATION OF MULTI-DOMAIN ROBOTIC CAPABILITIES

CENTER HALL

Ted Maciuba
Deputy Director, Robotics Requirements, Maneuver Capability Development and Integration Directorate, U.S. Army Futures Command

3:15 – 3:45 pm

NETWORKING BREAK IN EXHIBIT HALL

SOUTH HALL

3:45 – 4:45 pm

ROBOTICS UPDATES BY SERVICE

CENTER HALL

LTC Matt Dooley, USA (Ret)
Chair, NDIA Robotics Division
Moderator

COL Johnny Cochran, USA
Deputy Director, Close Combat Lethality Task Force, Office of the Secretary of Defense

CAPT Christian Dunbar, USN
Director, Future Concepts and Innovation, Naval Special Warfare Command

Col Kevin Murray, USMC
Director, Science & Technology, Rapid Capabilities Office, Marine Corps Warfighting Lab

4:45 – 5:15 pm

ROBOTICS AND AUTONOMOUS SYSTEMS IN ARMY SUSTAINMENT

CENTER HALL

MAJ Harry Terzic, USA
Manager, JTAARS & JCTD, Sustainment Capabilities Development and Integration Directorate, U.S. Army Futures Command

5:15 – 5:45 pm

ROBOTICS REAL-TIME RESULTS

CENTER HALL

COL Thomas Nelson, USA
Director, Robotics Requirements, Maneuver Capability Development and Integration Directorate, U.S. Army Futures Command

LTC Jonathan Bodenhamer, USA
Product Manager, Applique and Large Unmanned Ground Systems, PM-FP

5:45 – 7:15 pm

NETWORKING RECEPTION IN THE EXHIBIT HALL

SOUTH HALL

THURSDAY, APRIL 25

7:00 am – 12:00 pm **REGISTRATION**
SOUTH HALL LOBBY

7:00 – 8:00 am **NETWORKING BREAKFAST**
SOUTH HALL LOBBY

9:00 am – 12:00 pm **EXHIBIT HALL OPEN**
SOUTH HALL

TECHNICAL SESSIONS

8:00 am – 12:00 pm

TRACK I: ADVANCED AUTONOMY: OPERATIONAL AUTONOMOUS BEHAVIORS IN APPLICATION
CENTER HALL

8:00 – 8:25 am
Advanced GNSS Positioning for Cooperative Adaptive Cruise Control (CACC) Truck Platooning
Patrick Smith
Graduate Research Assistant, Auburn University

8:25 – 8:50 am
Towards a Multi-Agent/Multi-Domain World Model
Mark Hinton
Senior Systems Engineer, Johns Hopkins APL

8:50 – 9:15 am
Unmanned System (UxS) and Engineering Precepts for Safe Autonomy
Robert Alex
Engineer, Booz Allen Hamilton

9:15 – 9:40 am
Autonomy
Alberto Lacaze
President, Lead Engineer, Robotic Research

TRACK II: ROBOTICS IN APPLICATION AT THE TACTICAL LEVEL– PLATOON AND SQUAD
ROOM 211

8:00 – 8:25 am
GEDI Crazy Turtle- Stealth Performance Communication
Daniel Reyes
Chief Executive Officer, Crazy Turtle Robotics

8:25 – 8:50 am
Organic Precision Strike Using Robustly Networked Loitering Munitions and Robotic ISR
Dr. Adam MacDonald
Director, Business Development, AeroVironment

8:50 – 9:15 am
AI for Maneuver: Artificially Intelligent Robots in the Last Mile of Combat
Brandon Tseng
Chief Operating Officer & Co-Founder, Shield AI

9:15 – 9:40 am
Modular Mission Payloads for Small Unmanned Ground Vehicles (SUGV)
Dr. Richard Pettegrew
General Manager, IEC Infrared Systems

9:40 – 10:20 am **NETWORKING BREAK IN THE EXHIBIT HALL**
SOUTH HALL

10:20 – 10:45 am	**Adapting NASA Mars Rover Autonomy to Army Vehicles for Intelligent Autonomous Control** Carl Conti Technical Director, Spatial Integrated Systems	**Towards Autonomous Robotic Manipulation** Amanda Sgroi Principal Research Scientist, RE2 Robotics
10:45 – 11:10 am	**An Approach to the Development of Greater Autonomy for Combat Vehicles** Buck Tanner and Thomas McLoud BAE Systems Land and Armaments L.P.	**UAS Deployment of Micro UGV with Tactical Payloads** Mack Traynor Chief Executive Officer, ReconRobotics
11:10 – 11:35 am	**Autonomous Topography Localization and Analysis System (ATLAS)** Javier Rodriguez Aerospace Engineer, Air Force Research Lab (AFRL)	**Autonomous Precision Landing of sUAS onto Moving Vehicles at Night** David Twining Chief Operating Officer, Planck Aerosystems, Inc.
11:35 am – 12:00 pm	**Modular Multi-Purpose Autonomy-Enabled Platforms** Kevin Mulrenin Director, Pratt & Miller Engineering	
12:00 pm	**PROGRAM CONCLUDES**	

The NDIA has a policy of strict compliance with federal and state antitrust laws. The antitrust laws prohibit competitors from engaging in actions that could result in an unreasonable restraint of trade. Consequently, NDIA members must avoid discussing certain topics when they are together at formal association membership, board, committee, and other meetings and in informal contacts with other industry members: prices, fees, rates, profit margins, or other terms or conditions of sale (including allowances, credit terms, and warranties); allocation of markets or customers or division of territories; or refusals to deal with or boycotts of suppliers, customers or other third parties, or topics that may lead participants not to deal with a particular supplier, customer or third party.

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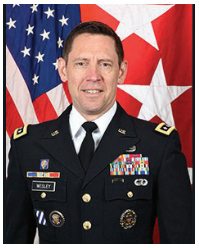
BIOGRAPHIES



LTG ERIC WESLEY, USA

Deputy Commanding General, Futures and Concepts Center
United States Futures Command

LTG Eric Wesley is currently serving as Deputy Commanding General, Futures and Concepts Center, United States Army Futures Command, Joint Base Langley-Eustis, Virginia.

LTG Wesley was commissioned as an Armor Officer from the United States Military Academy in 1986. He began his career as a Tank Platoon Leader, Scout Platoon Leader, and Battalion Logistics Officer in 2nd Battalion, 70th Armor Regiment, of the 1st Armored Division in Germany. In May 1991, he was assigned to the 1st Infantry Division at Fort Riley, Kansas where he commanded a tank company in 1st Battalion, 34th Armor, until Dec 1993. He then spent three and a half years with the United States Army Special Operations Command during which he deployed in support of OPERATION JOINT GUARD/ENDEAVOR in Bosnia-Herzegovina.

In June of 1998, he was assigned to the 2nd Brigade of the 3rd Infantry Division at Fort Stewart, Georgia, where he served as a Battalion and Brigade Operations Officer and the Brigade Executive Officer. In September 2002, he deployed with 2nd Brigade to OPERATION DESERT SPRING in Kuwait, followed by OPERATION IRAQI FREEDOM (OIF) where 2nd Brigade led the 3rd Infantry Division's attack into Baghdad. Upon redeployment, he led the staff effort to move the division to a modular organization.

LTG Wesley returned to Fort Riley in June 2004 and assumed command of a tank battalion, the 1st Battalion, 13th Armor. He deployed the "13th Tank" back to Iraq conducting combat operations in Baghdad in support of OIF from January 2005 to January 2006. Upon relinquishing command, he remained at Fort Riley serving as the Operations Officer of the 1st Infantry Division until June 2007. One year later, he returned to the "Big Red One" and assumed command of the 1st Brigade Combat Team, 1st Infantry Division. After command, he deployed to Kabul, Afghanistan serving as Chief of Current Plans for the International Security Assistance Force (ISAF) in support of OPERATION ENDURING FREEDOM. He then served for two years in the White House on the National Security Council as the Director for Afghanistan-Pakistan Policy. He later returned to Afghanistan where he was the Director for Future Plans for ISAF Joint Command in Afghanistan. He then served as the Deputy Commanding General (Support) for the 1st Infantry Division followed by duty on the Army Staff as the Deputy Director for Program Analysis and Evaluation (PAE) for the Army G8. LTG Wesley most recently served as the Commanding General, U.S. Army Maneuver Center of Excellence and Fort Benning, Georgia.

LTG Wesley's military education includes the Armor Officer Basic Course, the Armor Officer Advanced Course, and the U.S. Army Command and General Staff College. He is a graduate of the National War College, earning a Master's Degree in National Security and Strategic Studies. LTG Wesley also holds a Master's Degree in International Relations from Troy State University.

His awards and decorations include the Legion of Merit, the Bronze Star Medal for Valor, the Bronze Star Medal, the Meritorious Service Medal, and the Joint Service Commendation Medal. He has also earned the Combat Action Badge, the Parachutist Badge, and the Ranger Tab.

HELEN GREINER, SES

Army Highly Qualified Expert, Robotics, Autonomous Systems, and AI
Assistant Secretary of the Army (Acquisition, Logistics and Technology)

Helen Greiner was born in London in 1967. Her father came to England as a refugee from Hungary, and met his wife, Helen's mother, at the University of London. When Helen was five, her family moved to Southampton, New York. At the age of ten, Greiner went to see the popular film Star Wars and has said she was inspired to work with robots by R2-D2 in the film. Greiner graduated from the Massachusetts Institute of Technology in 1989 and earned her master's degree there in 1990.

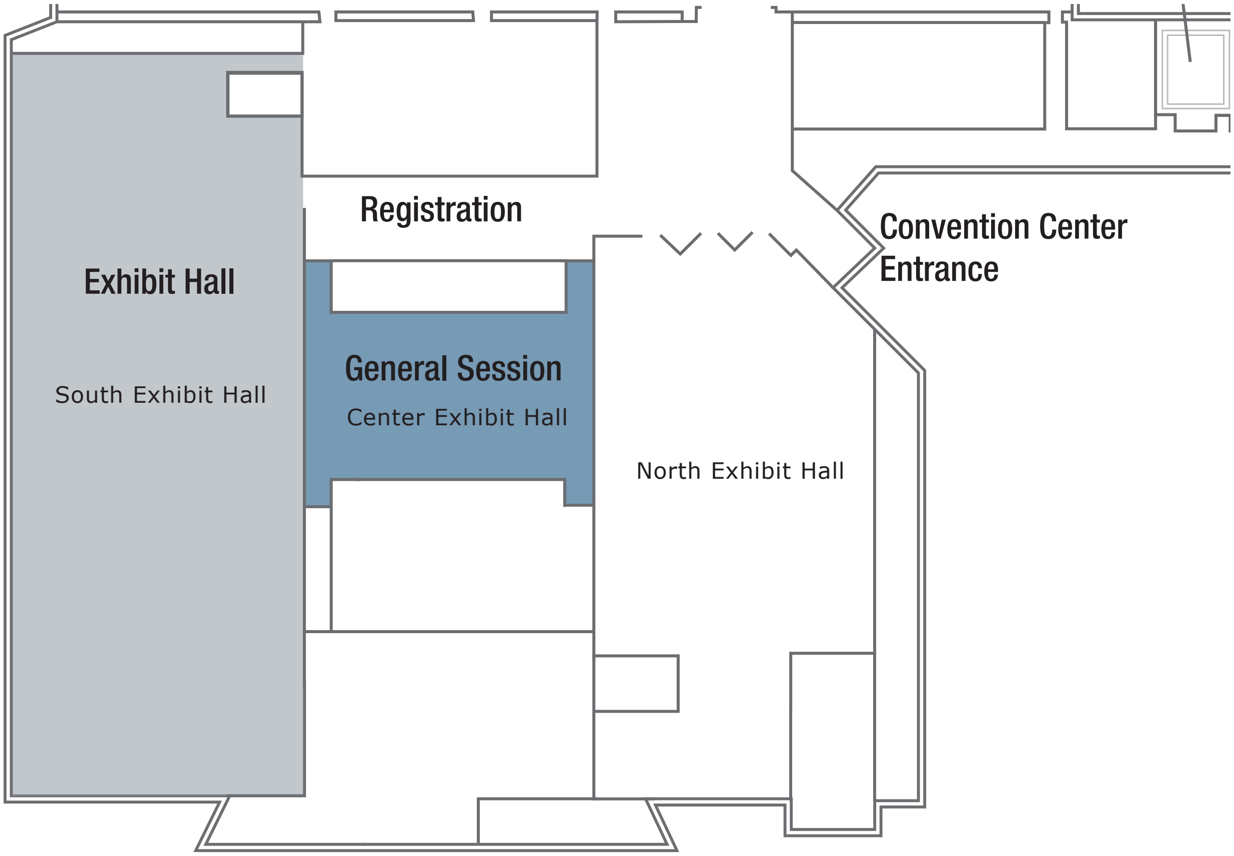
In 1990, along with Rodney Brooks and Colin Angle, Greiner co-founded iRobot, a robotics company headquartered in Bedford, Massachusetts, which delivers robots into the consumer market. She co-designed the first version of the iRobot Roomba.

Greiner served as President of iRobot (NASDAQ: IRBT) until 2004 and Chairman until 2008. During her tenure, iRobot released the Roomba, the PackBot and SUGV military robots. She built a culture of practical innovation and delivery that led to the deployment of 6,000 PackBots with the United States armed forces. In addition, Greiner headed up iRobot's financing projects, raising $35M in venture capital for a $75M initial public offering. She has worked at NASA's Jet Propulsion Laboratory and the MIT Artificial Intelligence Laboratory.

Greiner was recently CTO of CyPhy Works, home to the Persistent Aerial Reconnaissance and Communications (PARC) and Pocket Flyer multi-rotor drones. She also served on the board of the Open Source Robotics Foundation (OSRF). As of 2018, she works as an advisor to the United States Army.

VENUE MAP

LEVEL 1



LEVEL 2

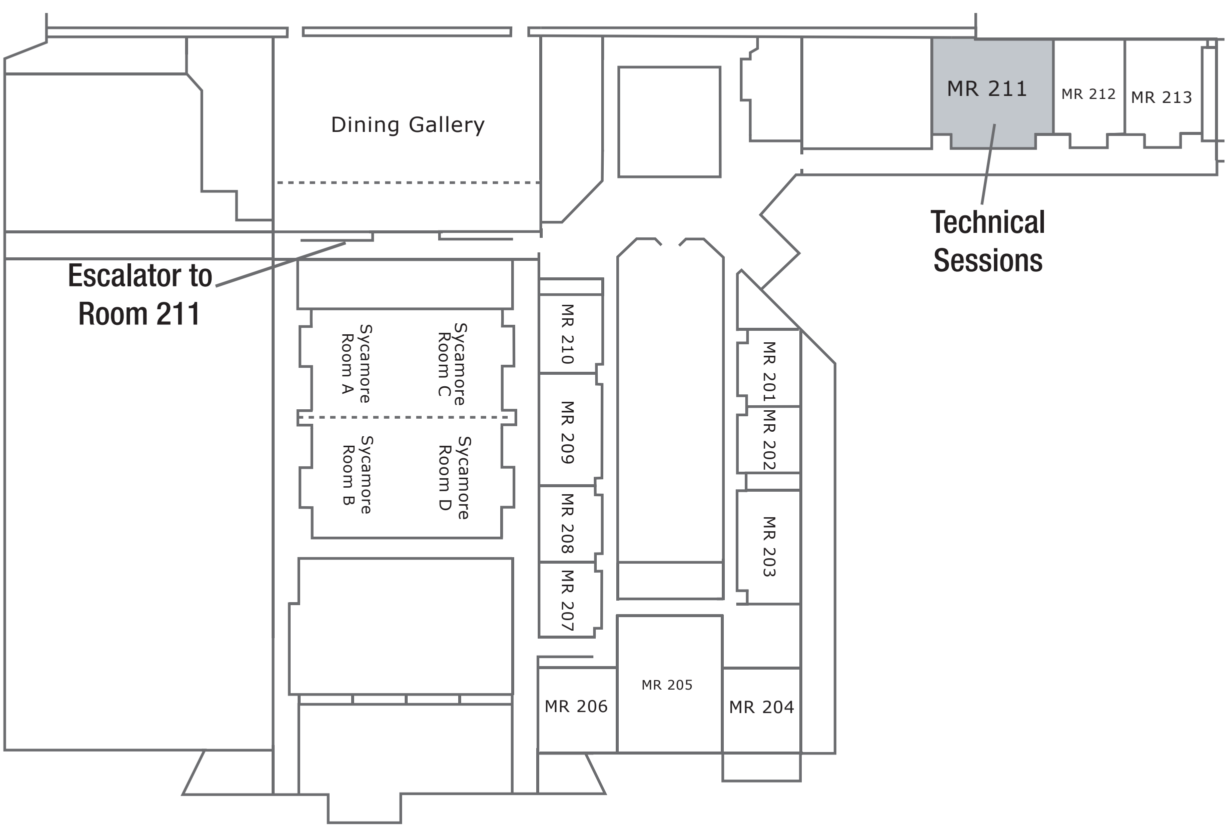


EXHIBIT HALL HOURS

WEDNESDAY, APRIL 24
9:00 am – 7:00 pm

THURSDAY, APRIL 25
9:00 am – 12:00 pm

EXHIBITORS BY COMPANY

EXHIBITOR DESCRIPTIONS

ALTAVIAN 201

Altavian is a privately held U.S.-based Unmanned Aircraft System design, manufacturing, and solutions provider. Founded in 2011, our extensive history includes working alongside organizations including U.S. Army Corps of Engineers, NASA, and the U.S. Army. We embrace open architectures in our systems design to bring proven commercial concepts to Group I UAS. Altavian is headquartered in Gainesville, FL.

DEFENSE MOBILITY ENTERPRISE 213

DME's mission is to provide the Government with ready, quality access to the broadest population of U.S. ground vehicle system (GVS), sub-system, and component technology developers and providers in a competitive environment; working in partnership with the Government to implement and refine business processes and tools to streamline individual project contract administration; and to expedite the innovation, development, and production of new GVS capabilities for U.S. warfighters.

DEFENSE SYSTEMS INFORMATION ANALYSIS CENTER DSIAC 312

The Defense Systems Information Analysis Center (DSIAC) is a component of the U.S. Department of Defense's Information Analysis Center (IAC) enterprise.

The purpose of DSIAC is to provide information research and analysis for DoD and Federal government users to stimulate innovation, foster collaboration, and eliminate redundancy.

DSIAC aims to be the premier information research partner and curator of technology advancements and trends for the defense systems community.

FLIR 205

FLIR UIS Division comprises the largest global provider of tactical unmanned ground vehicles as well as leading nano and Class-1 unmanned aircraft systems (UAS). We design and build the most trusted, rugged, easiest-to-operate robots used to safeguard life and property around the world. Whatever the mission, our advanced robots are out there every day supporting US and international military, law enforcement, and industrial users.

GHOST ROBOTICS 311

Robots That Feel the World® Ghost Robotics™ is revolutionizing legged robotics and the market for autonomous unmanned ground vehicles (Q-UGVs) used in unstructured terrain and harsh environments. Our Q-UGVs are unstoppable. Beyond all terrain operation, a core design principle for our legged robots is size-scalability, and reduced mechanical complexity with total software (SDK) control when compared to other legged and traditional wheeled and tracked UGVs on the market.

HARRIS CORPORATION 211

Harris Corporation is a leading technology innovator, solving customers' toughest mission-critical challenges by providing solutions that connect, inform and protect. Harris supports government and commercial customers around the world. Learn more at harris.com.

NEYA SYSTEMS 310

Neya Systems, LLC, is a 40-person unmanned systems company in Warrendale (Pittsburgh), PA. Our expertise includes off-road autonomy in unstructured natural environments, multi-robot mission planning and collaboration, interoperability, and open architectures. Neya works with Government and industry customers to provide custom autonomy solutions to challenging outdoor problem. Neya is a wholly owned subsidiary of Applied Research Associates.

ODU USA 217

ODU is a worldwide leader in designing and manufacturing high-performance connector solutions and cable assemblies for various industries including medical, military, industrial, test and measurement, eMobility, energy and broadcasting. ODU Advanced Connector Solutions: lightweight & compact, robust design, high speed data transmission, watertight protection and cable assembly integrated solutions.

QINETIQ NORTH AMERICA 306

Around the world, our land robots such as TALON and Dragon Runner have provided safety and support to the military and first responders. We offer robots in various sizes and capabilities to support specific tasks, such as IED defeat, CBRN/hazmat, reconnaissance, security, dismounted troop support and route clearance. We are proud to be named the winners of the RCIS (Route Clearance Interrogation System) and CRS-I (Common Robotic System-Individual) Program of Record by the US Army.

REAL-TIME INNOVATIONS 314

Real-Time Innovations (RTI) is the Industrial Internet of Things (IIoT) connectivity company.

The RTI Connext® databus is a software framework that shares information in real time, making applications work together as one, integrated system. RTI is the largest vendor of products based on the Object Management Group (OMG) Data Distribution ServiceTM (DDS) standard.

RECONROBOTICS, INC. 307

ReconRobotics is the world leader in tactical micro-robot and personal sensor systems. Worldwide, over 6,000 of the company's robots have been deployed to the U.S. military and international friendly forces, federal, state and local law enforcement agencies, bomb squads and fire/rescue teams. The Recon Scout® and Throwbot® devices are used daily to protect their personnel, minimize collateral damage, and gain immediate reconnaissance within dangerous and hostile environments.

SHIELD AI 215

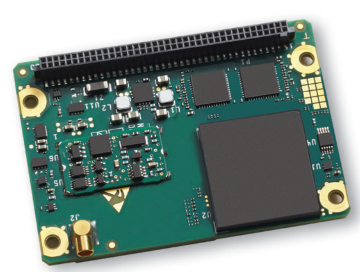
Shield AI is an artificial intelligence robotics company building products for the DoD and first responders. Our mission is to protect service members and civilians with artificially intelligent systems. Shield AI's current products are Hivemind and Nova. Hivemind is an AI framework that enables robots to see, reason about, and search the world. Nova is a Hivemind-powered, robotic quadcopter that autonomously searches buildings while streaming video and building maps back to the user.

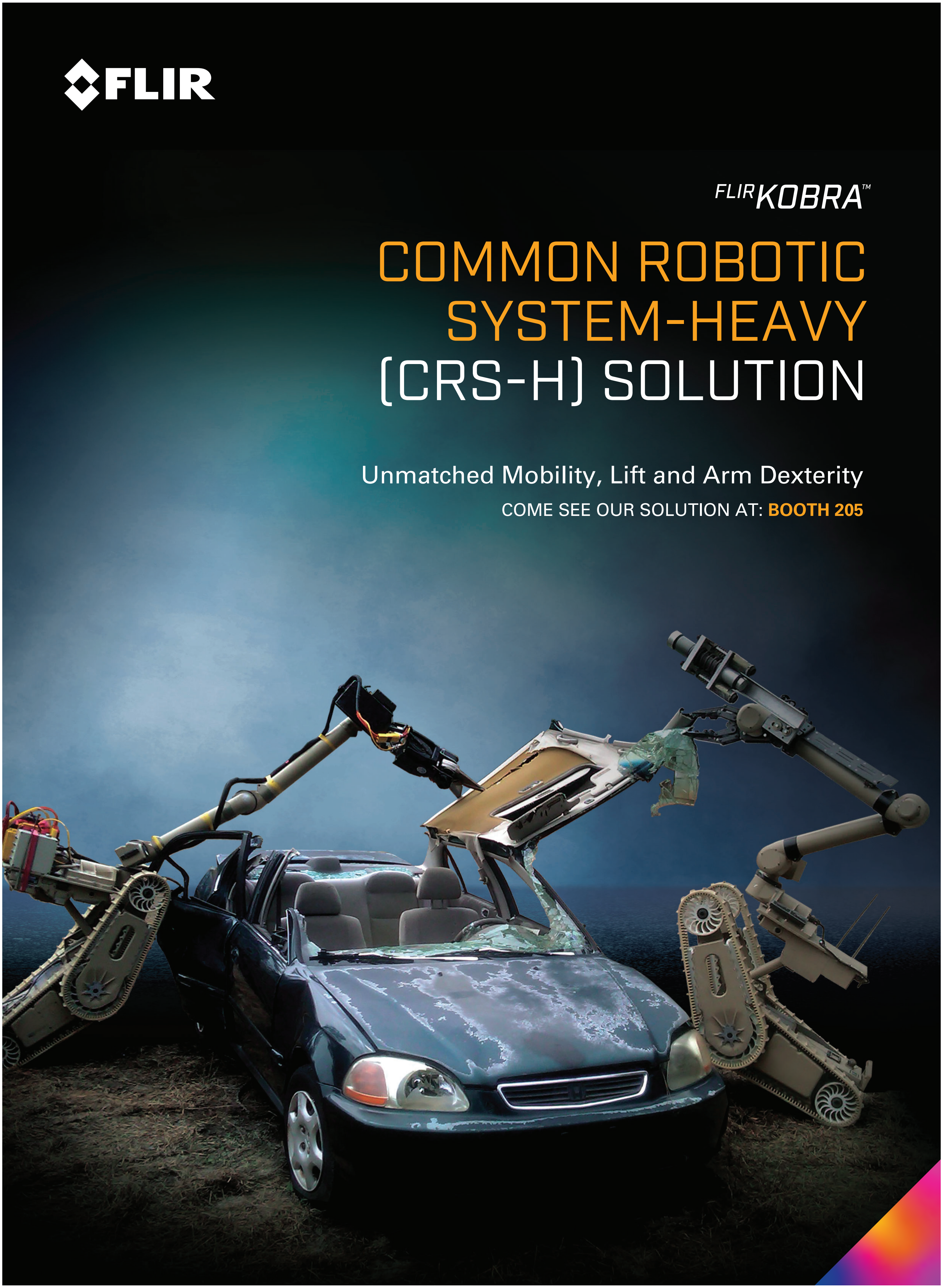
TOMAHAWK ROBOTICS 203

Tomahawk Robotics is a leading innovator of unmanned systems control solutions- reducing cost, optimizing system performance and improving ease of use through intuitive, user-centric design. This customer-focused approach is captured in Kinesis, addressing the many challenges of operating multi-domain robotic systems beyond line-of-sight. From desktop to mobile, Kinesis delivers a collaborative, one-to-many, control system enabling users to seamlessly interact with their environment.

NOTES

Photo courtesy of Oshkosh Defense, LLC.




FLIR
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Unmatched Mobility, Lift and Arm Dexterity
COME SEE OUR SOLUTION AT: BOOTH 205

Futures and Concepts Center

LTG Eric Wesley
Director, Futures and Concepts Center
24 APRIL 19

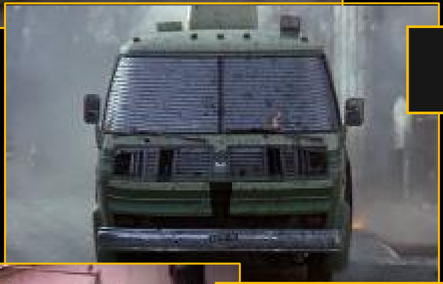
Compete Penetrate Dis-Integrate Exploit Re-Compete

Next Generation Combat Vehicle

EM-50 Urban Assault Vehicle

EM-50 Urban Assault Vehicle

Mobile



Survivable

Troop Transport

Lethal

It even closed with,…

…engaged, and destroyed…

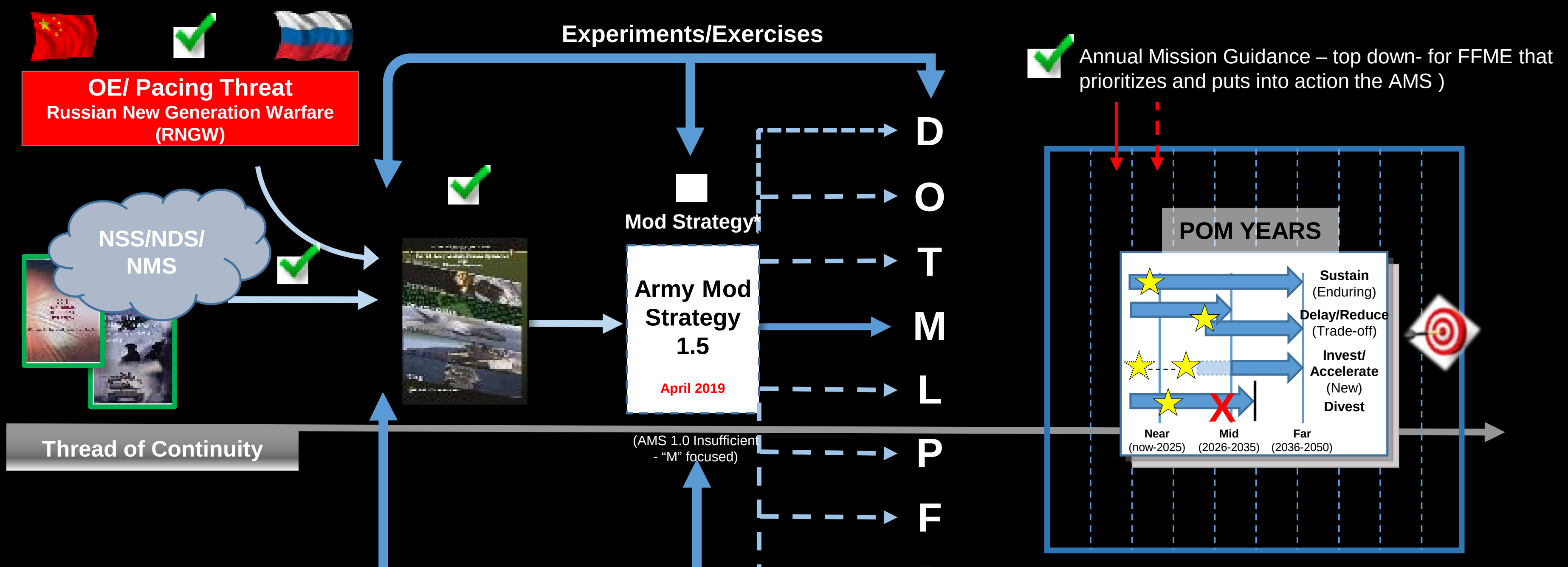
…an enemy in close combat

And easy to learn and operate by even the most “challenged” of soldiers

…who may one day rise to become a General Officer.

Modernization Framework

"The Army of 2028 will be ready to deploy, fight and win decisively against any adversary, anytime and anywhere, <u>in a joint, combined, multi-domain, high-intensity conflict,</u> while simultaneously deterring others and maintaining its ability to conduct irregular warfare"
- SEC Mark Esper, GEN Mark Milley



The Army needs a threat/OE based, operationally driven framework for modernization (AMS 1.5, ACP, …<u>a single, nested narrative</u>)

*Note: AMS 1.5 must address a comprehensive DOTMLPF-P modernization plan; the current AMS is "M" focused while CAC has sought to maintain doctrinal change commensurate with capability.

Ideally, the AMS becomes an Army guidance document driving the entire enterprise across the ACOMs…potentially serving as the modernization chapter to the ACP (LOE #2 of the Army Strategy)

Concepts Drive Change

Operational Environment

- ❑ Identifies four interrelated trends that shape the future Operational Environment
    - ➢ Contested in all domains
    - ➢ Increasingly lethal and hyperactive battlefield
    - ➢ Leverage Competition Space
    - ➢ Multiple Layers of Standoff
- ❑ Challenged deterrence

Central Idea

Army forces, as an element of the Joint Force, conduct Multi-Domain Operations to prevail in competition; when necessary, Army forces penetrate and dis-integrate enemy anti-access and area denial systems and exploit the resultant freedom of maneuver to achieve strategic objectives (win) and force a return to competition on favorable terms.

Current Force Posture Options

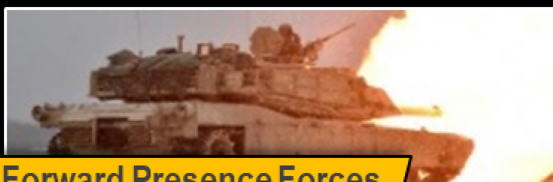
- ***Do nothing*** and concede competitor actions and readjust strategic objectives
- ***Win a protracted conflict*** by regaining the operational initiative and defeating enemy forces

MDO Capable Force 2028/2035 Options

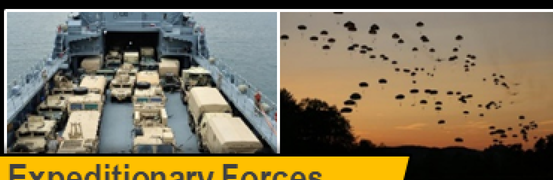
- ***Do nothing*** and concede competitor actions and readjust strategic objectives
- ***Expand the competitive space*** on favorable terms to deter enemy aggression *(preferred method)*
- ***Respond quickly*** to deny a *fait accompli* attack and achieve an operational position of advantage
- ***Win a protracted conflict*** by regaining the operational initiative and defeating enemy forces

Tenets of Multi-Domain Operations

Calibrated Force Posture



Forward Presence Forces

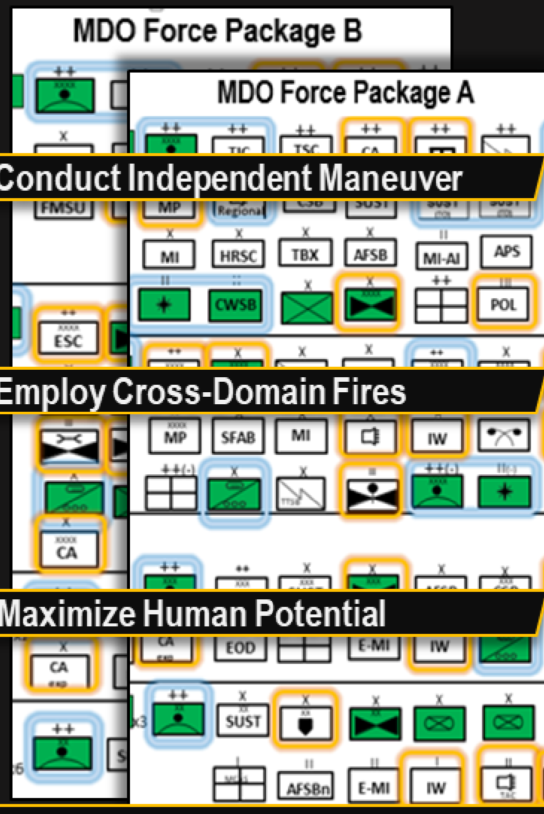


Expeditionary Forces

National-Level Capabilities

Authorities

Multi-Domain Formations

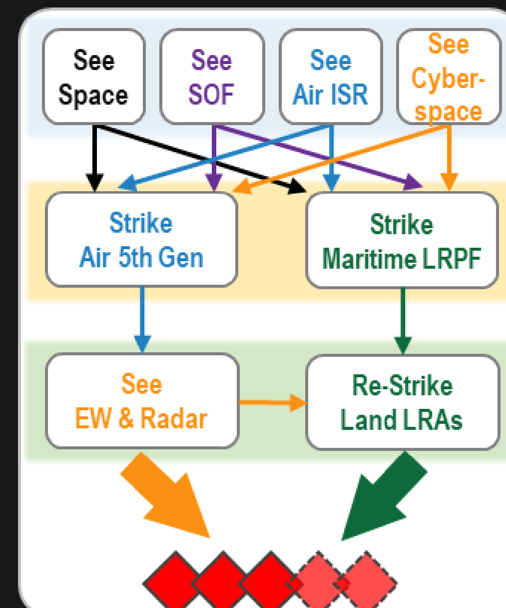


- Conduct Independent Maneuver
- Employ Cross-Domain Fires
- Maximize Human Potential
- Echelons Above Brigade Formations

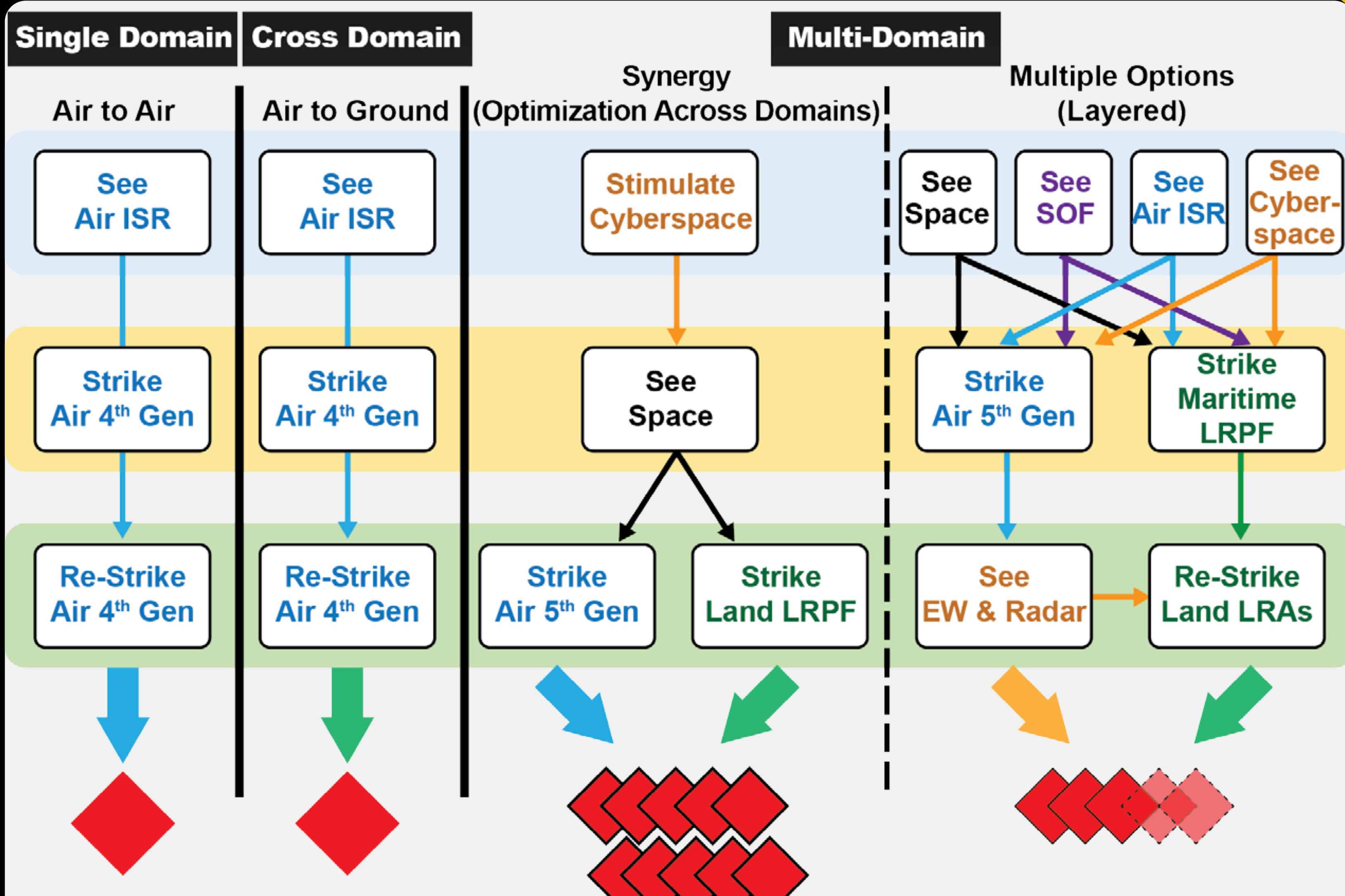
Convergence

The rapid and continuous integration of capabilities in all domains through:

- Cross-Domain Synergy
- Redundant Kill Chains
- Mission Command



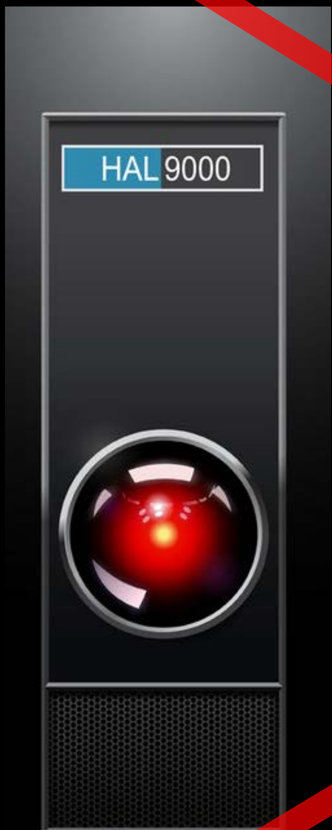
Convergence

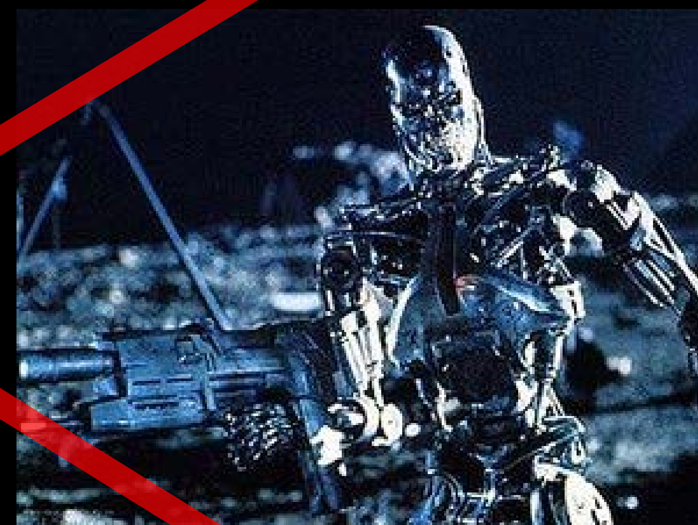


Multi-domain operations today rely on episodic synchronization … executing capabilities after days and weeks of synchronization … in future operations against a peer threat it will require rapid and continuous integration … integrating capabilities within hours

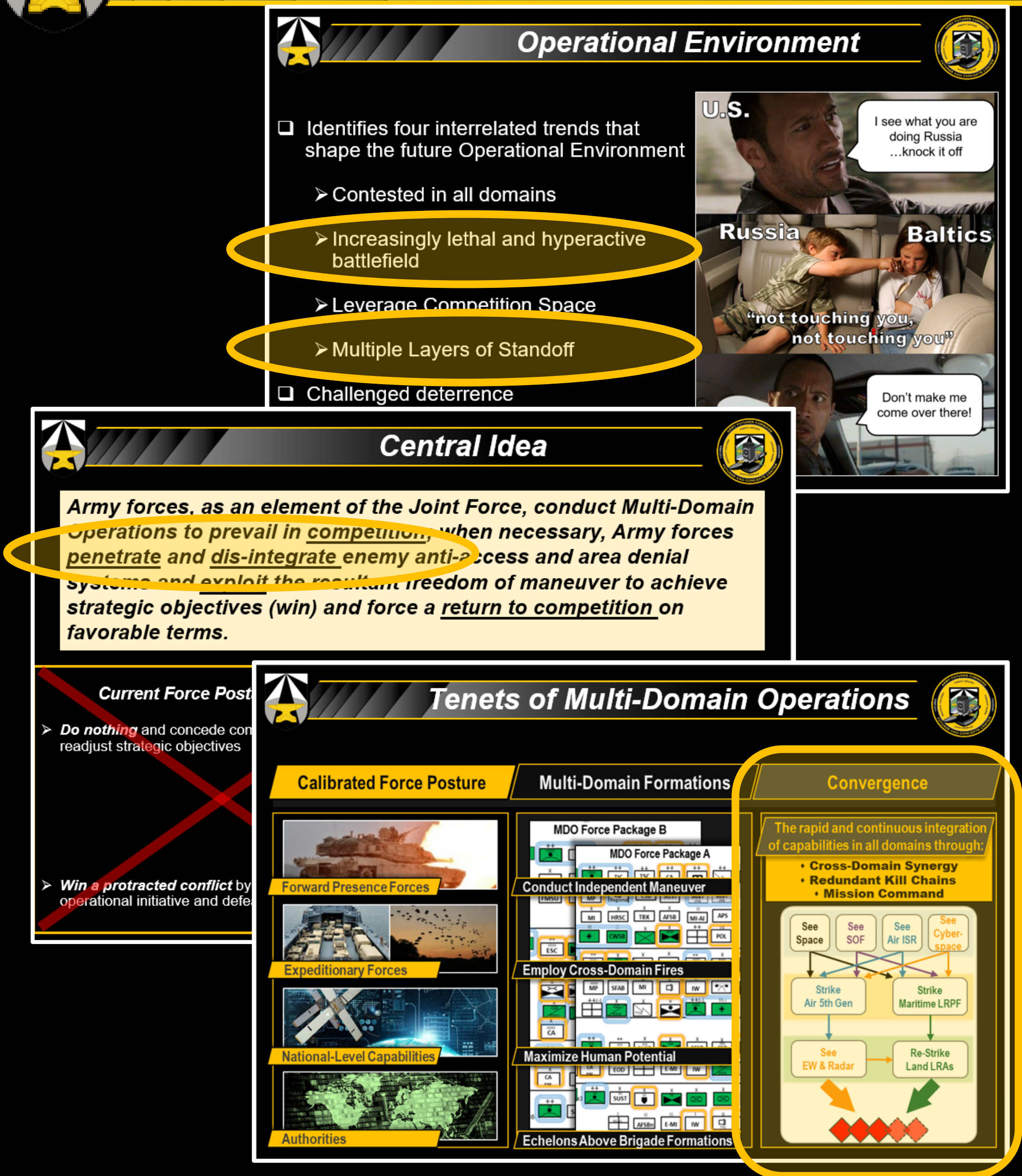
Technology: Missing the Mark

What We Are Not Trying To Do…





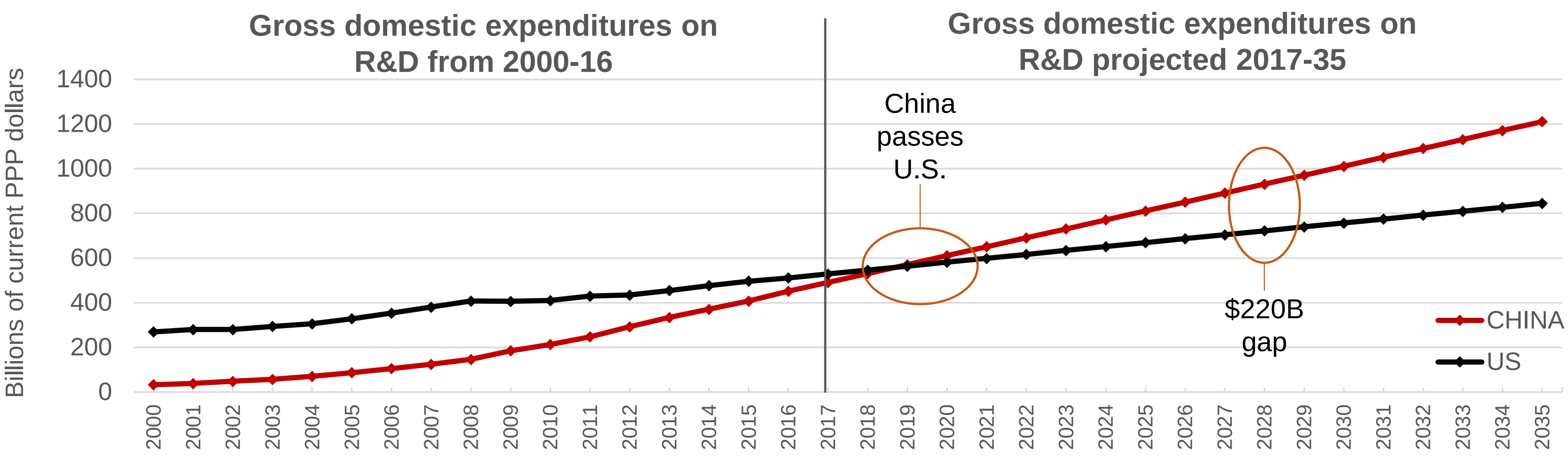
Key Take-Aways



- ***Lethality***
- ***Stand-Off***
- ***Penetration***
- ***Convergence***

US-China R&D Expenditures

The U.S. may lead in basic research – but China is slipping past us in applications.



Overall Spending Growth ('00-'15):
U.S. = 4% avg.
China = 18% avg.

At current growth rates – China will surpass the U.S. in the next few years and outspend the U.S. by $220B by 2028.

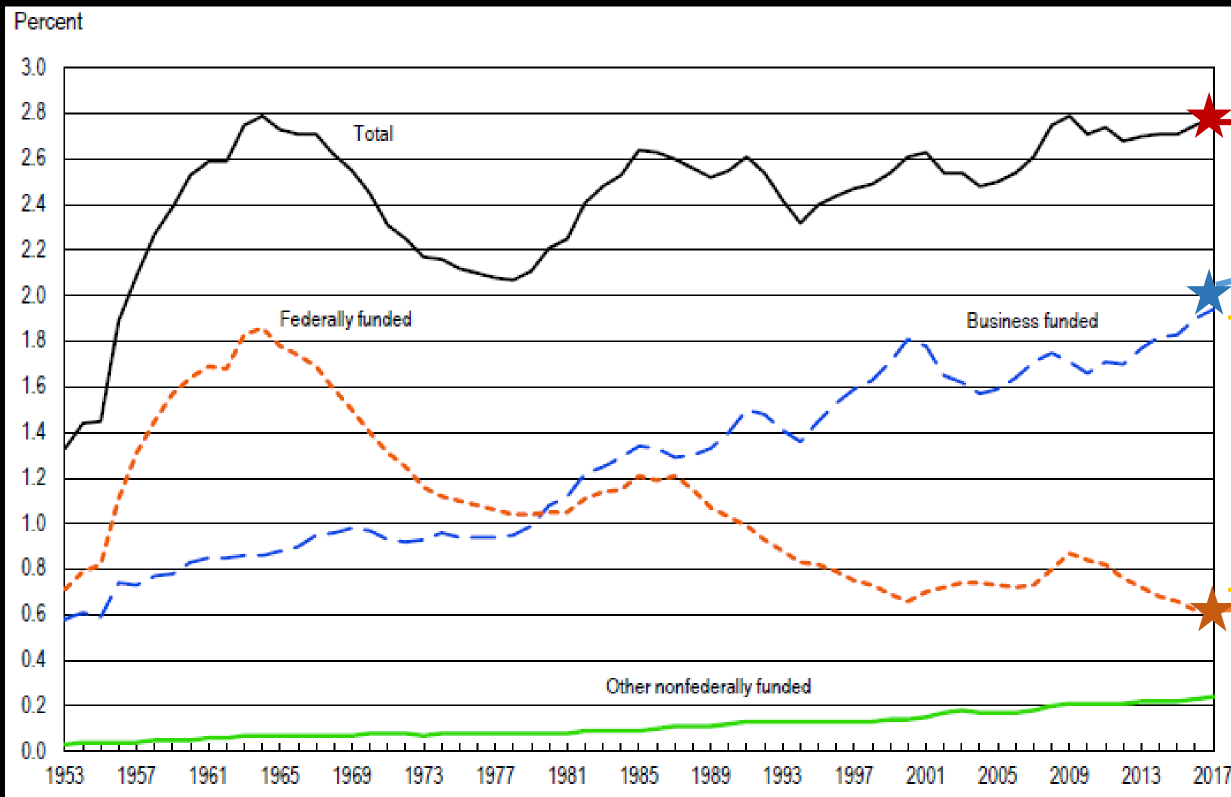
"China's plans for technology innovation comprise *'a top-down, government-driven agenda that provides a roadmap for strategic collaboration between industry, academia, and civil society'* …and the U.S. should reflect on the Chinese government's recognition of innovation as a driver of economic growth."

– Elise Stefanik (R-NY)
House Armed Services Subcommittee

http://data.uis.unesco.org/Index.aspx

https://www.aip.org/fyi/2018/biennial-report-shows-us-risk-losing-global-rd-leadership-china

US R&D spending by sector



2016 record for highest US R&D spending ($515.3B)

Business 69% ($355.5B)

*Applied/Experimental R&D

$239.4B gap between Business-Federal R&D

Federal 23% ($116.1B)

*Mostly Basic R&D

https://www.nsf.gov/statistics/2019/nsf19308/

Keeping pace and achieving overmatch of our adversaries requires a new way of modernizing our forces…and that way requires closer partnerships with industry to enable faster adoption of new technologies and rapid innovation.

Holyfield-Tyson

Conflict like Holyfield

- Strategic reach
- Precision
- Technical
- Agile

Compete like Tyson

- Closes distance
- Punching power
- Aggressive
- Feared

LTG ERIC J. WESLEY

Deputy Commanding General
Army Futures Command
Director, Futures and Concepts Center

@AdaptingTheArmy

https://futuresconcepts.army.mil

Military Robot Development

Helen Greiner

Some Downsides to Robots on Battlefield

- More complexity might mean less reliability
- More complexity makes service and support more difficult
- Sensors may transmit energy that may be detectable
  - Active sensors: LIDAR, RADAR
  - Passive sensors: FLIR, vision, acoustic
- Not as autonomous as a soldier
- No “common sense”

So there better be darn good reasons

- Safer standoff distance
- Riskier missions
  - Get closer
  - Check for non-combatants
  - Shoot second
  - Commander sign off
- Longer missions
- Soldier comfort not design criterion
- Soldier protection not needed

Unmanned systems will be an important disruption in combat

Arguments

- Comms will be disrupted->they will be more autonomous
- Sensors can be spotted->passive sensor techniques will mature
- No common sense->neither do missiles, use appropriately
- Technology isn't ready->the only way to make it ready is to build

Things We Could Improve

- Best value criteria, not lowest cost
  - Delivery of similar product in past
  - Multi-generation design
  - User feedback
- Recognize that field needs nurturing
- Multi-generation product lines are more likely to succeed than one shot development efforts
- Commit to quantity predictions for programs

Think in Generations

- Innovate, develop, test
- Roll out to select units
- Test, upgrade, purchase, repeat
- Help technologies and systems cross “valley of death”
- Keep production lines running

If you are not fielding, you are failing
-General Rick Lynch

Things that have improved

- Futures Command
  - New way of doing business
  - Focus on the future and how tech can be applied
  - More tightly coupled
    - CFTs, IPTs
    - Colocation, tightly coupled to ASA(ALT) PEOs
- New Contracting Mechanisms
  - 804 Middle Tier Acquisition
  - Industry Consortiums with OTA contracts
- Robot Programs of Record
  - Programs of Record (POR)
  - More in development

Culture for Tech Development

- Hard technical discussions early
- Ideas come from everywhere in the community
- Best tech input comes from most close to tech not top of hierarchy
- Best decision comes from leaders with access to differing input
- Healthy competition of ideas is good
- Leaders should change their minds upon reflection or when presented with new data
- Never shoot the technical messenger

Family of Robotic Systems*

* Subject to size, weight, and power realities

- Army needs commonality in robots to
  - Reduce sustaining costs
  - Help ATEC certification
  - Helps small companies compete
  - Reuse technology between programs and platforms
  - Must respect "secret sauce" intellectual property
- Commonality MUST NOT
  - Stifle innovations, so
    - Exceptions can be made for good reasons
    - Exceptions may dictate future direction
  - Inhibit performance ie add too much latency

Candidate Standards

- Ubuntu Linux
- Robot Operating System (ROS 2)
- Robot Operating System – M (ROS-M)
- Inter Operability Profiles (IOP)
- Ethernet or USB-C

“A Rising Tide Floats All Boats”

Robot Operating System (ROS) Improvements Needed

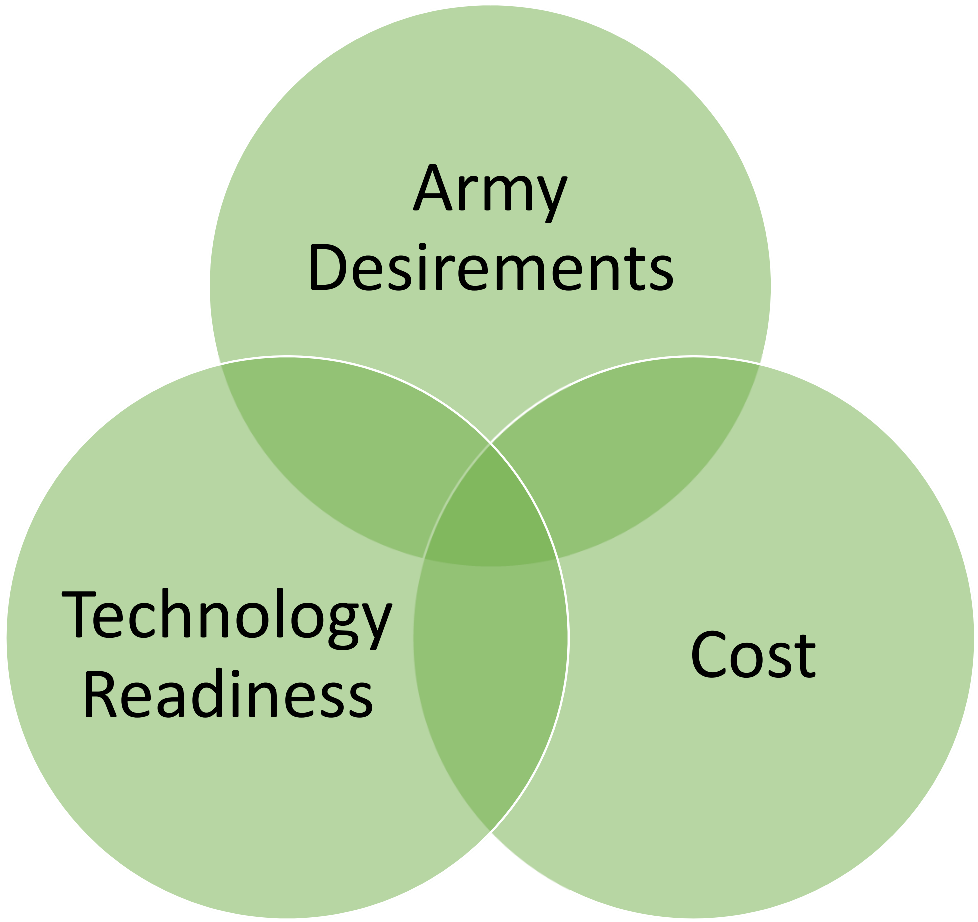
- ROS 2 for all projects
- More modularity
- Embedded system support
- Cross compiling infrastructure

"While ROS 1 is invaluable in R&D and prototyping activities, it can't reasonably be taken through the QA process that is applied to products that include, for example, safety-critical systems. Based on that feedback we are designing and developing ROS 2 in such a way that it will be amenable to approval for use in such applications." - Open Robotics CEO

Drive By Wire

- Steer by Wire
- Shift by Wire (Park by Wire)
- Brake by Wire
- Accelerate by Wire (Electronic Throttle)

- Turret by Wire
- Automatic Loading


Army Desirements
Technology Readiness
Cost

Aided by Commercial Technology

- RCV off-road autonomy
  - Self driving cars on-road autonomy
- Small UAS
  - Hobby drones
- Mobility
  - Personal transportation
- Dispersed Logistics
  - Delivery drones

Great Opportunities

- Unique capability
  - Short Range Recon (SRR) drone
  - Soldier Borne Sensor (SBS)
  - Small Unmanned Ground Vehicles – (SUGVs)
- Cognitive load reducing behaviors
  - Automatically cue potential items of interest
  - Turret auto-tracking
- Labor intensive and unchanging
  - Loading ammo
- Riskier missions
  - Robot Combat Vehicle
  - Engineers Breaching Robot
  - CBRNE Detect

This is a great time for robotics in general and military robots in particular

U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND

Robotics S&T: Enhancing Ground Combat Capabilities Through Manned/Unmanned Teaming w/ Robotics Systems

Paul Decker,

Deputy Chief Roboticist, Ground Vehicle Systems Center (GVSC), Warren, MI

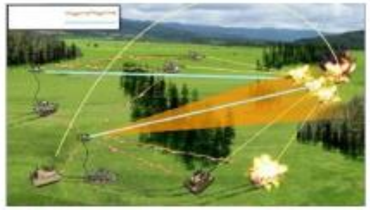
Army Futures Command - Combat Capabilities Development Command

23 April 2019

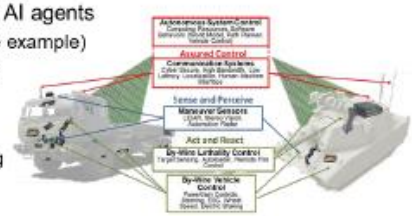
VIDEO

(aka Robert's Rules ~~Of Order~~ For Robots)

- **Let the Robot Die First**
  - Dull, Dirty, Dangerous on Steroids
    - New Tradespace: Survivability, Lethality, Mobility, Cost
    - Robots can be tougher than humans – not just sleep
      - 6 Watt Ride (Shock/Vibe), Overpressure Limits, Acceleration Limits
  - *Robots Don't Flinch Under Fire (Well at least not yet)*

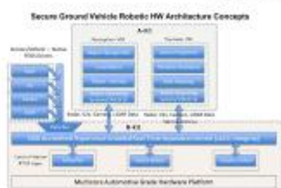


- **From a Tool to a Teammate**
  - It's not just manned-unmanned teaming… also about AI agents
    - Reducing cognitive load (Health Usage Monitoring just one example)
    - What about COA analysis, Real time mission assessment
  - Beyond *Siri for Robots* to a two way conversation
    - Negotiation
    - Scalable, Shared World Model w/Contextual understanding
    - Hand and Arm Gestures
  - Ability to give a backbrief and eventually an AAR



- **Whom do you Trust? – Safe Learning Enabled Components** DARPA
  - Explainable AI / Assured Autonomy
  - Training Validation followed by Runtime Safety, Behavior, and Mission Assurance over a Dynamic mission profile
  - Can adaptable systems remain within safe operating region?
  - Continuous recertification? CTT/Table VI for AI…

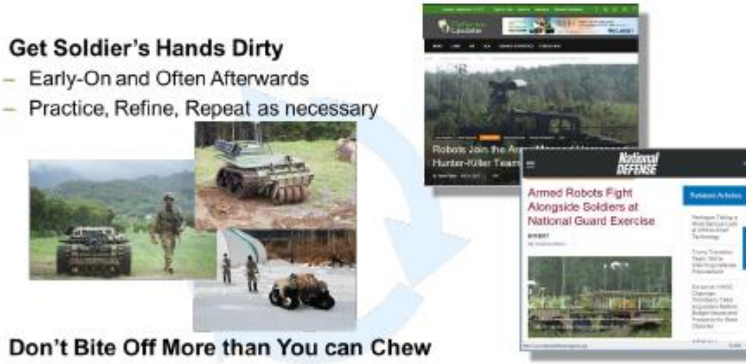
- **Baked in Cyber**: Assured HW/SW architecture
  - Leverage best practices from aviation community
  - Cyber/red teaming part of the development process
  - Tools to validate Open Source Software
  - *On platform AI agents for IDS*



- **Need More M & Ms**: Getting from Movement to Combined Arms **Maneuver**
  - Multi-Domain, Combined Arms, METT-TC informed
  - Vehicle paired UxS that can provide a SALUTE report, Scan IV Lines, keyhole shots, etc.

Cross country maneuver at operationally relevant speeds

- **Get Soldier's Hands Dirty**
  - Early-On and Often Afterwards
  - Practice, Refine, Repeat as necessary



- **Don't Bite Off More than You can Chew**
  - Incremental delivery rather than gold-plated requirements upfront
    - **Minimally Viable Product** is somewhat different in a military context
    - Design for Growth
  - User based Prioritization
  - Spiral/Sprint/Scrum out Capability

- **It Takes a Village**: Academia, Industry, Innovators, Gov't Labs
  - Requires solutions from many sources

- **Let's Play Together:** Autonomy App Store
  - Common architecture, Development environment
  - Not your normal app store - Building a marketplace
  - Enables non-traditional partners / innovation community to play

ROS-M

- **Don't Go It Alone:** We fight as a joint, combined coalition team
  - Leverage partners
  - ANVEL for Allies
    - RAS Sim environment
    - Includes Soil Interactions

(AKA ROBERT'S RULES ~~OF ORDER~~ FOR ROBOTS)

- **How Much (Testing) is Enough?**
  - Solving the TEV&V Risk Riddle
  - Can simulation solve the trillion-mile challenge
  - Will we experiment with higher safety risk systems
  - *Can we use AI to "drive" M&S to reduce physical test?*

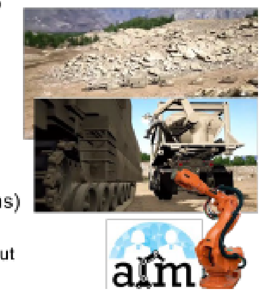
- **No longer in the Driver's Seat:** Adapting COTS to MOTS
  - DoD no longer sets the pace for microelectronics
  - Modified Automotive grade may be good enough
  - Design architectures that accept new components

- **FAR, FAR Away – Use an OTA or Other Transactional Agreements (as appropriate…)**
  - Modular Open Systems Architecture coupled with Rapid prototyping
  - Little appetite for typical acquisition EMD timelines

- **"Are We Really that Smart?" – Will AI save the world (or doom it)?**
  - AI/ML vs. Artificial General Intelligence
  - Challenged by sparse, biased data sets: dirty, dinky, deceptive… ,
  - Transfer learning
  - Are you a tool? …. This morning: Comb/Brush, Toothbrush, Fork/Spoon
  - *Think about soldier adaptation, improvisation, curiosity, and initiative …*

- **"Are We there Yet ? - Challenging the Status Quo**
  - Untapped potential as RAS becomes integrated in Army formations
  - Room Breach

  - Robotic Arms in the Wild (Dexterous/Safe Industrial Arms)
    - Transforming Sustainment (Enhance Optempo)
    - Automating R3P point for minimal footprint/maximal throughput



NEW

- **Bend Virtual Metal First: Role of M&S and Gaming**
  - Virtual Prototypes / Behavior Development
  - TTP and CONOP Development
  - Not a substitute for prototyping

- **BLUF: Enhanced Robotic Modularity – Sustainable RAS** (MOSA w/Code Re-Use)
  - Modularity in Software: Messaging/Middleware and the Autonomy App Store
  - Modularity in Hardware: Interoperability Profiles and Modular Mission Payloads
  - Commonality in Controller Interfaces: Multi-domain, UCS convergence

PROBLEM STATEMENT

Bridge 6.1-6.4 "Valleys of Death" by leveraging a common developmental framework, scalable approach, and experimental playground with robotic stables

- **SPEAK THE SAME LANGUAGE**
- **SUCCEED/FAIL SMALL & CHEAP**
- **REDUCE BARRIERS TO ENTRY & ENABLE NICHE PLAYERS**

VISION: Create a Focused Development **Pipeline** to **Accelerate Soldier Informed Capability Transition** from our Partners thru **Experimentation** that gets capabilities in **Formations Faster**.

Leverage ongoing efforts using Modular "Open Source" Software Approach, Adaptable Robotic Capability, and a Secure Repository to build the *Army Autonomy App Store*

ROS-M

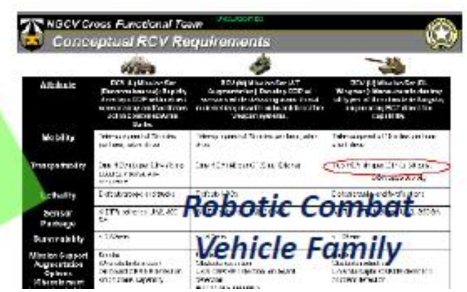
FBGA – Oct 2018

Wingman JCTD

JWA 2019

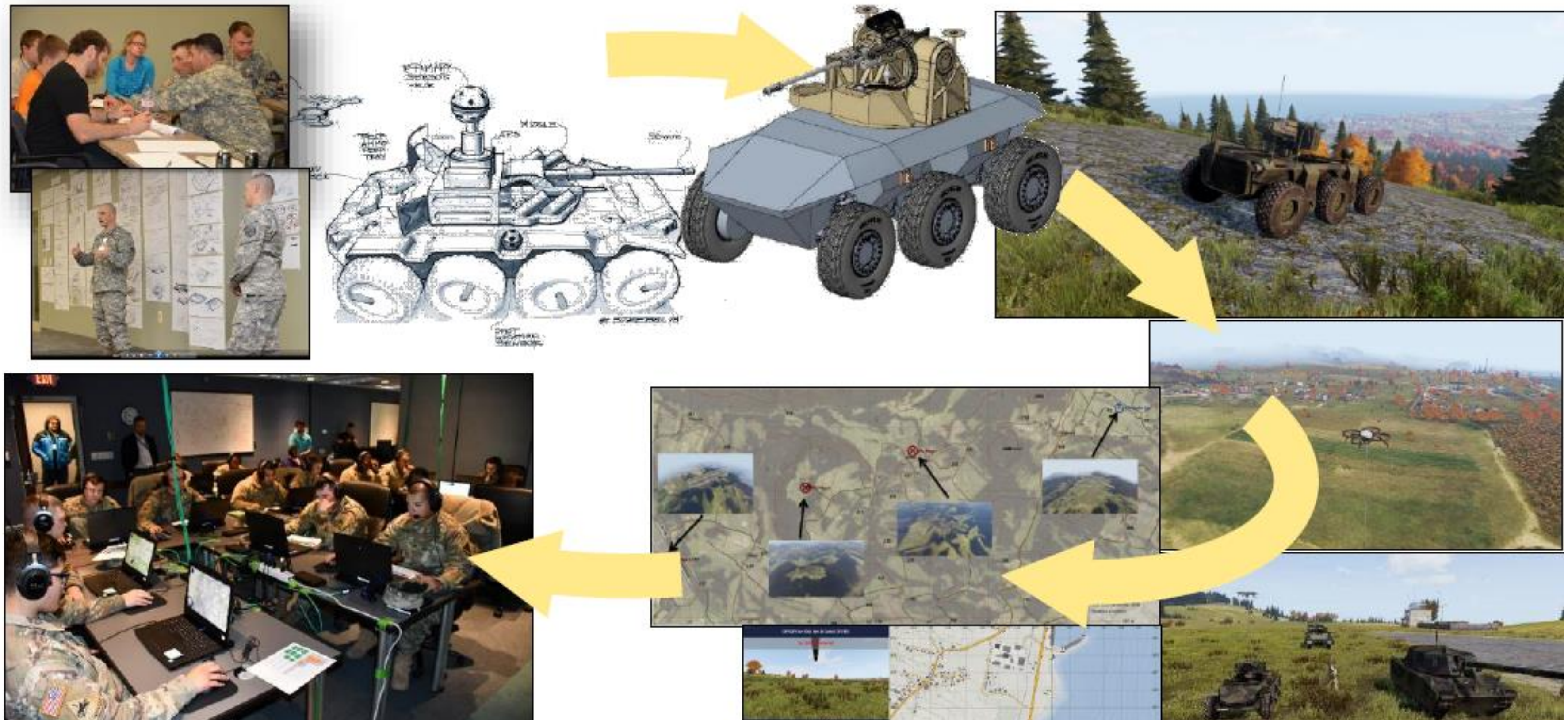
Warrior Machine Interface

Project Origin FY19-20



Robotic Combat Vehicle Family

BENDING VIRTUAL METAL: SOLDIER ENGAGEMENT THRU SOLDIER INNOVATION WORKSHOIPS AND VIRTUAL EXPERIMENTS



<u>NGCV-VE #1 (DEC 2018 @ GVSC):</u> *1st Armored Division, Ft. Bliss*

xplore TTPs and gather Soldier input for two distinctly different RC

<u>NGCV-VE #2 (MAR 2019 @ GVSC):</u> *1st Cavalry Division, Ft. Hood*

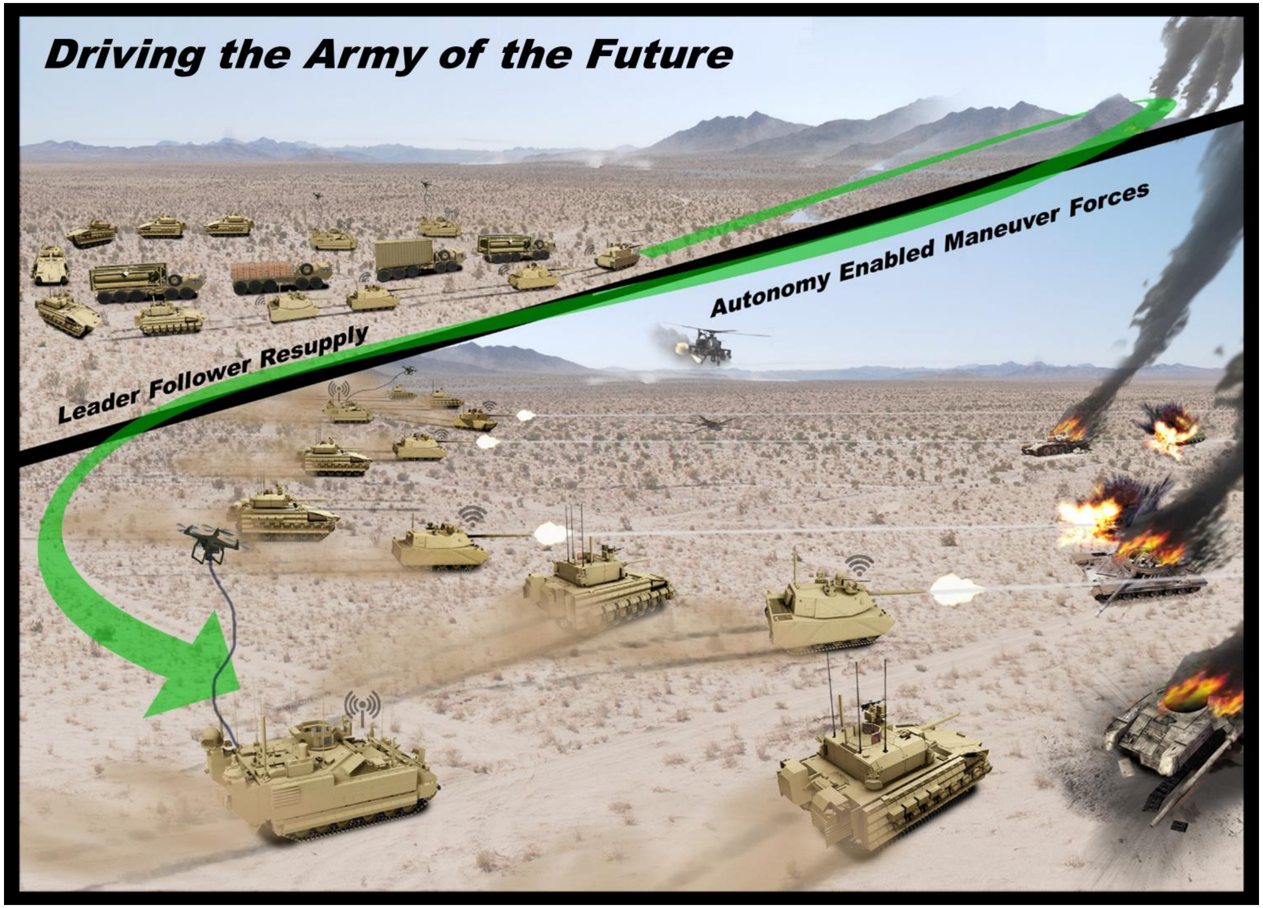
Explore TTPs and gather Soldier input for OMFV-RCV control ratios/handoffs

<u>NGCV-VE #3 (4QFY19)</u>: *32 Soldiers*

Experiment objectives, missions, and tech based on lessons learned from VE #1 / #2

<u>NGCV-VE's FY20</u>: *Scale to 100+ participants, to allow execution of Company level*

AUTONOMOUS MOBILITY THRU INTELLIGENT COLLABORATION (AMIC)



Develop/integrate Artificial Intelligence and Machine Learning (AI/ML) technologies to increase autonomy and mobility to perform teamed operations with manned and unmanned air and ground vehicles in a military relevant environment through data collection on relevant Soldier training exercises.

AMIC FOCUS AREAS

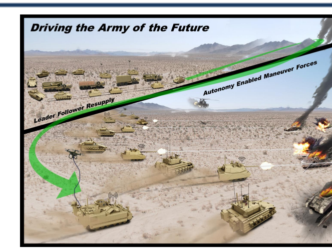
AMIC is focused on the mobility portion of the Manned-Unmanned Teaming. From an operational perspective, it adds the required pieces for further unmanned operational missions like lethality, RSTA, and others.

Data Collection

Data collection will involve both simulation and live collection events. Simulation will provide a base to correctly collecting, cleaning, and analyzing data that meets the need for developing algorithms for both Formation Control and UAV Map Input for UGV Mobility. Live data will start with Surrogate platforms in local areas. This will allow proper collection techniques, tools, and data to maximize embedded autonomy using Machine Learning and other Artificial Intelligent methods before utilizing live training events for data collection.

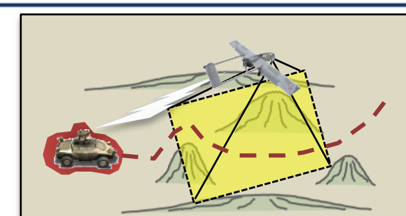
Formation Control

Use AI/ML techniques to develop/integrate intelligent formation control to be used on maintained roads and in complex terrain without the need for GPS. Data will be collected from mounted platforms utilizing special internal and external sensors to develop algorithms for exact positioning, undistributed formation control, and increased speeds of unmanned platforms.



UAV map input for UGV mobility

Use AI/ML techniques to develop intelligent autonomous ground platform planning through the use of UAV mapped areas. Data collected from air vehicle will be converted to maneuverable information for unmanned ground platform with the identification of enemy positions, go/no-go areas, terrain classification, and optimal suggested paths.



DATA COLLECTION

Crawl

- Simulate single vehicle
  - Use CCTT or other simulation
  - Sync voice and location
- Use multiple vehicle simulator like SEGA or other
  - Sync voices with positon of vehicles

This data will help sync global movements with voice to create tools for cleaning and analyzing data as well as to help understand live data to collect.

Walk

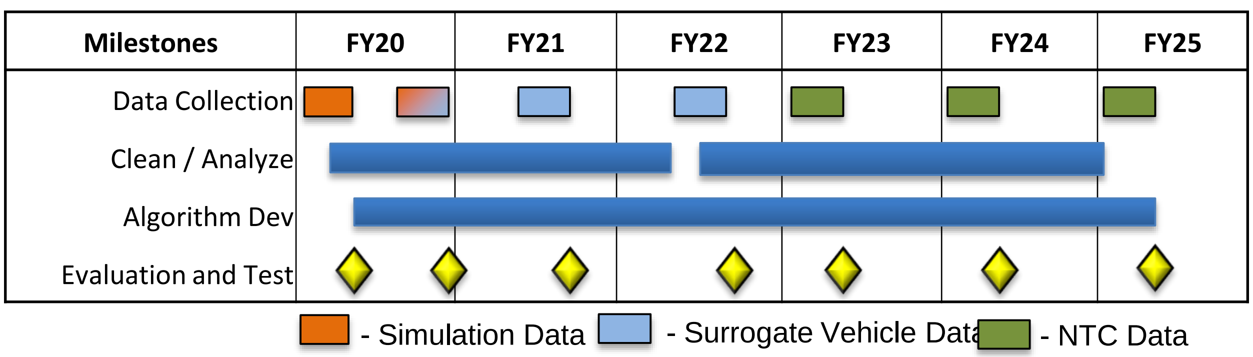
- Live data collection using surrogate vehicles
  - Sync voice, position, and BFT data along with low level data (vehicle vibrations, SBT, and terrain data)
- Clean and analyze data. Build algorithms for formation control.
- Update SEGA and CCTT/other simulations with live data

This will help update and validate simulations, understand proper data to collect from training exercises, and develop collection, analysis, and validation tools.

Run

- Live data collection at NTC during training exercises.
  - Capture, clean, analyze, and develop algorithms
- Develop transition algorithms between environments and between vehicles.

Data will continue to be collected and updated from the change in environment and vehicles. Transition functions will help extend the data past the trained environments.



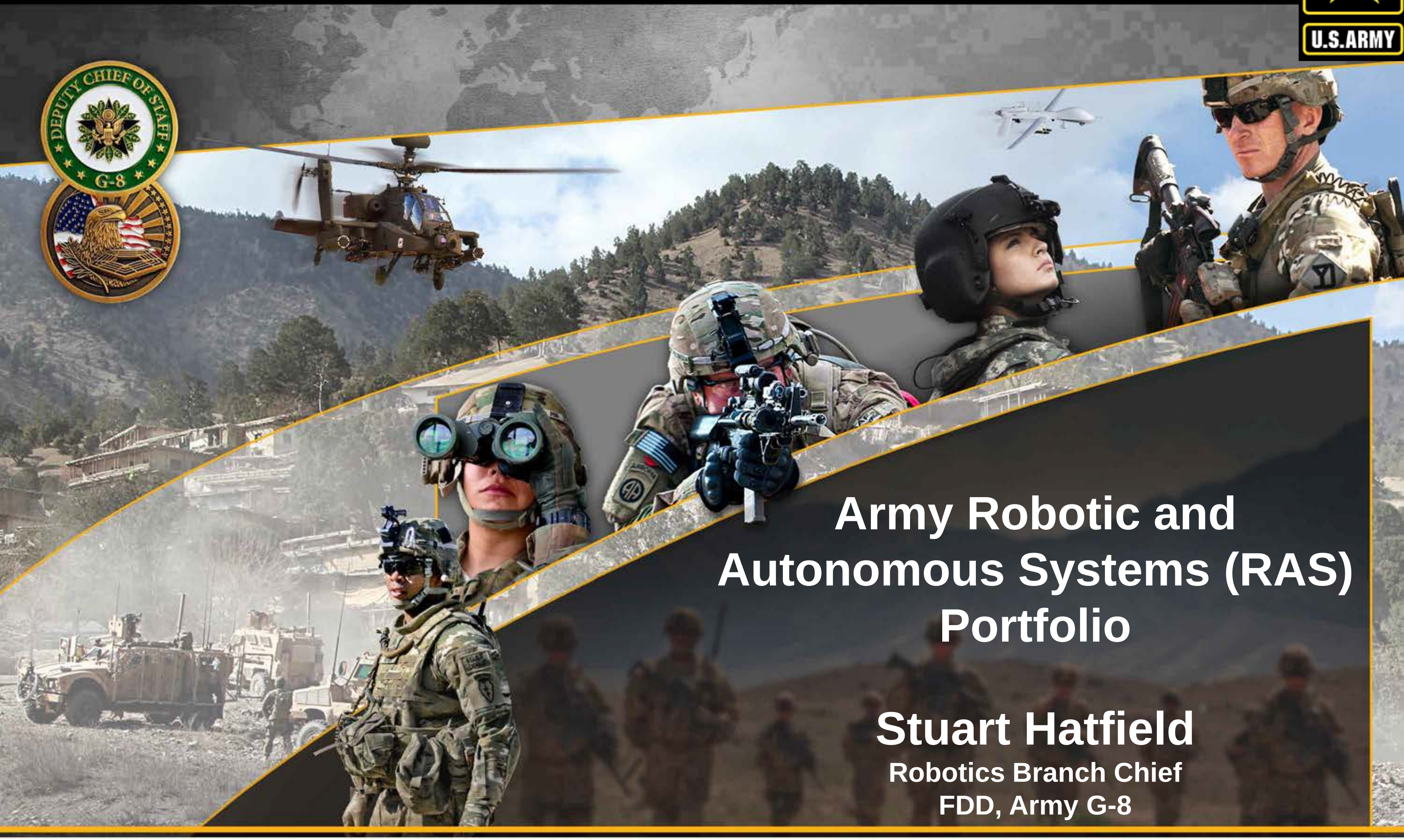
Mobility Data
- Unclassified
- GVSC/ARL lead

Shoot Data – *Not AMIC*
- Mostly classified
- ARDEC/CERDEC/ARL lead

CCTT – Close Combat Tactical Trainer BFT – Blue Force Tracker SEGA –Soldier Experimental Gaming Analysis SBT – Steering, Brake, Throttle NTC – National Training Center

14,000,000

SUMMARY / QUESTIONS



Army Robotic and Autonomous Systems (RAS) Portfolio

Stuart Hatfield

Robotics Branch Chief
FDD, Army G-8

stuart.a.hatfield.civ@mail.mil

As of 23 April 2019

This briefing is:

UNCLASSIFIED

Strategic Guidance

2018 National Defense Strategy - "the character of war is changing based on rapid technological advancements in the areas of advanced computing, "big data" analytics, **artificial intelligence**, **autonomy**, **robotics**, directed energy, hypersonics, and biotechnology..."

2018 Army Multi-Domain Operations – "Integrated unmanned systems play a pivotal role in our ability to penetrate and defeat multiple layers of stand-off in all domains--land, sea, air, space and cyberspace.

"The Army of 2028 will be ready to deploy, fight and win decisively against any adversary, anytime and anywhere, in a joint, multi-domain, high-intensity conflict, while simultaneously deterring others and maintaining its ability to conduct irregular warfare. Further, and this is very important....The Army will do this through the employment of modern **manned and unmanned** ground combat vehicles, aircraft, sustainment systems, and weapons, coupled with robust combined arms formations and tactics based on a modern warfighting doctrine, and centered on exceptional Leaders and Soldiers of unmatched lethality."

Dr. Mark T. Esper,
Secretary of the Army
26 March 2018

Army Modernization

Modernization Strategy: Regain Overmatch Against Near & Mid-Term Threats

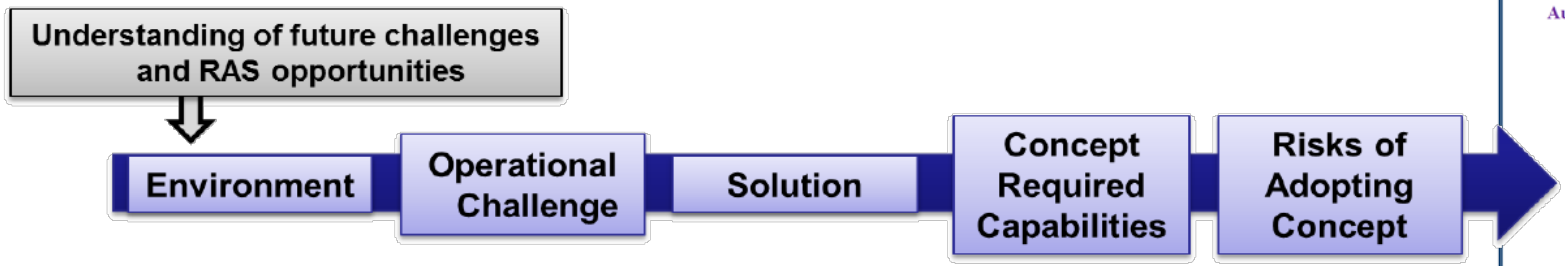
- Continue to make **incremental improvements** to existing combat systems to ensure the U.S. can fight and win in the near term
- **Focus our Science and Technology** investments, on a **limited number** of prioritized portfolios, to guarantee our Soldiers have formation based tactical overmatch and technological superiority in the near to mid-term
- **Begin prototyping** a select number of next generation combat system technologies and vehicles IAW **Army Modernization Priorities**; begin development as soon as the technologies are mature enough we can rapidly move from prototype to production.
- **Enable Cross Functional Teams** to develop Next Generation Systems that make our Soldiers and units more lethal
- **Sustain** current systems to extend useful life
- Continue to **divest** less important capabilities to free resources for higher priorities

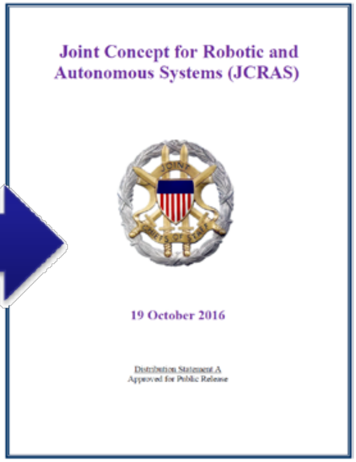
Modernization Priorities

1. **Long-Range Precision Fires**
2. **Next Generation Combat Vehicle**
3. **Future Vertical Lift**
4. **Army Network**
5. **Air and Missile Defense**
6. **Soldier Lethality**

- Buy down Risk by leveraging **Rapid Prototyping** and **Rapid Fielding** of innovative system components or technologies
- Increase acquisition agility with the use of **ACAT IV** programs and delegation of MDA authority of select ACAT II/III/IV directly to PEOs
- Smart contracting to leverage commercial item procurement and **Other Transaction Authority** (OTA)
- Reduce **testing time and cost**
- Maintain visibility of cutting edge industry technology through a **Buy-Try-Decide-Acquire** methodology
- Rapidly deliver systems to operational units to gain early **Soldier Feedback** to inform concepts and requirements
- Don't let the **perfect** be the **enemy of the better**

Joint Concept for Robotic and Autonomous Systems




Joint Concept for Robotic and Autonomous Systems (JCRAS)

19 October 2016

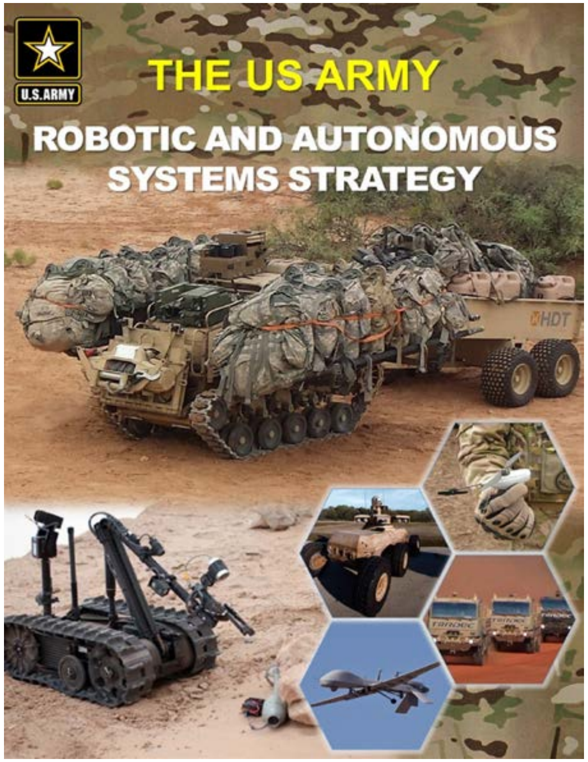
Distribution Statement A
Approved for Public Release

Operational Challenge: How will the joint force employ RAS to gain and maintain operational advantage in a future operating environment featuring increased lethality and sophistication, accelerated pace of operations, eroding military advantages, and congested environments?

Central Idea: By 2035, the Joint Force will employ integrated teams of humans and RAS in a wide variety of combinations to expand the Joint Force commander's options.

Precept #1: Employ Human-RAS Teams
Precept #2: Leverage Autonomy as a Key Enabler
Precept #3: Integrate RAS to Develop Innovative CONOPs

Army Robotic and Autonomous Systems Strategy



March 2017

Overview:

- The strategy synchronizes Army RAS activities and fosters unity of effort to identify and develop opportunities to accelerate and integrate RAS capabilities
- The Army will employ RAS to protect Soldiers, increase capabilities to maintain overmatch, and extend the area and time over which a force can be effective
- Technology development seeks to achieve the optimal level of autonomy by designing systems that will maximize strengths of both humans and machine through Manned-Unmanned Teaming (MUM-T)

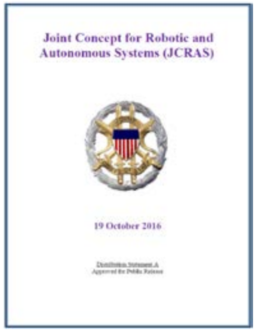
Priorities:

- Improve situational awareness and persistently monitor the environment
- Lighten physical and cognitive workloads
- Sustain with increased distribution, throughput, and efficiency
- Facilitate movement and maneuver
- Protect the force

Endstate:

Robotics and Autonomous Systems (RAS), through Manned-Unmanned Teaming (MUM-T), enable Army formations to increase their endurance, persistence, lethality, protection and depth.

Establishing Common Terms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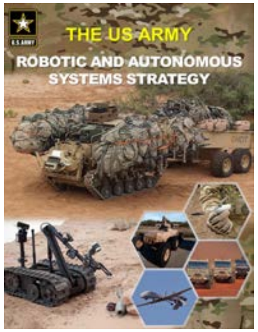


US Army

RAS
ICD

14 Dec 18

Key Terms

- **Autonomy** is 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.

- A **Robot** is a powered machine capable of executing a set of actions by direct human control, computer control, or a combination of both. It is comprised minimally of a platform, software, and a power source.

- **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 this 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.

Pursuing Greater Autonomy, while maintaining Flexible Autonomy based on system capabilities and limitations, complexity of the mission, and characteristics of the environment

RAS Assured Control

Assured Control: The operator has reasonable confidence that the Robotic and Autonomous System (RAS) will perform as designed and directed. Loss of control may be caused by, but is not limited to: loss of link with operator's controller, cyber-attacks, or anomalies in the programming. RAS should render itself inert, automatically return to base, or conduct safe manual recovery.

- RAS Initial Capabilities Document
  14 December 2018

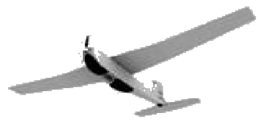
Assured control is critical for the establishing the trust and confidence required for the integration of increasingly autonomous systems into the force, especially armed systems.

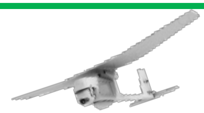
Robotics Portfolio Overview

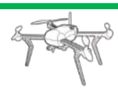
U.S.ARMY

Family of SUAS

Small Unmanned Aircraft Systems

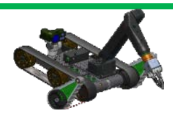

Long Range Recon (LRR)


Medium Range Recon (MRR)


Short-Range Recon (SRR)


Soldier Borne Sensor (SBS)

Individual Transportable


Common Robotic System Individual (CRS-I)

Family of Integrated Sensors (FITS)

Lightweight Reconnaissance Robot (LR2)

Vehicle Transportable


MTRS INC 2


M160 Light Flail


CRS-Heavy

Common Robotic System Vehicle (CRS-V)


NSE-Robots
MTRS - I
MTRS-RC

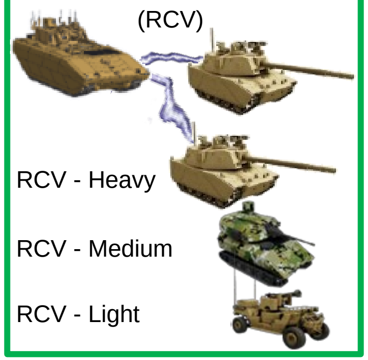
Enhanced Robotic Payloads

Self Transportable


Squad-Multipurpose Equipment Transport (S-MET)

SMET Modular Mission Payloads (MMPs)

Robotic Combat Vehicle (RCV)


RCV - Heavy
RCV - Medium
RCV - Light

Robotic Applique


Leader Follower


Exoskeleton


Warrior Exosuit

Photos are notional


Universal Robotic Controller (URC)

Other

Robotics Development

Robotics Architecture

Robotics Enhancement Program (REP)

Robotics

6 Sub Portfolios

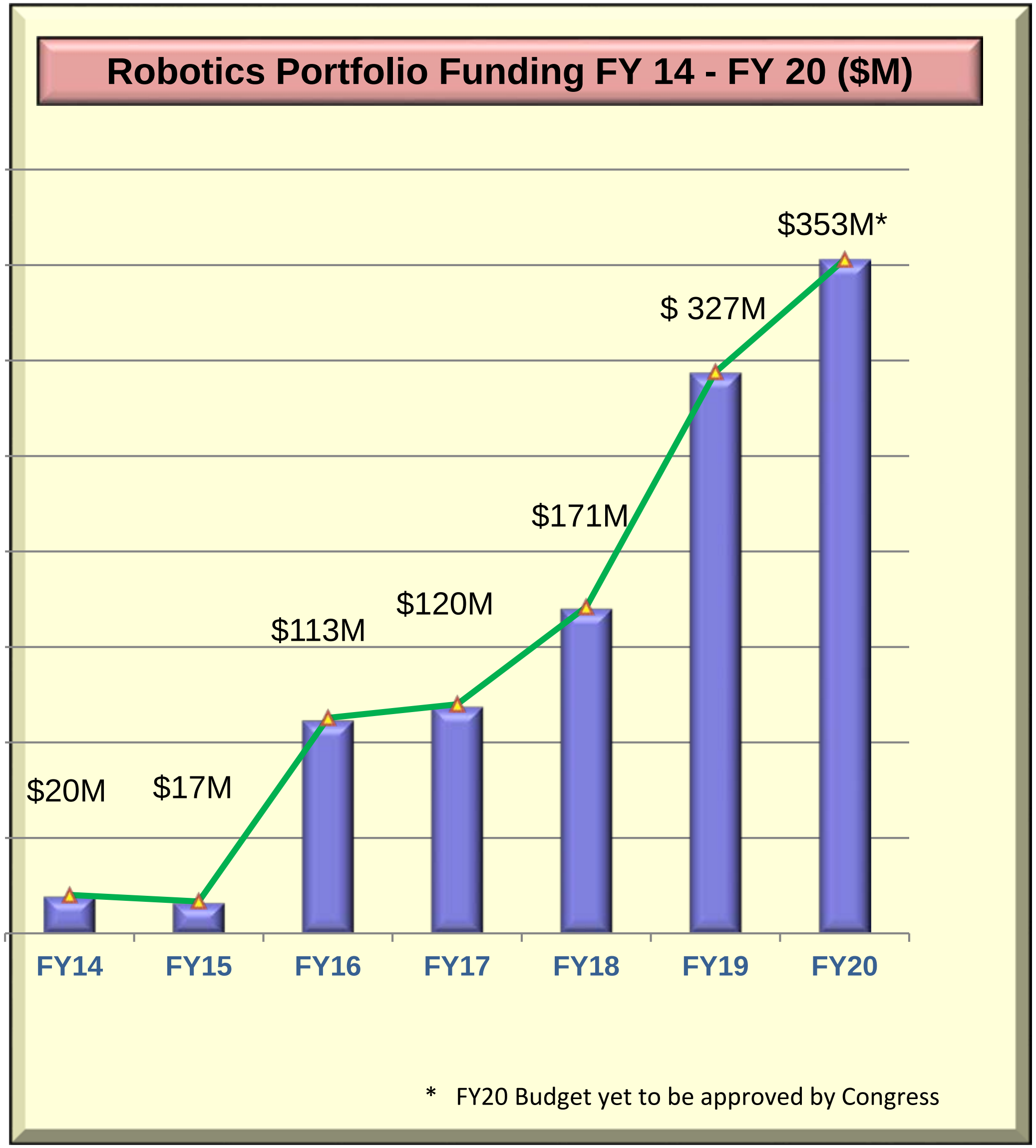
22 Programs

13 Roots

Emerging Programs	6
Actively Managed	15
Programs in Sustainment	1
Total Programs	**22**

Emerging Programs **Actively Managed** **Sustainment**

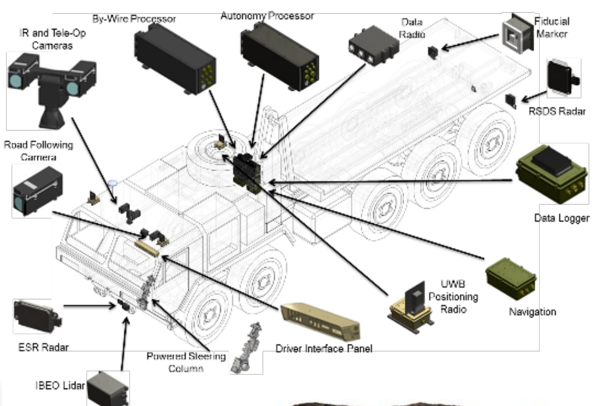
Robotics Portfolio Resources



UNCLASSIFIED

Army RAS Operational Technology Demonstrations

- Squad Multipurpose Equipment Transport (SMET)
  - Nov 2018 – Jun 2019
  - 80 systems to two IBCTs



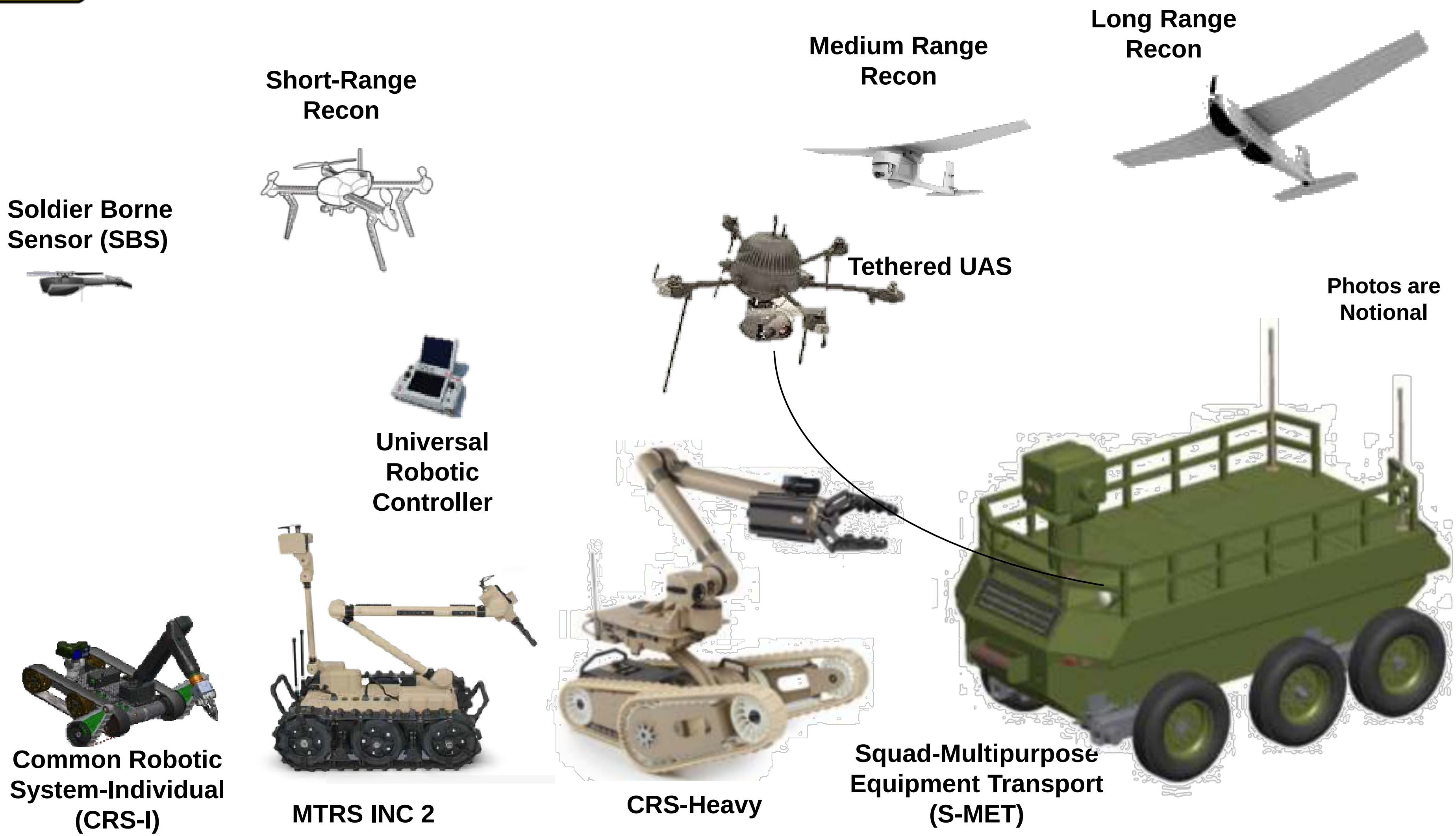
- Leader – Follower Technology for Tactical Wheeled Vehicles
  - Sep 2019 – Nov 2020
  - 60 systems to two PLS Truck Companies

- Next Generation Combat Vehicles (NGCV)

Robotic Combat Vehicle (RCV)
  - Four RCV-Heavy Surrogates in FY20
  - Platoon of each RCV-Light/Medium/Heavy in FY21
  - Two platoons of RCV-Heavy in FY23

Photos are notional

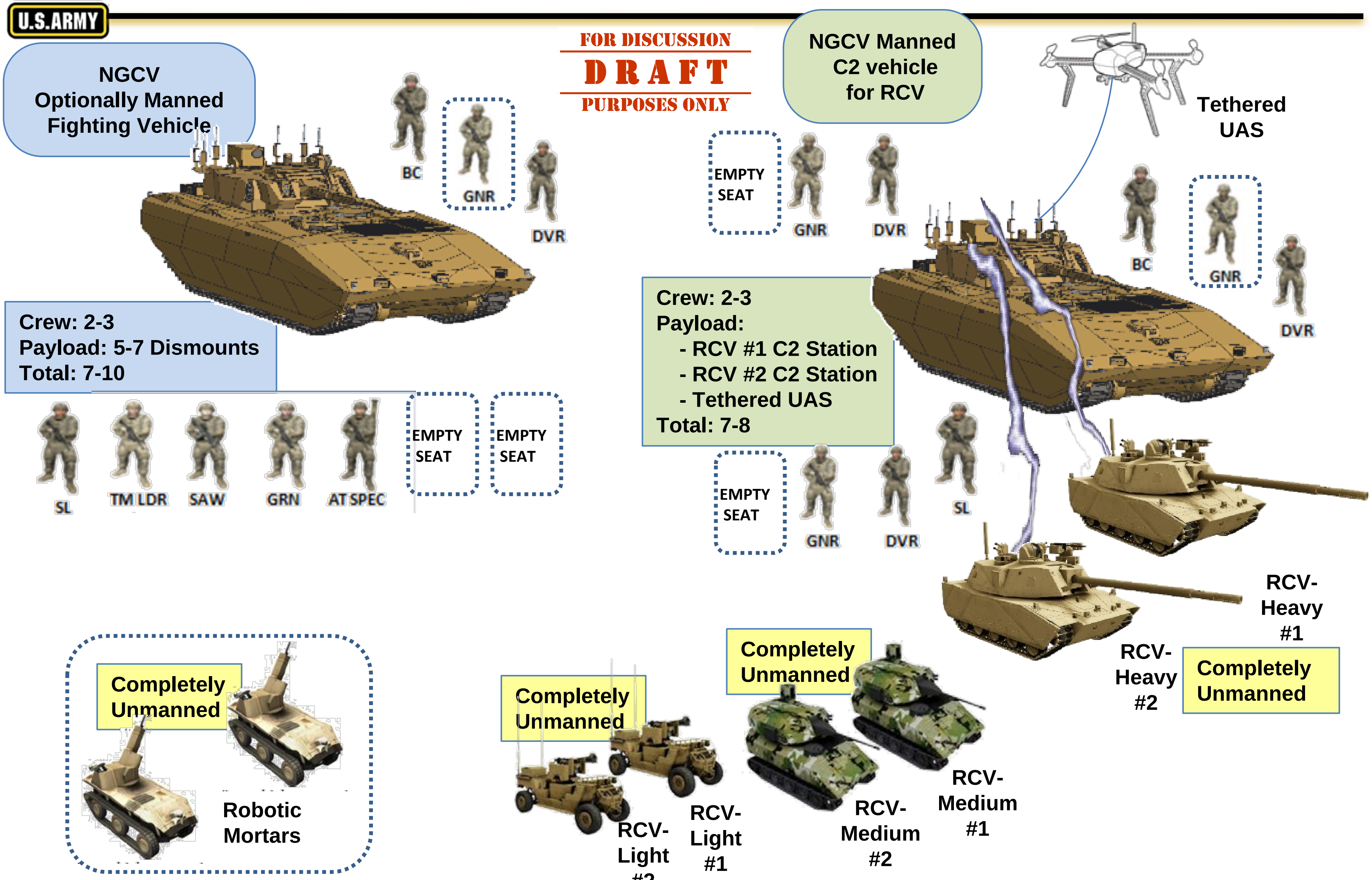
Innovation and Better Buying Power 3.0
Rapid prototyping, Operational Evaluation, and Transition to Procurement



Payload:

~ 5 lbs	~50 lbs	~300 lbs	~1000 lbs

NGCV Optionally Manned Fighting Vehicle (MFV) and NGCV Robotic Combat Vehicle (RCV)Concept



RCV Family of Vehicles

- Limited on-board lethality (self defense, ATGM, recoilless weapons); Intelligent network cues appropriate MDO (off-board) strike to provide decisive lethality
- Robust Sensor package to establish enemy COP (UAV integration).
- Attritable system.

- Increased onboard lethality to defeat some Tier I threats (medium cannon / multiple ATGM / recoilless large cannon)
- Sensor package to establish enemy COP for MDO strike for remaining targets
- Durable system.

- On-board direct fire weapon systems defeat all Tier I threats
- Off-board sensor systems develop COP.
- Non-expendable system.

Intelligent Network leverages sensor-data to optimize multi-domain strikes

Increasing Platform Survivability and Cost

Increasing *on* Platform Lethality

Notional RCV Vehicle max size/weight constraints *(Based on limits for different air transportability envelopes)*

RCV Light (L)	RCV Medium (M)	RCV Heavy (H)
< 7 Ton GVW 224 x 88 x 94 in* **Transport one RCV(L) by Rotary Wing** ** L x W x H*	~10 Ton GVW 230 x 107 x 94 in* **Transport one RCV (M) by C-130** ** L x W x H*	~20 Ton GVW 350 x 144 x 142 in* **Transport two RCV (H) by C-17** ** L x W x H*

Notional pictures for representative vehicle characteristics only, not to be considered an endorsement or preference to any specific system or subsystem

Robotic Combat Vehicle enables a continuum of Decisive Lethality options

Emerging Science & Technology Development

Don't be this guy

Send in the Robot

- **Interoperability Profiles (IOP)** and Common Standards
- **Modular Mission Payload** integration to expand common chassis functions
- **Robotic Operating System – Military (ROS-M)**
- **Next Generation Combat Vehicle (NGCV) Robotic Combat Vehicles (RCV)**
- **Manned – Unmanned Teaming (MUM-T)**
- **Autonomous Subterranean Mapping and Exploitation**
- **Autonomous Ground and Aerial Resupply**

Questions?

Robotic Combat Developments

Dr. Buck Tanner, Chief Engineer, Combat Vehicles

24 April 2019

Early U.S Efforts

- **Command Center**

Command Center Development Stations

*FMC Corporation's AGVT (advanced ground vehicle technology) demonstrator, **based** on an M113-series armored personnel carrier.*

Advanced Ground Vehicle Technology - 1985

Autonomous Mobility Efforts

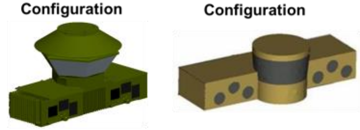
- Autonomous Land Vehicle, 1985
- ARL: Robotic Demos

- DARPA Challenge: 150 mile course
  - 2004: 15 participants; zero completed; 7.4 miles most completed

  - 2005: 23 participants; 5 completed entire course

- FCS: Autonomous Navigation System

Imaging Perception Module (IPM)



Laser & Imaging Perception Module (LIPM)

BAE SYSTEMS

URAN 9

- 30 mm cannon (2A72)
- 7.62 mm coax
- ATGM (9M120-1 Ataka)
- Rockets (Shmel flamethrower; or Strela anti-air)

- **Tele-operation**: limited autonomous capabilities if signal lost
- Some limited ablity to detect, identify and engage enemy forces without manual human direction
- Weighs 12 tons and is five meters long
- 22 mph on highways, 15 mph off-road
- Protection from shell splinters and small-arms
- Thermal and electro-optical sights and sensors

BAE SYSTEMS

Lessons Learned

- **War time experience**
- Not able to perform the assigned tasks in the classical types of combat operations
- Thermal and electro-optical sensors proved incapable of spotting enemies beyond 1.25 miles
- Sensors, and the weapons they guided, were useless while the Uran-9 was moving due to a lack of stabilization
- When fire commands were issued, there were significant delays
- Unreliable
- EW vulnerability
- Loss of communications/control

- Estimates 10-15 more years before UGVs are ready for such complex tasks

UNCLASSIFIED

Robotics at the Tactical Edge

Ted Maciuba, PE
Deputy Director, Robotics Requirements
Maneuver Capability Development and Integration Directorate
Futures and Concepts Center
US Army Futures Command

Robotics Overview

- Exciting time to be in the business of Army Robotics
  - Approved Initial Capabilities Document
  - Significant Funding of Robotics
  - Significant Key Leader Support of Robotics

- Mission - Manage Army Futures Command level activities to include requirements generation, force modernization, industry engagement, and concept development for both air and ground robotics

- Vision - Enable Army Formations to increase their lethality, endurance, persistence, protection and depth

Unclassified

Robots as Teammates in a Constellation of Systems

Robotic Programs

- Squad Multipurpose Equipment Transport – Capability Development Document staffing
- Soldier Borne Sensor – First Unit Equipped May 19
- Short Range Recon – working assessment with PM Small Unmanned Aircraft Systems
- Robotic Combat Vehicle - Assisting Next Generation Combat Vehicle Cross Functional Team
- Common Robotic System (Individual) – QinetiQ selected for the contract award
- Long Range Recon – working requirements
- Universal Robotic Controller – working requirements
- Exoskeleton – working requirements
- Counter Small Unmanned Aircraft Systems – MCDID lead, working requirements
- Family of Integrated Tactical Sensors – working requirements

Robotic Critical Enabling Technologies

- Assured Communications
- Autonomy
- Soldier/Robotic System Interface
- Power & Energy

Artificial Intelligence

Robotically Equipped Infantry Platoon

Hypothesis: A robotically equipped dismounted Infantry Platoon can be up to 10 times more effective than the current dismounted Infantry Platoon.

Plan: Infantry Platoons will integrate – through Manned-UnManned Teaming (MUMT) – robotic ground, air, water, and virtual systems that increase the dismounted Infantry Platoon's lethality, mobility, protection, situational awareness, endurance, persistence, and depth.

Technologies to be considered for integration include:

- Network with appropriate bandwidth and protection
- Ground, Air, Water and Virtual Unmanned Systems
- Tactical Robotic Resupply (Ground and Air)
- Exoskeletons
- Lethality, protection, mobility, sustainment, network, situational awareness etc. modular mission payloads
- Common Robotic Controller with appropriate Soldier interface device
- Autonomy
- Artificial Intelligence

Artificial Intelligence Enabled Infantry Platoon

Hypothesis: Enabling Platoon leaders and Soldiers with Artificial Intelligence will enable the platoon leaders and Soldiers to observe, orient, decide, and act (OODA Loop) up to 10 times faster and with better decisions than their current capability.

Plan: Artificial Intelligence tools will take disparate streams of information from organic UxV sensors and higher echelon mission command, intelligence, and sensors; weave them into a coherent picture using Artificial Intelligence; and then provide that picture to the Soldier in an intuitive way.

Technologies to be considered for integration include:

- Network with appropriate bandwidth
- Multimodal sensor fusion from both organic UxVs and higher echelon systems
- Mission Command and relevant intelligence fusion
- Assessment of the natural environment
- Facial recognition
- Language translation
- Identification of materiel – weapons, vehicles, aircraft, watercraft, uniforms…
- Appropriate Soldier interface devices

Robotics Timeline

- Robotics Week (Columbus & Fort Benning GA)
  - SMET Modular Mission Payload Assessment – 22-26 Apr
  - NAMC Membership Meeting/Outcome Based Innovation Project – 23 Apr
  - NDIA National Robotics Conference and Exhibition – 24-25 Apr
- Robotic Complex Breach Concept Demonstration (Yakima, WA) – 1-10 May
- Robotics and AI Council of Colonels (Pittsburgh, PA) – 15 May
- Tech Demo Request for White Papers (RWP) – 15 May
- Tech Demo Table Top Exercise (TTX) – 16-19 Jul
- Tech Demo Simulation Exercise (SIMEX) – Oct/Nov
- AI & Robotic Dismounted Infantry Platoon Tech Demo – Sep 20

Questions / Discussion

Contact Information

Ted Maciuba, PE

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PROJECT MANAGER
FORCE PROJECTION

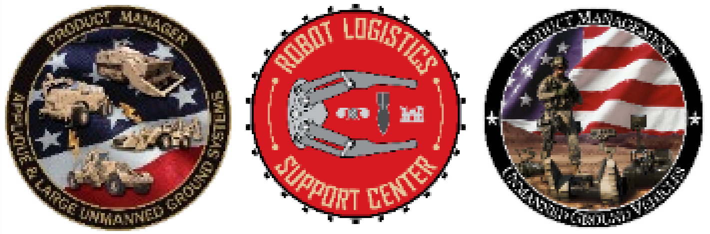
PM Force Projection Robotics Update
NDIA Robotics Capabilities Conference & Exhibition

25 April 2019

LTC Jon Bodenhamer
PdM Applique and Large Unmanned Ground Systems

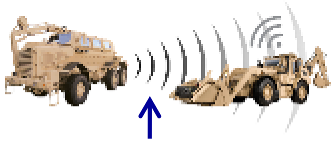
PEO CS&CSS Robotics Portfolio

PEO CS&CSS



M160 Light Flail

Route Clearance & Interrogation System



Semi-Autonomous Control

Robotic Enhancement Program

Man-Transportable Robotics System Increment II

Common Robotic System Individual

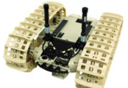
Squad Multipurpose Equipment Transport*

Non-Standard Equipment

MTRS MK II MOD I (Talon IV RESET)

MTRS MK II MOD II (Talon 5A)

TALON IV CBRNe



Dragon Runner

FirstLook

SUGV 310 Mini-EOD

Common Robotic System Heavy*

Enhanced Robotics Payloads*

S&T Lead

Leader Follower Transition to PdM FY20

Automated Convoy Operations CCDEVCOM GVSC Lead

Robotic Combat Vehicle Transitioned to PM NGCV

** Images are conceptual representations, not endorsements*

Squad Multipurpose Equipment Transport (SMET)

Description: 80 systems (20 each GD, ARA, HDT, H&H) issued to Soldiers in 2 IBCTs for a 6 month Technology Demonstration to evaluate performance and operational impact

Two Configurations: Unmanned and Optionally Manned

Required Capabilities:

- Carry 1000 pounds
- Operate over 60 miles in 72 hrs
- Power Generation of 3KW stationary and 1KW moving

Objective Requirements and Modular Mission Payloads

• Full Autonomy • Enhanced Commo • Waypoint Navigation • CASEVAC	• Silent Watch • Universal controller compatibility • Dems (Lane Clearing and Interrogation) • Lethality (CROWS/PLWRWS)	• Enhanced CBRNE Sensing • Imbedded Video TMs and Manuals • ISR suite




Modular Mission Payload Assessment Event

Event

- Location
    - Ft. Benning, GA
- Date
    - 22-26 April 2019
- Duration
    - 1 week

Overview

Demonstrate

- Phase II Contractor MMP products
- Government Projects:
    - R2V2 – TARDEC
    - DEMS – CERDEC
    - RWS – ARDEC
    - CASEVAC – MEDCOM
    - CBRNE – JPEO CB
- Examples:
    - Enhanced Comms
    - Enhanced Sensing
    - Autonomy
    - Lethality

Contracting Strategy

- Through current Phase II OTA each vendor will demonstrate their current MMP designs
- MEDCOM, CERDEC, & JPEO CB are all participating at no cost
- 1144 with TARDEC & ARDEC for minimal costs

Stakeholders

- RAS CDID
- TCM-IBCT
- FORSCOM
- MCOE
- MsCOE
- USMC

Benefits

- Inform the SMET CPD with MMP requirement
- Assess MMP TRL levels
- Evaluate vendor payload options
- Formalize SMET IOP hardware interface and power requirements

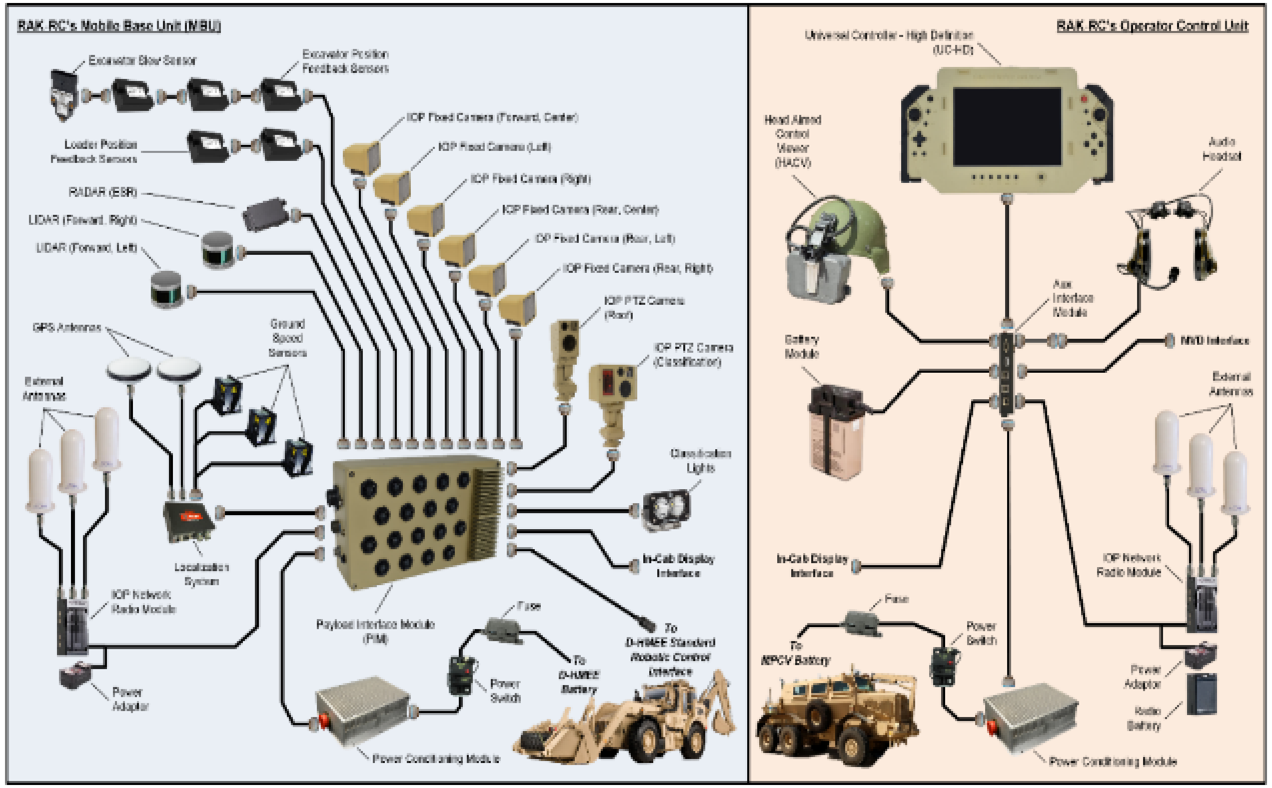
Route Clearance & Interrogation Systems Type I

Mission: The RCIS Type I protects Soldiers performing excavation, interrogation, and classification of deep buried IEDs, explosive hazards and caches. It enables the ability to neutralize explosive hazards. Soldiers semi-autonomously control HMEE from a protected stand-off position (minimum 200meters) inside a Buffalo vehicle.

Route Clearance & Interrogation Systems (RCIS) Type I provides Tele-operation and an optional RADAR-based Follow-Me capability, LIDAR obstacle detection, onscreen predictive turning map, & customizable camera views, using commercial-based technology integrated to a legacy Army platform. It is modular and can be adapted to other systems

RCIS Type I Provides:

- Soldier protection while performing threat interrogation
- Ability to neutralize explosive hazards from a stand-off position up to 200 m
- Modular, robotics capability from tele-operation to Follow-me semi-autonomy
- RADAR-Based follow-me technology for route clearance convoy ops
- Teleoperation for excavation of suspected hazards
- On-screen predictive mapping
- LIDAR-based obstacle sensing
- Customizable camera views



Distribution A: Approved for Public Release

PLS A1 Leader Follower Capability

System Description: The Leader Follower capability is a suite of robotic applique sensors and vehicle by-wire and active safety upgrades to provide an unmanned capability to the PLS A1 Fleet of vehicles for convoy operations. Fully developed sensor and autonomy kit will be compatible with majority of Army line haul truck and trailer fleet.

TWV-LF Capabilities:

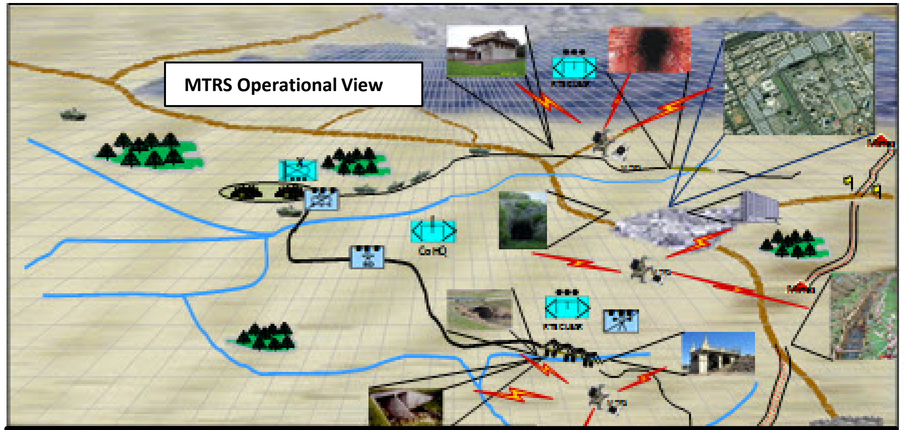
- ❑ Increase Line Haul Company daily convoy mission capacity.
- ❑ Force protection and logistics throughput for line haul convoy missions for the PLS Fleet of TWVs.
- ❑ Wirelessly link unmanned follower PLS' to a soldier operator Leader PLS vehicle.
- ❑ Reduces number of soldiers required to operate convoy, resulting in reduced number exposed to risk of injury from attack.

Near Term Major Events

- ❑ Contractor led, Government observed testing at Ft. Bliss Jan – May 2019
- ❑ ATEC testing to support Technology Demonstration Testing start Jun 2019

- **Acquisition Category (ACAT): III Pre-MDD**
- **Acquisition Objective (AAO/APO): 4566/3300**
- **Capability Production Document (CPD): Estimated AROC in 4QFY2020**
- **Full Material Release: TBD**

MTRS Inc II Program Overview / Update



- The Man Transportable Robotic System (MTRS) Inc II is a remotely operated, man-transportable, robotic system
- Provides a standoff capability to interrogate, detect, confirm and neutralize presence across War-fighting functions
- Capability to identify and disposition explosive hazards
- Army's medium sized common platform allowing use of various platform payloads in support of current and future missions

* AAO includes EOD requirement of 587

- ✓ CPD: Approved, MAY 2013
- ✓ Contract: Awarded, SEP 2017
- First Unit Equipped (FUE): 2QFY20

AAO: 1,210

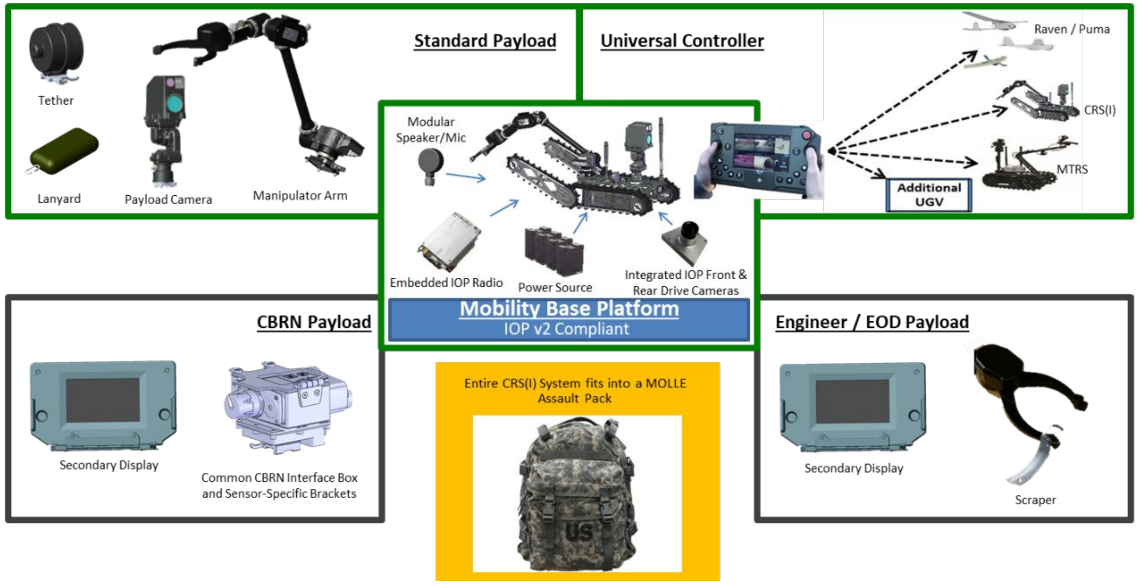
Users: Engineer, CBRN, EOD and SOF

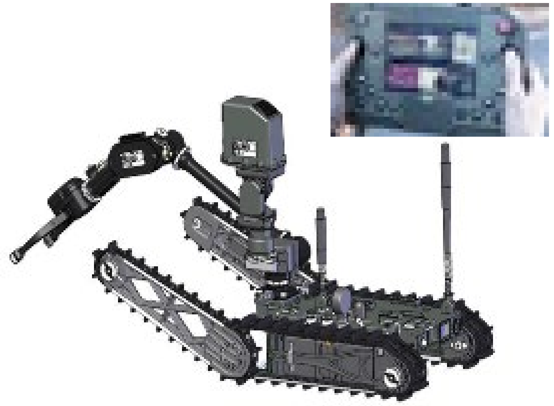
Common Robotic System (Individual) {CRS(I)}

System Description: The CRS(I) is the Army's small sized (<25 lbs), common platform, remotely operated and Soldier back-packable robotic system providing Soldiers dismounted increased standoff capability from hazardous threats. The system consists of a Universal Controller (UC), a suite of payloads, an open architecture common mobility platform allowing for future capability growth.

Capabilities:
- Standoff short range Intelligence, Surveillance, & Reconnaissance (ISR)
- Remote Chemical, Biological, Radiological, and Nuclear (CBRN) detection
- Remote Explosive Obstacle Counter Measure (EOCM)
- Remote Explosive Ordnance Disposal (EOD) operations
- Remote clearance of danger areas
- UC with ability to control battalion and below unmanned system PORs

✓ **CDD: Approved, 5 JAN 2016**
✓ **Milestone B: 2QFY18**
✓ **Milestone C: 2QFY19**
- First Unit Equipped 2QFY20
- AAO: 3,258
- APO: 690
- Users: INF, CBRN, ENG and EOD





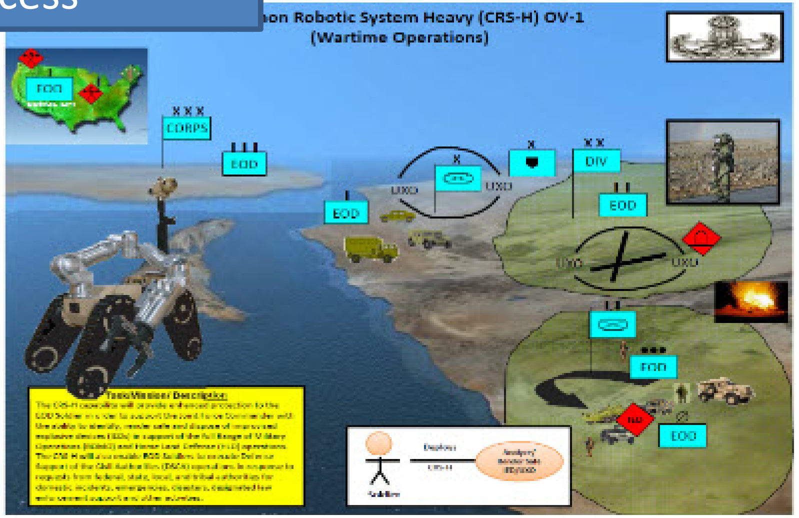
QinetiQ North America

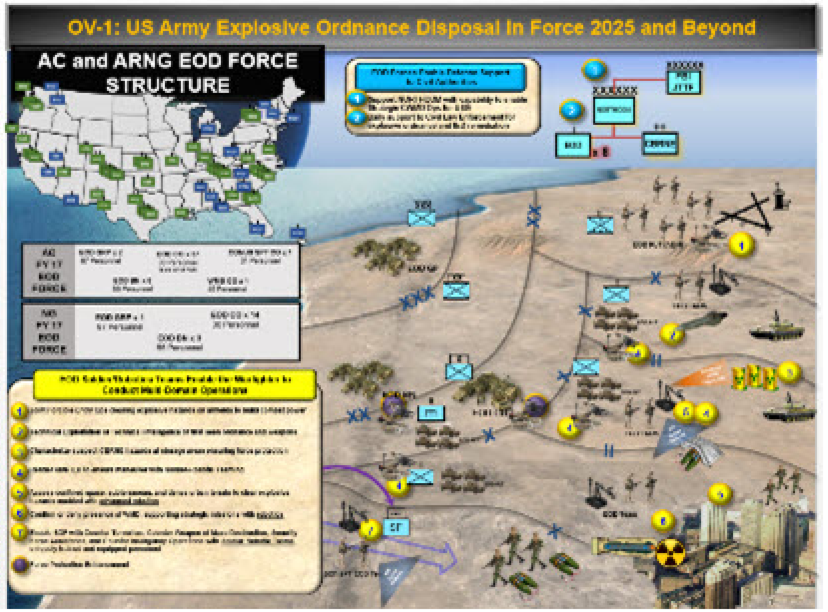
LRIP contract awarded to QinetiQ North America on 11 March 2019

Distribution A: Approved for Public Release

Common Robotic System Heavy (CRS(H)) Program Overview

Fly-Off #2 In Process





System Description:
The CRS(H) is the Army's large sized, vehicle transportable, common robotic platform capable of accepting various mission payloads enhancing protection to the EOD Soldier by providing increased standoff capability to identify, render safe and dispose of explosive ordnance and improvised explosive devices in support of the Range of Military Operations and Homeland Defense operations.

Performance Requirements:
- Manipulator Arm Lift Capacity (Close to Platform > 275 lbs; Full Extension (72 in) > 100 lbs)
- Platform Speed > 6 mph
- Obstacle Clearance > 32 in (New Jersey Barrier)
- Platform Endurance > 7 hrs
- Weight < 700 lbs curb weight, 1000 lbs gross system weight (includes 300 lbs of non-native payloads)
- Interoperability – IOP compliant & utilize Universal Controller
- Cyber Hardened

✓ CPD: Approved, May 2018
✓ Fly-Off Agreements (OTA) Issued: Aug 2018
✓ Fly-Off 2 In progress (25 Mar – 7 Jun 19)
- **Production OTA projection award Aug 2019**
- **FUE: 2QFY20**

AAO: 248
Users: EOD and CBRN

** Images are conceptual representations, not endorsements*

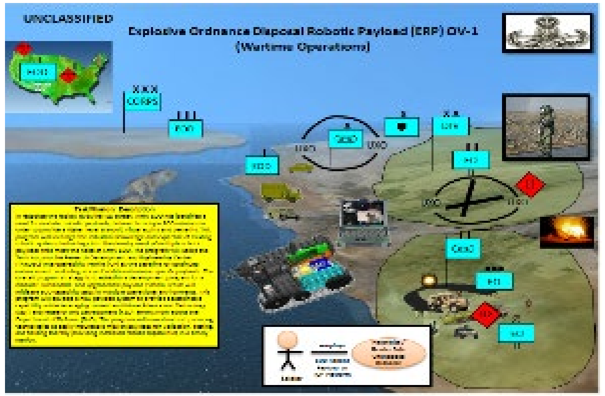
Enhanced Robotic Payloads

CPD staffing initiated

System Description:

The ERP is a suite of modular capabilities designed with open architecture to provide an increased level of standoff, situational awareness, disruption capability and dexterity to respond to current and emerging Engineer, CBRN and EOD requirements. These multiple, modular robotic mission payloads will use open architecture to integrate with the MTRS Inc II and CRS(H) platforms to form the Army's next generation platform adaptable robotics systems.

Capabilities:
- Dual Arm Dexterity
- Multi-Shot Disrupter
- Fine Precision Aiming Module
- Multispectral Overlay Camera
- Obstacle Avoidance & Digital Modeling
- Extended Range Radio & Mesh Networking
- Extended Range UAV & Surveillance



- **CPD Approval: ~FY19**
- **Solicitation Release: TBD**

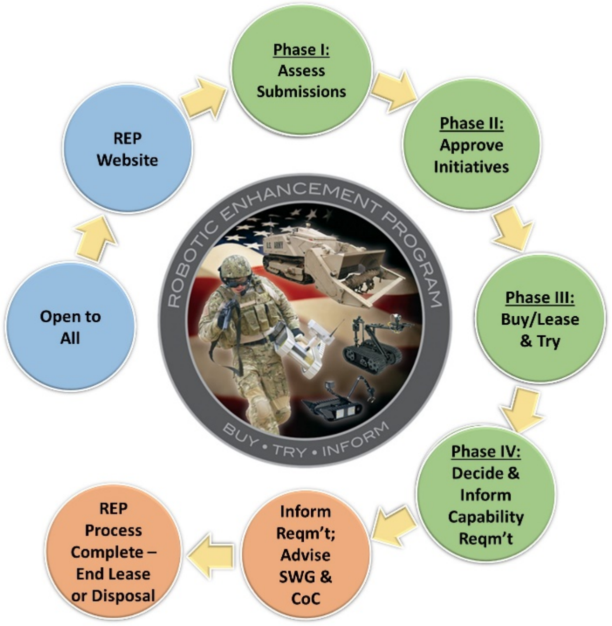
Users: CBRN and EOD

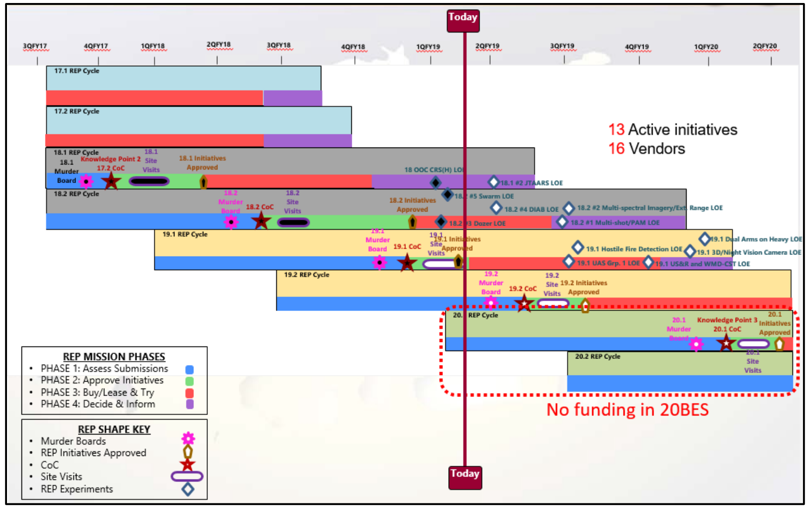
** Images are conceptual representations, not endorsements*

Distribution A: Approved for Public Release

Robotic Enhancement Program Update

- REP defunded in FY20 and beyond to support higher priority Army efforts
- REP CoC 19.1 and prior approved initiatives to continue through completion
- Final REP initiative expected to complete in 2QFY20





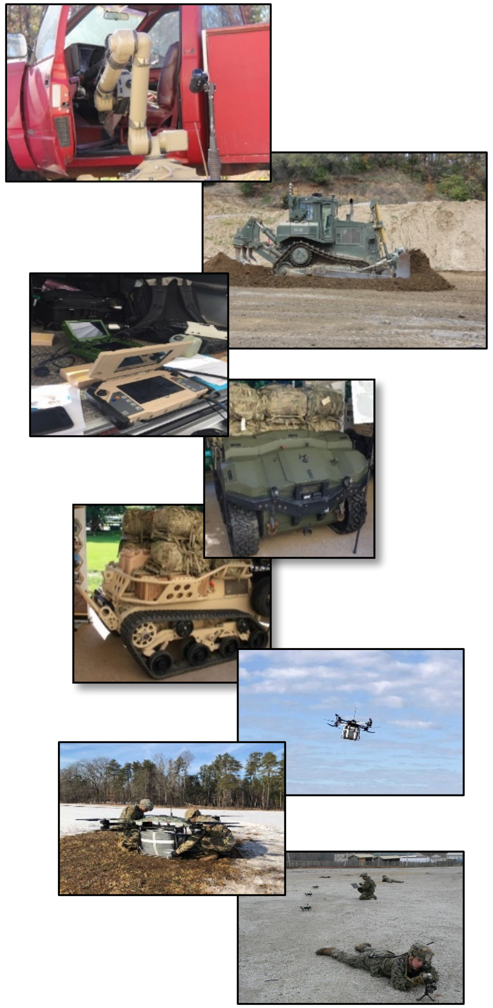
REP Accomplishments – 2015 – 2019

Through the support of the Robotics Industry, REP conducted (REP Cycles 16.1 - 18.2)

- 20 initiatives evaluated in operational environments:
  - Directly informing 14 capability documents (CPD, CDD, AoA)
  - Indirectly informing 19 capability documents indirectly informed (CDD, ICD, CPD)

– Accomplishments:

- CRS(H) - Eliminated a need for EMD Phase, accelerated acquisition by 10 – 12 months
- Universal Controller: Demonstrated maturity, reduced the EMD phase by 24 months
- SMET: Facilitated 1-Year Technology Demonstration, accelerated acquisition by 10 – 12 months with goal of first unit equipped within 24 – 36 months
- JTAARS: FUE pulled 48 months ahead
- Offensive Swarm: Provided feedback on challenges on communication bandwidth when utilizing multiple UGVs and UASs



Thank you for your support

Discussion

Advanced GNSS Positioning for Cooperative Adaptive Cruise Control (CACC) Truck Platooning

Patrick Smith

AUBURN UNIVERSITY

GPS & Vehicle Dynamics Laboratory

Outline

- Background and Motivation
- CACC System
  - Hardware Setup
  - DSRC radio communication
  - CACC algorithms and software
- Testing and Demonstrations
  - Phase II
  - Phase III
- Conclusions and Future Work

Background and Motivation

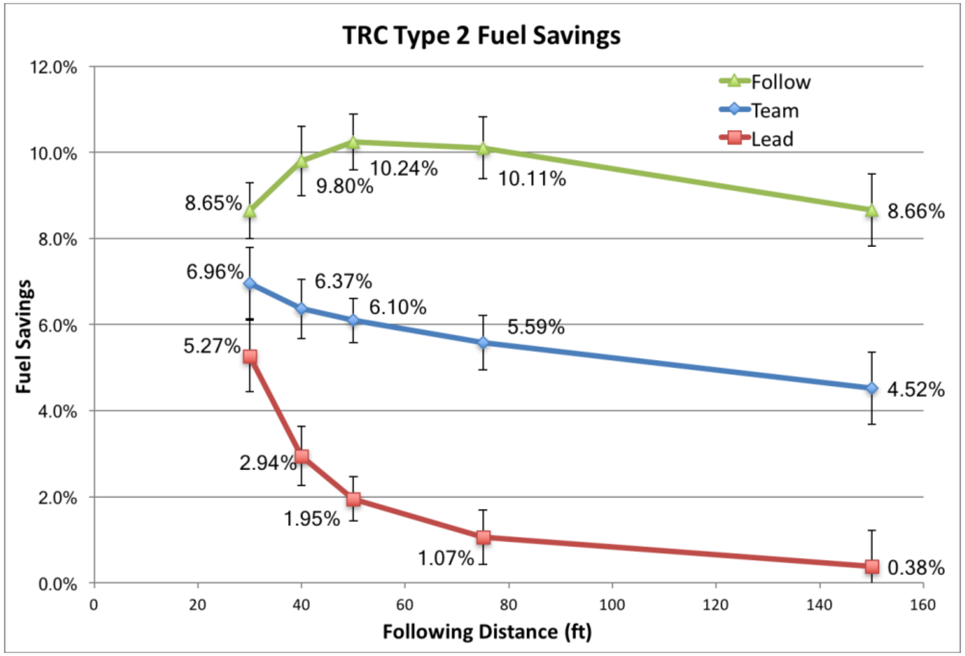
Background/Motivation

- Although combination trucks account for ~1% of all motor vehicles on US roads, these vehicles drive approximately 50,000 more miles than the next vehicle type [1]

- Decline of truck drivers, e.g. in the Canadian forestry industry [2]

Background/Motivation Cont.

- ATRI showed highest operational cost for truck fleets of all sectors was fuel usage, coming in at 38% of the total marginal operating cost [3]
- 36% of all freeway accidents occurred on entrance ramps [4]

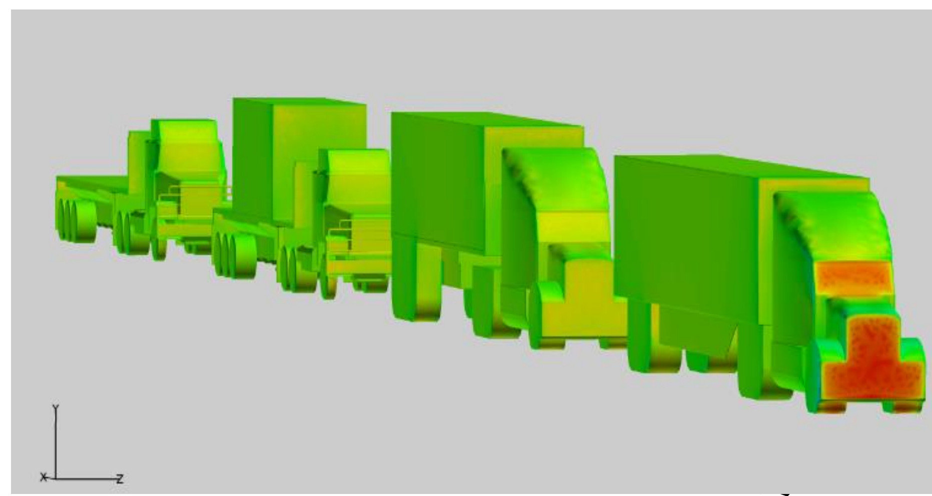


[5]

CACC System

CACC Overview

- Cooperative Adaptive Cruise Control
- Extension of Adaptive Cruise Control (ACC)
- V2V network to share information
- Auburn's CACC system
  - Level 1 Autonomy
  - Longitudinal (throttle and braking) control
  - Manual steering



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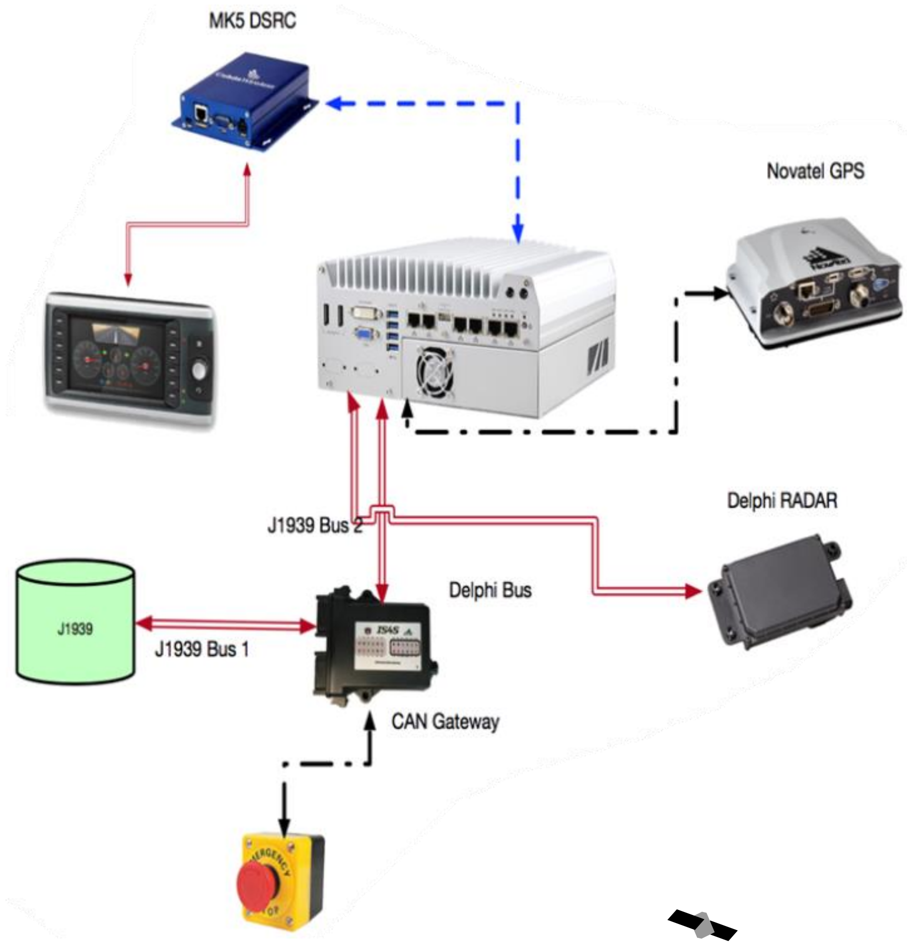
Hardware Setup

- System components
  - PC for vehicle interface and algorithms
  - DSRC radio
  - GPS receiver
  - Automotive radar
  - By-wire kill switch for disconnect from CAN bus
  - GUI Display



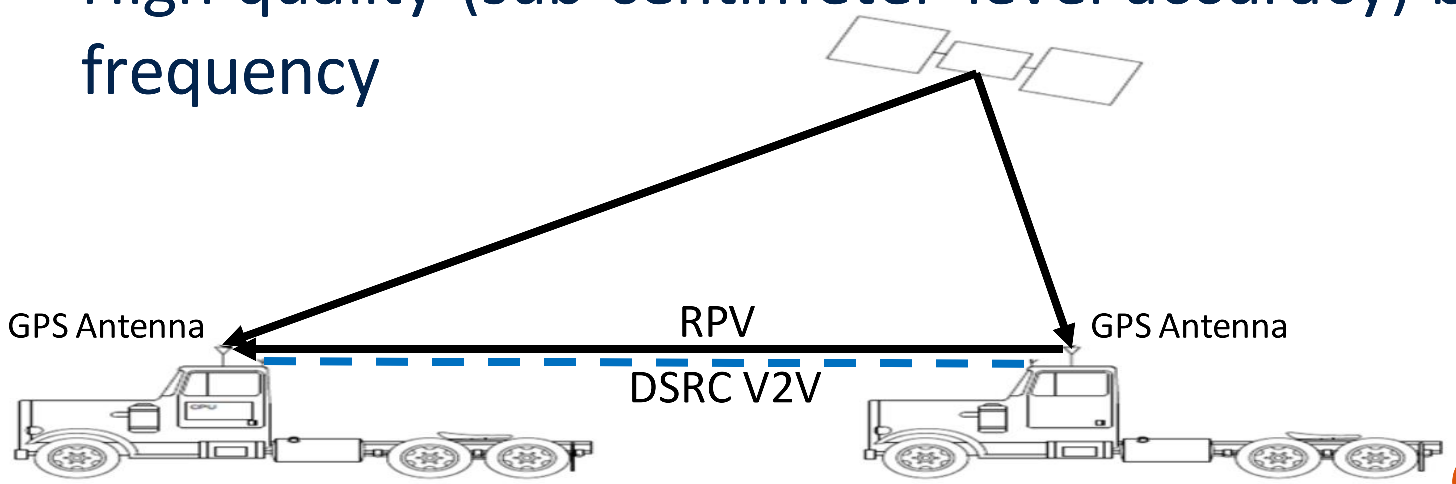
DSRC Radio Communication

- Dedicated Short Range Communication (DSRC)
- Current industry standard
- Developed two implementations
  - Denso
  - Cohda Wireless MK5
- Custom UDP data packet
  - Vehicle state information
  - Raw GPS observables

CACC Algorithms

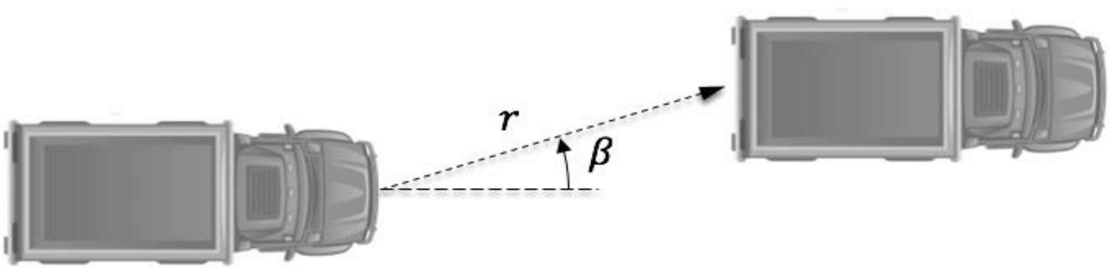
Range Estimation

- Dynamic-base Real Time Kinematic (DRTK) [6]
  - Differential GPS technique; extension of RTK
  - Uses GPS carrier phase measurements to calculate Relative Position Vector (RPV)
  - High quality (sub-centimeter level accuracy) but low frequency



CACC Algorithms

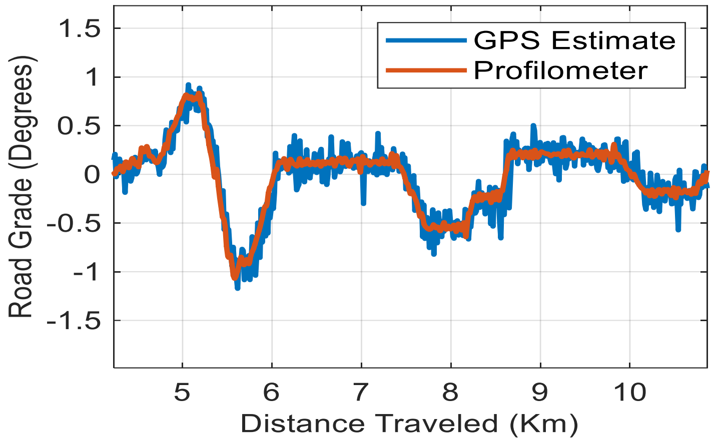
- Kalman Filter
  - Fuses complementary measurements of radar and DRTK
  - Produces reliable estimates of inter-vehicle range, range rate, and bearing
  - Track neighboring vehicles using radar and predict forward path for cut-in detection [7]

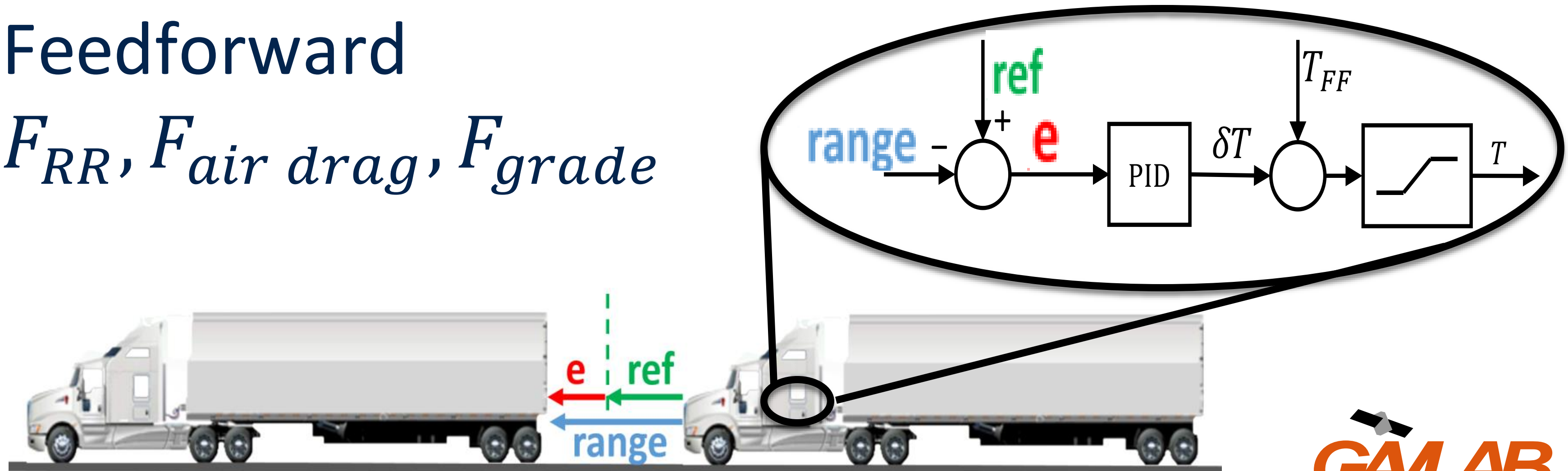


CACC Algorithms

Control System

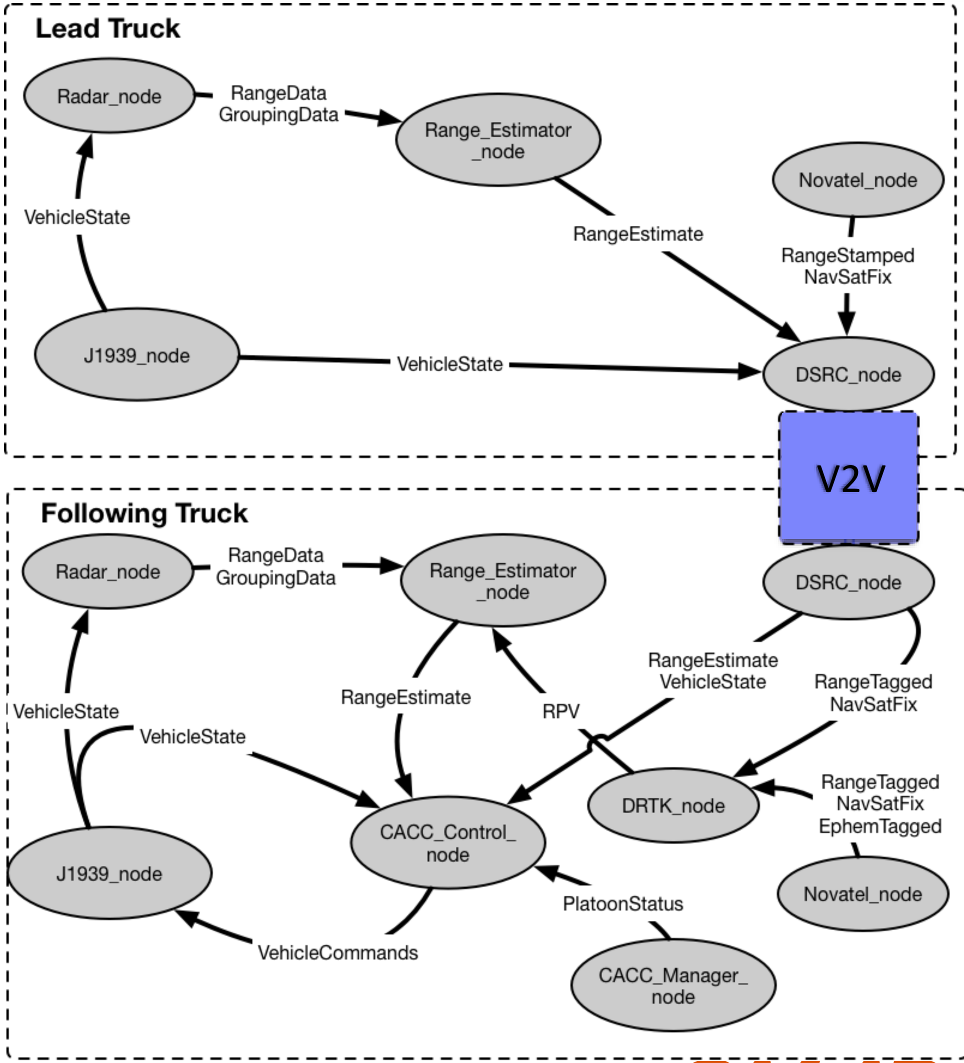
- Longitudinal headway, or gap, controller
- PID with feedforward control
- Feedforward $F_{RR}, F_{air\ drag}, F_{grade}$





CACC Software

- Real time implemented in ROS architecture [8]
  - Sensor/hardware Drivers
    - J1939 CAN
    - Delphi ESR Radar
    - Novatel GPS
    - DSRC V2V communications
  - Controller and Estimation
    - Range Estimation filter
    - DRTK RPV filter
    - CACC control Node
    - Convoy Manager



Testing and Demonstrations

Phase II

Phase IIC

- Blue Water Bridge Crossing
- October 5, 2017 in Port Huron, Michigan
- Convoy across bridge from USA to Canada and back for VIP event

Phase II Cont.

Phase IIB

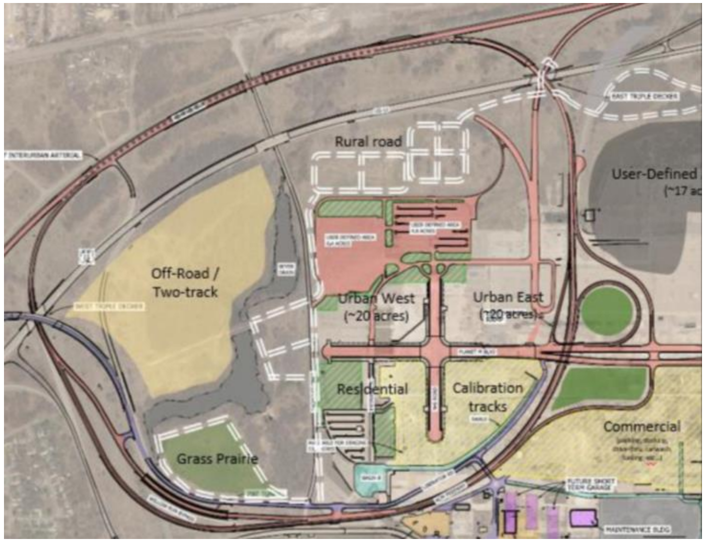
- Truck Platooning on highway I-69 in Michigan
- October 16-19, 2017
- Convoy tests for controller validation
  - Spacing: 50, 75, 100, and 200 ft.
  - Speed: 55 mph

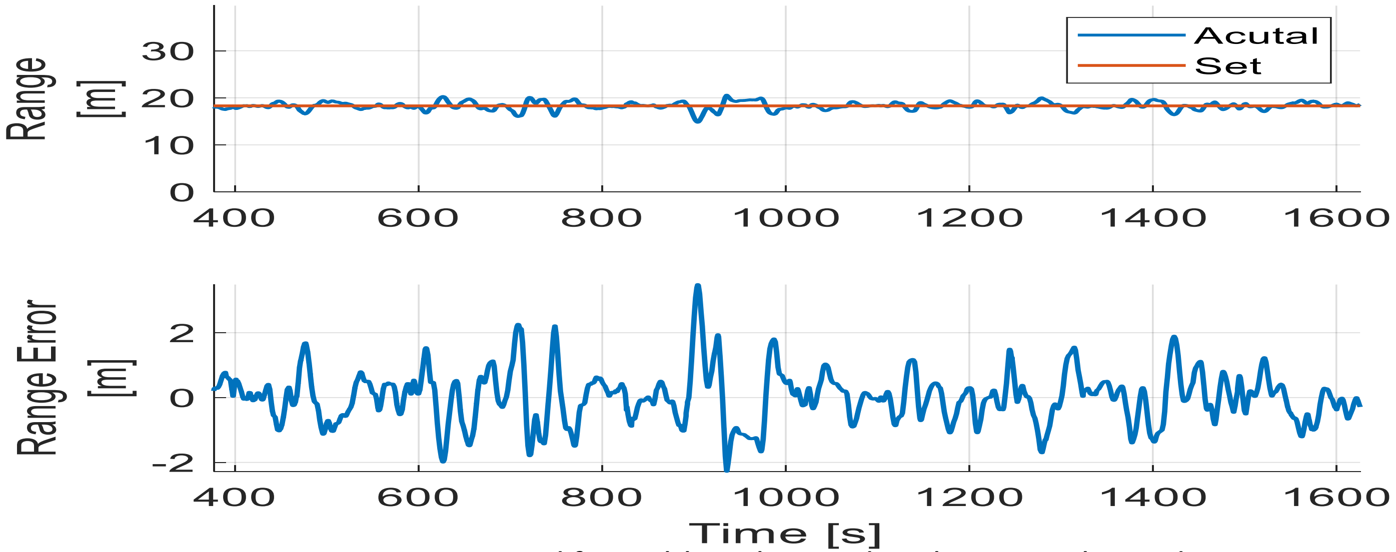
Phase II Cont.

- Demonstration totals during testing:
  - Operation time: ~3.5 hours
  - Distance: >170 miles

Phase III

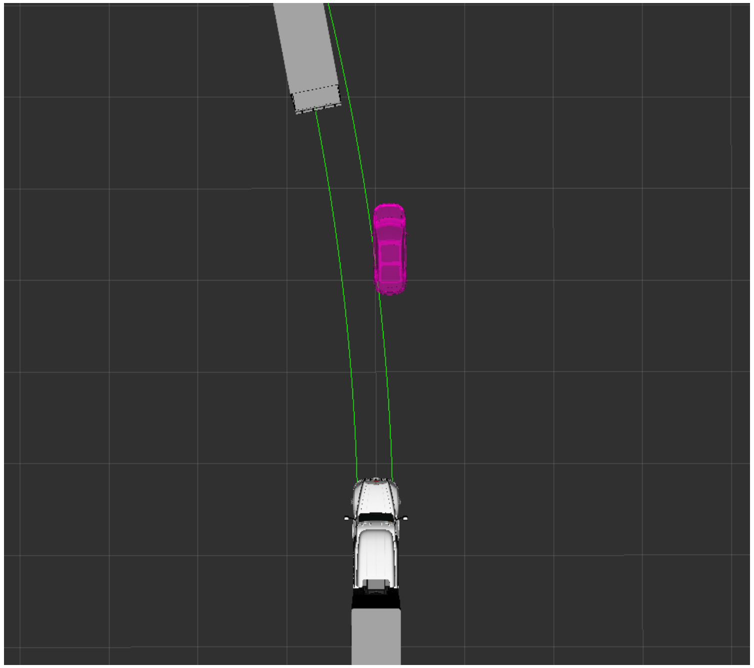
- October 22-27, 2018
- Four vehicle platoon
- Longitudinal control, vehicle cut-ins, and connected vehicle merging





Phase III Cont.

- Cut-in detection
  - Track neighboring vehicles
  - Project forward path and determine if vehicle is inside
  - Fall back to safe distance
  - Range off cut-in; maintain DRTK to leader



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Phase III Cont.

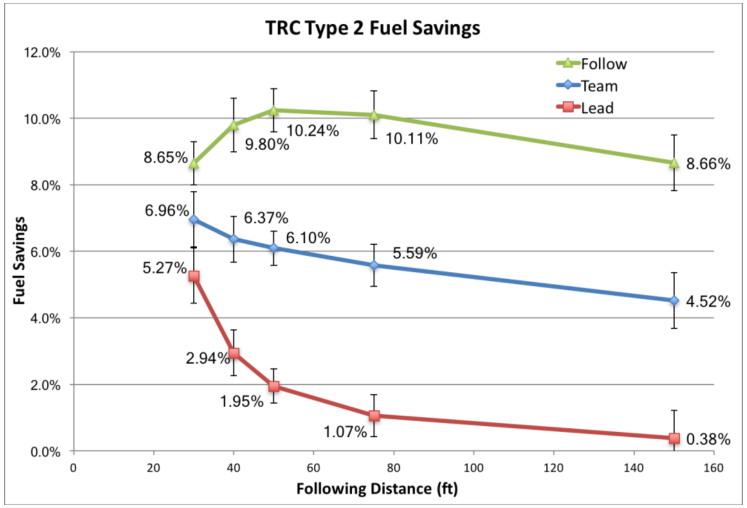
- Connected vehicle merging
  - GPS position/velocity, merge point/speed limit known
  - Estimate time to merge point
  - First In First Out (FIFO) logic

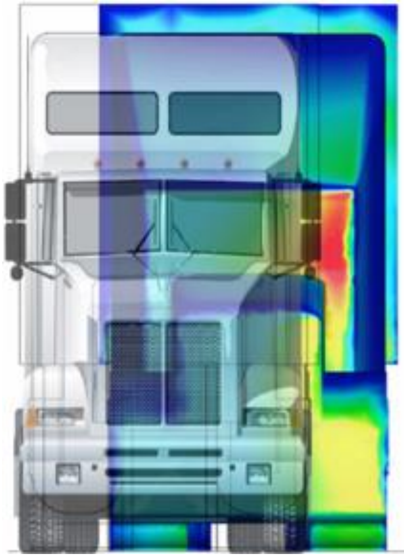
Phase III Cont.

Conclusions and Future Work

Conclusions/Future Work

- Successfully developed and implemented a CACC system
- Demonstrated capabilities that have potential safety, fuel benefits
- Future work:
  - Level 2 Autonomy (lateral control)
  - Fuel testing
  - Optimal platoon configuration and terrain





Acknowledgements

Sponsor

- U.S. Army Combat Capabilities Development Command (CCDC) Ground Vehicles Systems Center (GVSC)

Collaborators

- University of Michigan-Dearborn
- Integrated Solutions for Systems (IS4S)
- National Center for Asphalt Technology test track

Questions?

Thank You!

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JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Towards a Multi-Agent/Multi-Domain World Model

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Mark Hinton
Christine Piatko

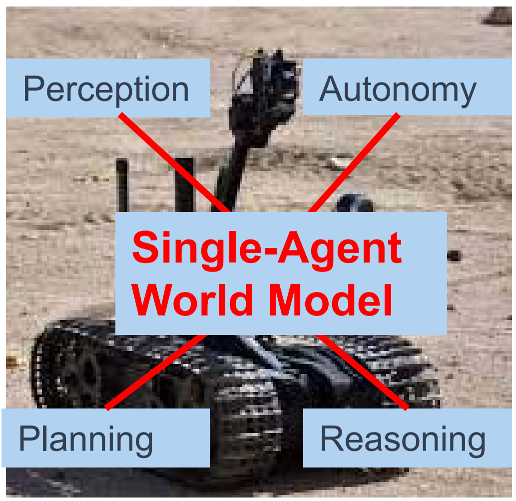
April 25, 2019

Outline

- Our Goal
- Scenario - Multi-Agent/Multi-Domain Squad
- Multi-Agent World Model
  - Definition
  - Requirements
- Our Approach
  - Multi-Agent World Model Demo
  - Standards

Our Goal

Previous work on World Modeling focuses on information integration on a single agent

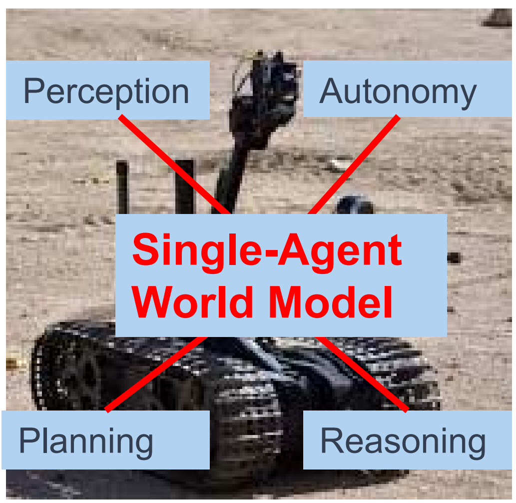


Single-Agent World Model

- Repository for storing, providing and sharing information relevant to a system's operational environment and beliefs
- Processed sense data
- Environmental beliefs derived from sense data
  - Object identification and classification, including threat identification, etc.
- History of behavioral decisions made as a result of sense data and derived beliefs
  - Path modification for obstacle avoidance, etc.

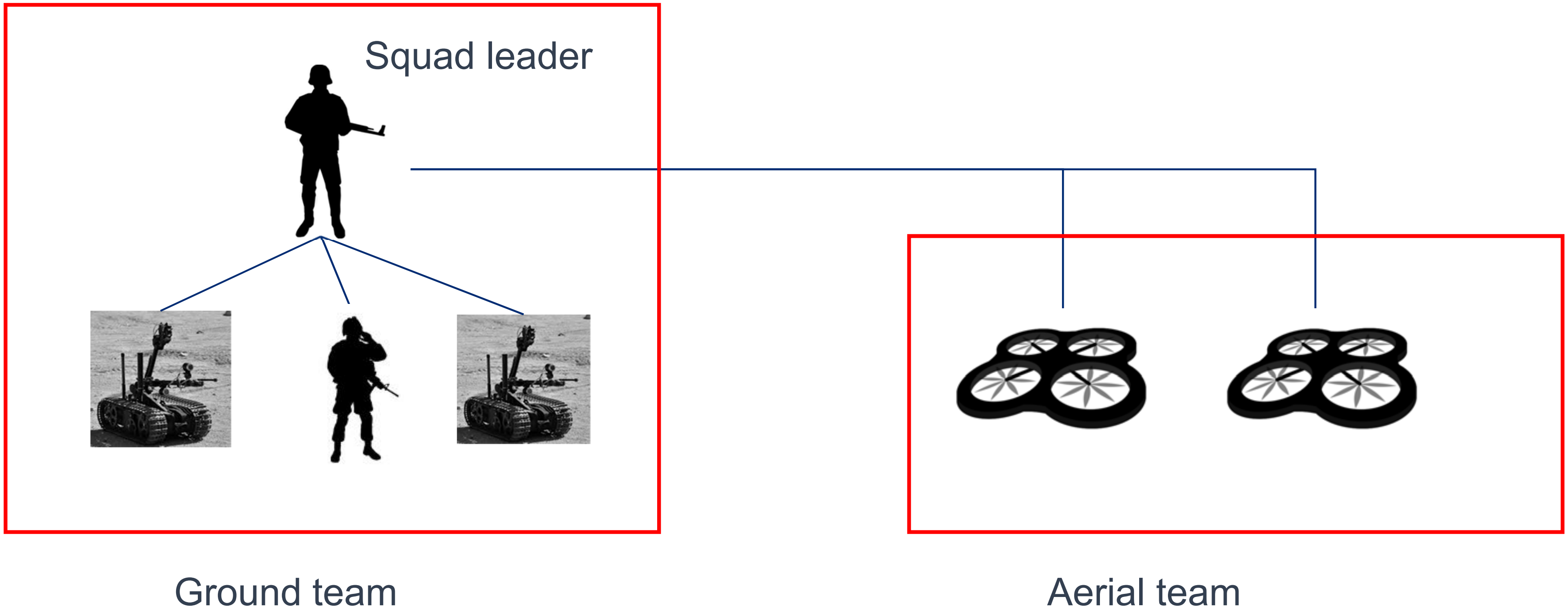
Our Goal

Previous work on World Modeling focuses on information integration on a single agent



What does “World Model” mean for a Multi-Agent/Multi-Domain system?

Scenario – Multi-Agent/Multi-Domain Squad



Scenario

- Mission: Area reconnaissance for IED threats
- Multi-Domain team needs to
  - Do aerial scan of geographic area
  - Identify suspicious areas
  - In-depth reconnaissance with ground team
  - Identify possible threats

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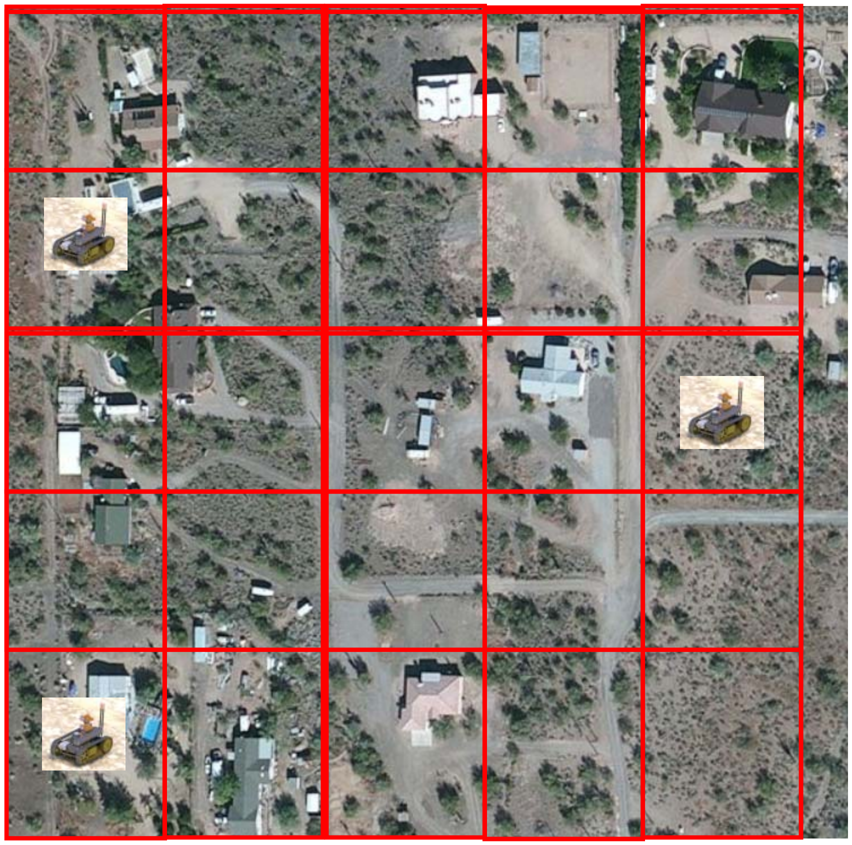
  - identify suspicious areas
  - In-depth reconnaissance with ground team
  - Identify possible threats



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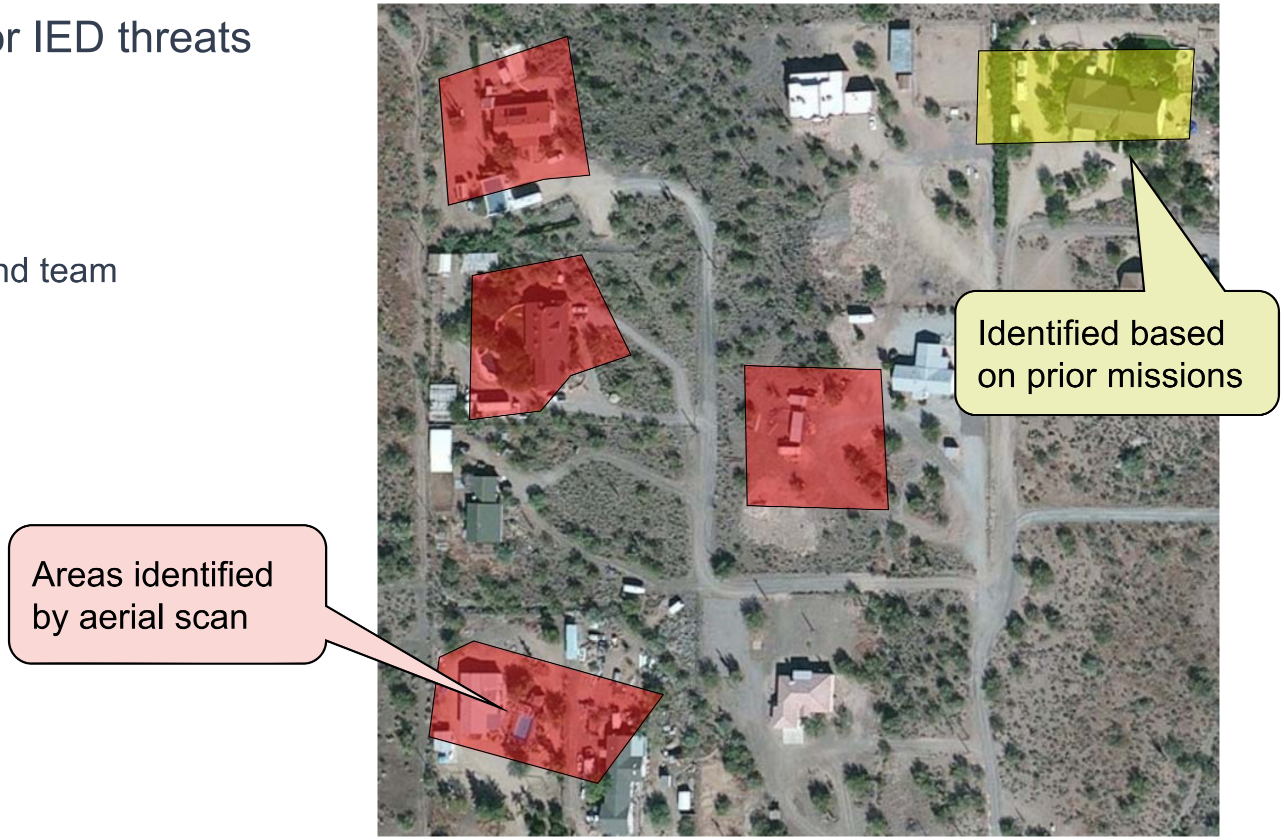

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  - **In-depth reconnaissance with ground team**
  - Identify possible threats

https://news.usni.org/2015/08/27/advanced-eod-robotic-system-variant-approved-for-emd-phase

Scenario

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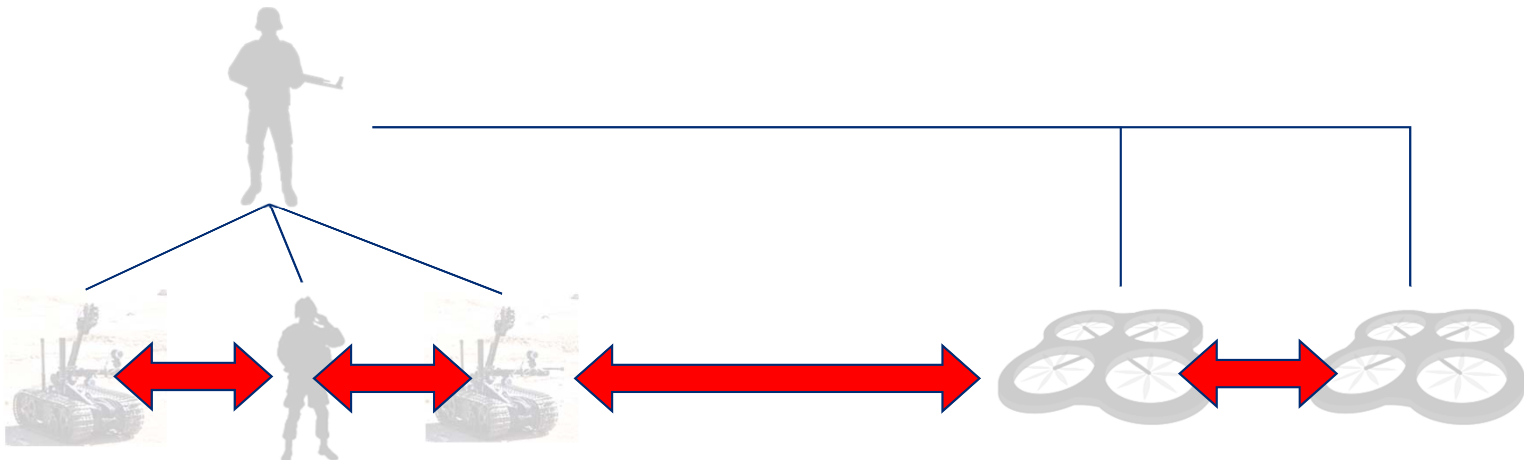
  - In-depth reconnaissance with ground team
  - **Identify possible threats**

https://upload.wikimedia.org/wikipedia/commons/a/a5/IED_Baghdad_from_munitions.jpg

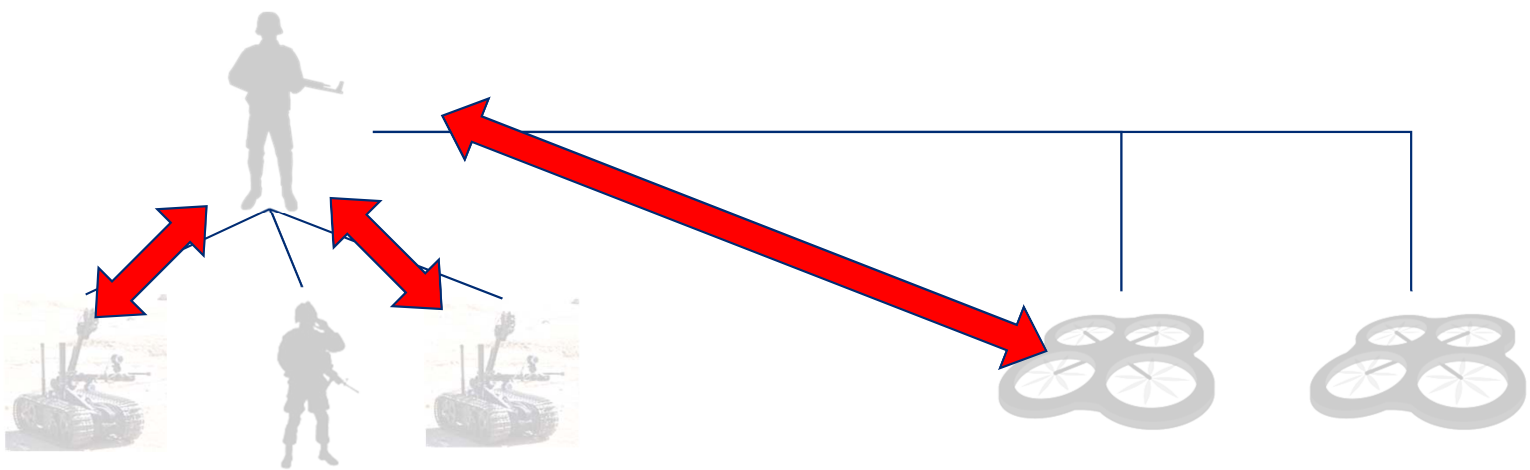
Scenario – Multi-Domain Squad

Horizontal sharing of information within a squad



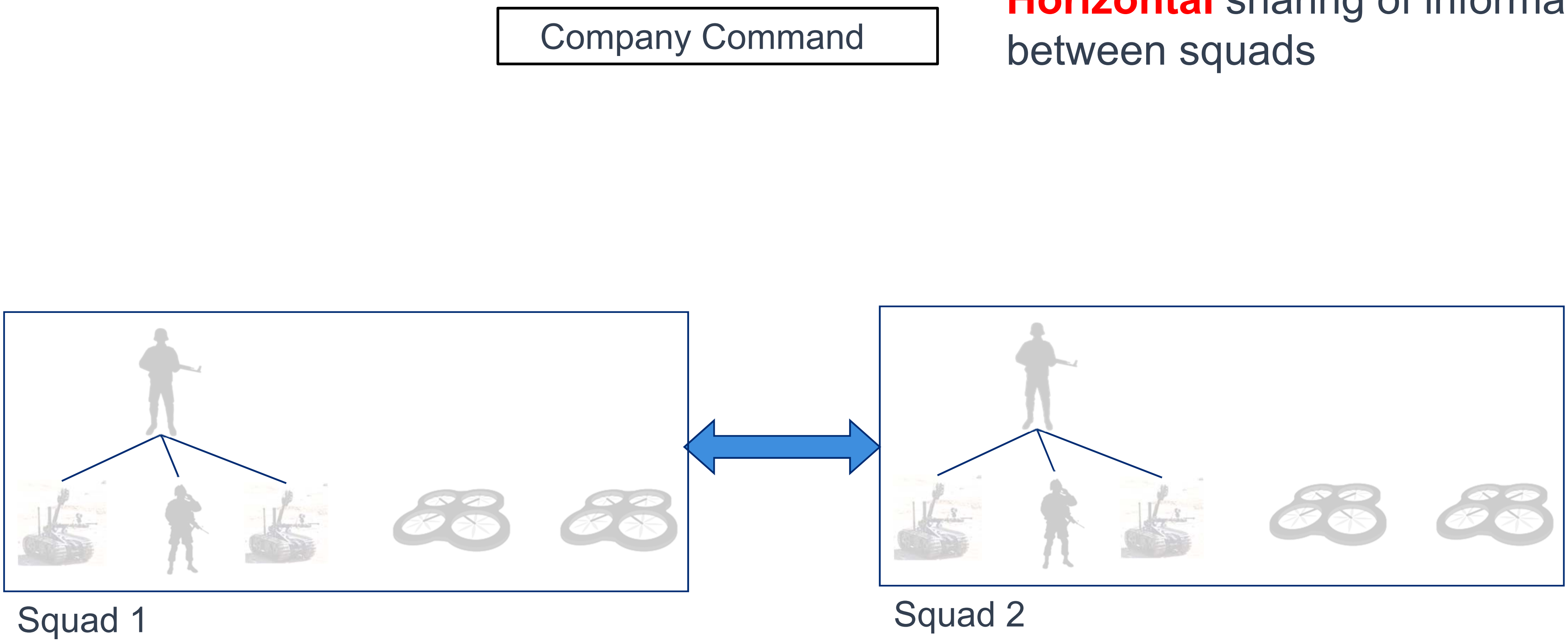
Scenario – Multi-Domain Squad

Vertical sharing of information with squad leader



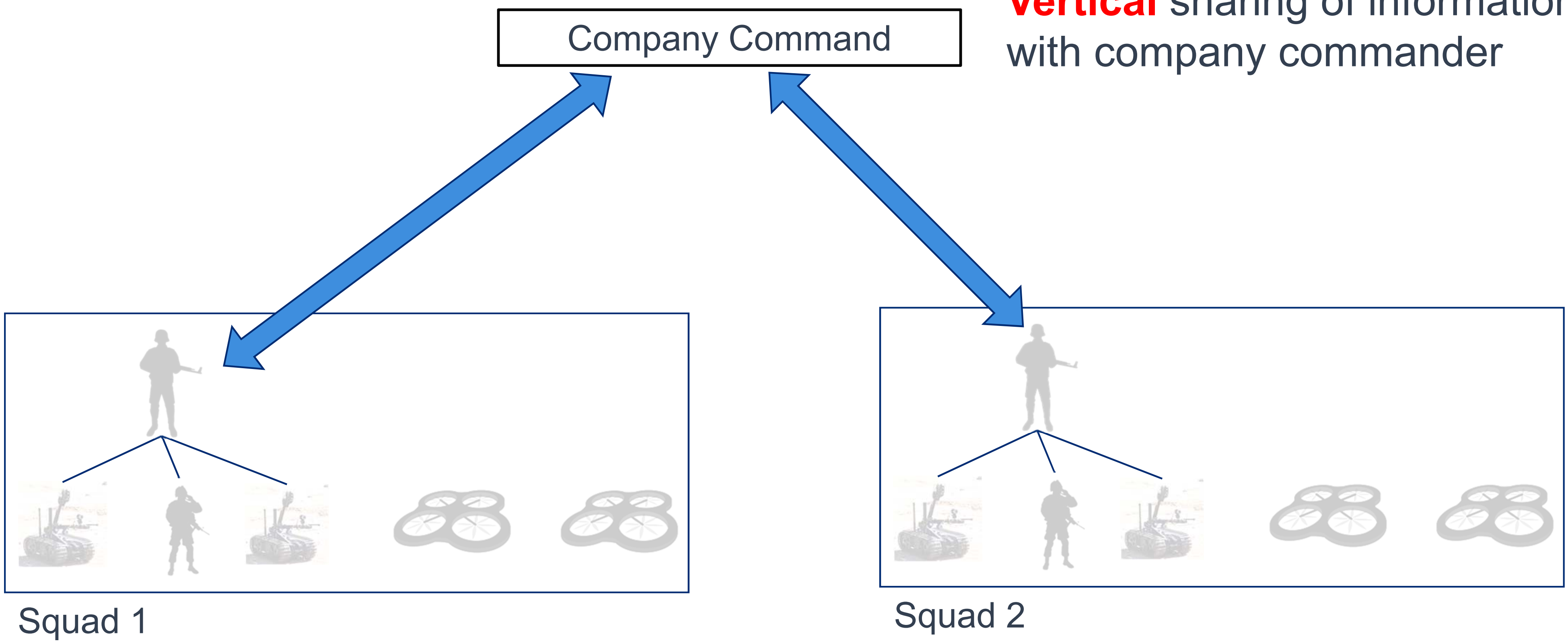
Scenario – Multi-Domain Squad

Horizontal sharing of information between squads

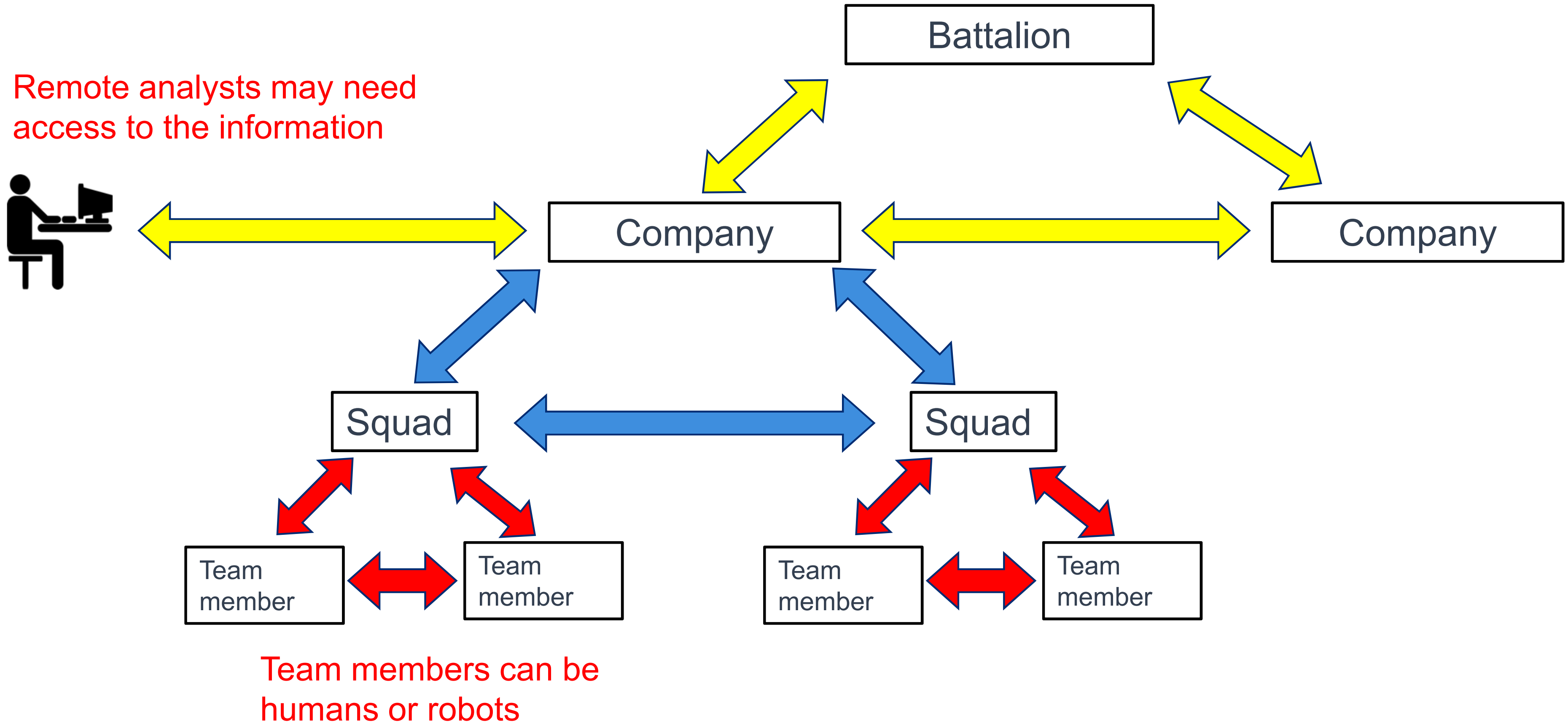


Scenario – Multi-Domain Squad

Vertical sharing of information with company commander



Scenario – Multi-Domain Squad



Multi-Agent World Model

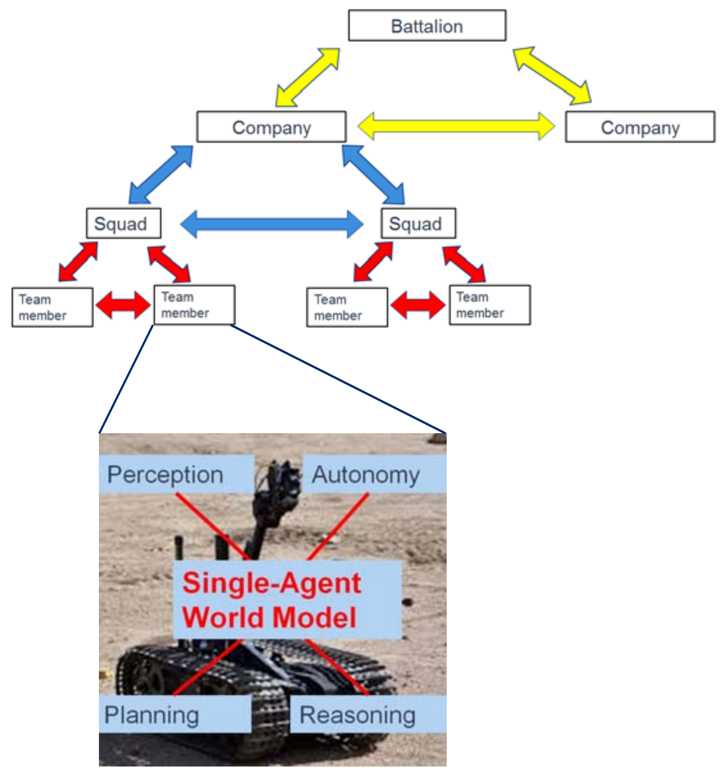
Multi-Agent/Multi-Domain World Model

Facilitates

- Common Operating Picture
- Situational Awareness across System of systems
- Command and control

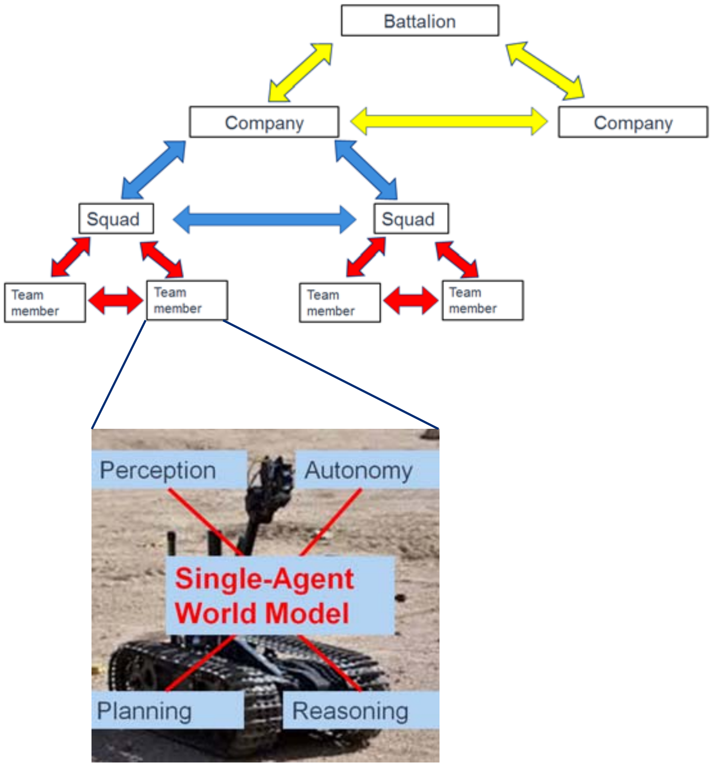
Enables

- Semantic data interchange among heterogeneous robot and human teams



Multi-Agent World Model - Requirements

- **Shared**
  - Within and across systems
  - Vertical and horizontal
  - Timely and relevant (right information, right place, right time)
- **Scalable**
  - Across many heterogeneous agents
  - With differing capacities (network, compute, storage)
- **Extensible**
  - New kinds of missions and tasking
  - New kinds of domains (e.g., amphibious robots)
- **Interoperable**
  - Interoperability of data across lifetime of systems
  - Across multiple vendors
- **Resilient**
  - Unreliable networks and topologies
  - Node failures
  - Unexpected tasking (on-the-fly teaming)



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World representation is **meaningful** across:

- Heterogeneous robots
- Human operators
- Aggregated data repositories
- Reasoning engines

Focus on **semantic data** rather than raw sensor data & specific algorithms

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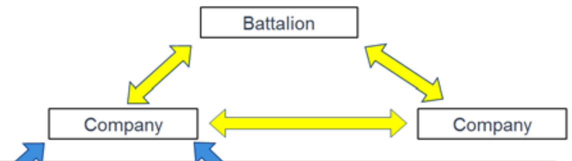

Data is available
- Across system topologies
- Across node capabilities

Efficient use of network bandwidth

Multi-Agent World Model - Requirements

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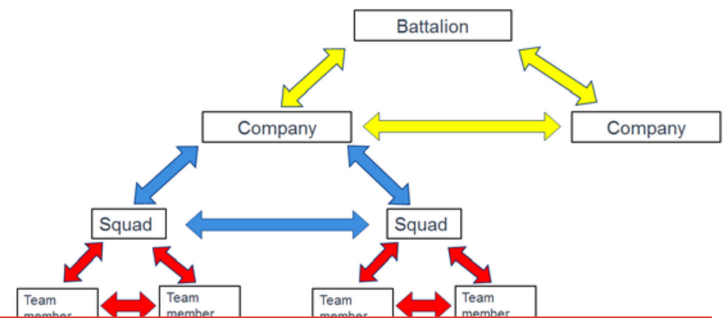
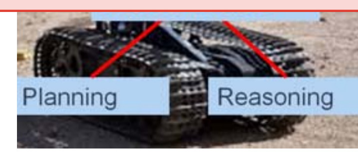


Data definitions are **dynamic** (add new types of data on the fly, e.g., vehicles, weapons)

Data is **self-describing**
- Facilitate aggregation across composite sources, querying



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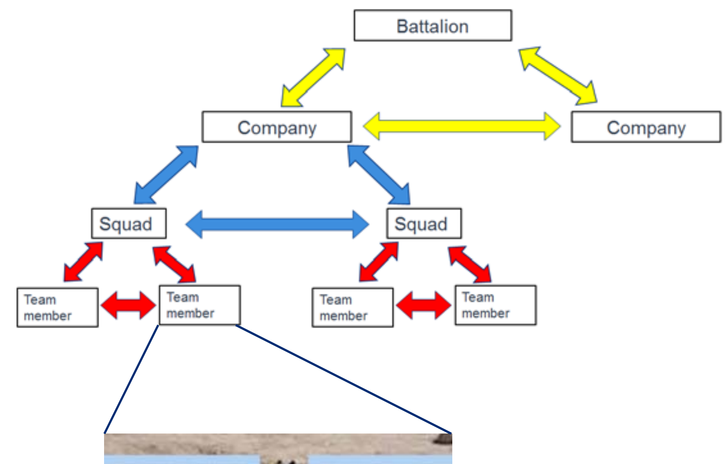

Requires **standards**

- Data formats
- Semantics (ontology)
  - Things in the world
  - Relationships between them
  - Types of missions

Multi-Agent World Model - Requirements

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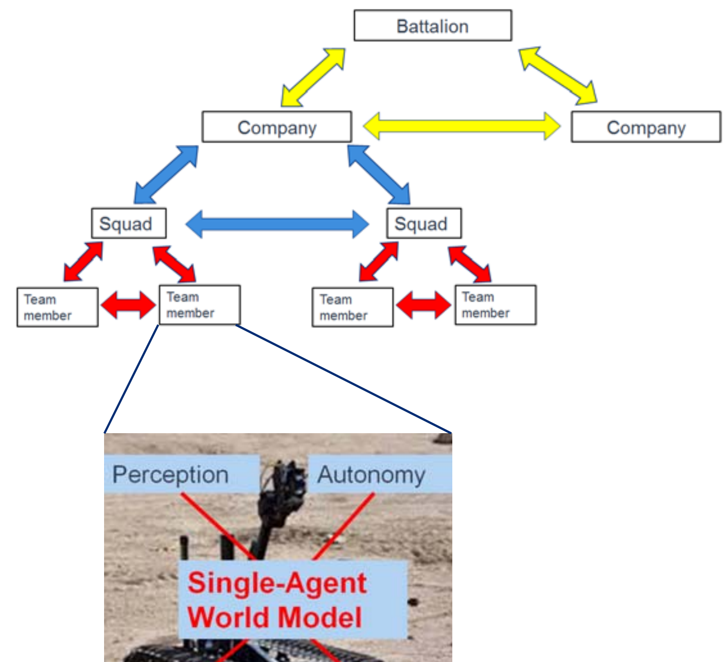


- Robust
- Persistent
- Available

Outline

- Our Goal
- Scenario - Multi-Agent/Multi-Domain Squad
- Multi-Agent World Model
  - Definition
  - Requirements
- Our Approach
  - Multi-Agent World Model Demo
  - Standards

Multi-Agent World Model Demo - Motivation

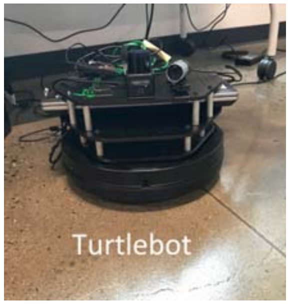
- Work through a scenario
- Motivate design for standard
- Proof of concept
  - Viability of approach (key part of a world model is need to accommodate legacy systems)

Multi-Agent World Model Demo

In Theater

Commander

Turtlebot
Operator



Recon robot

Traxxas
Operator

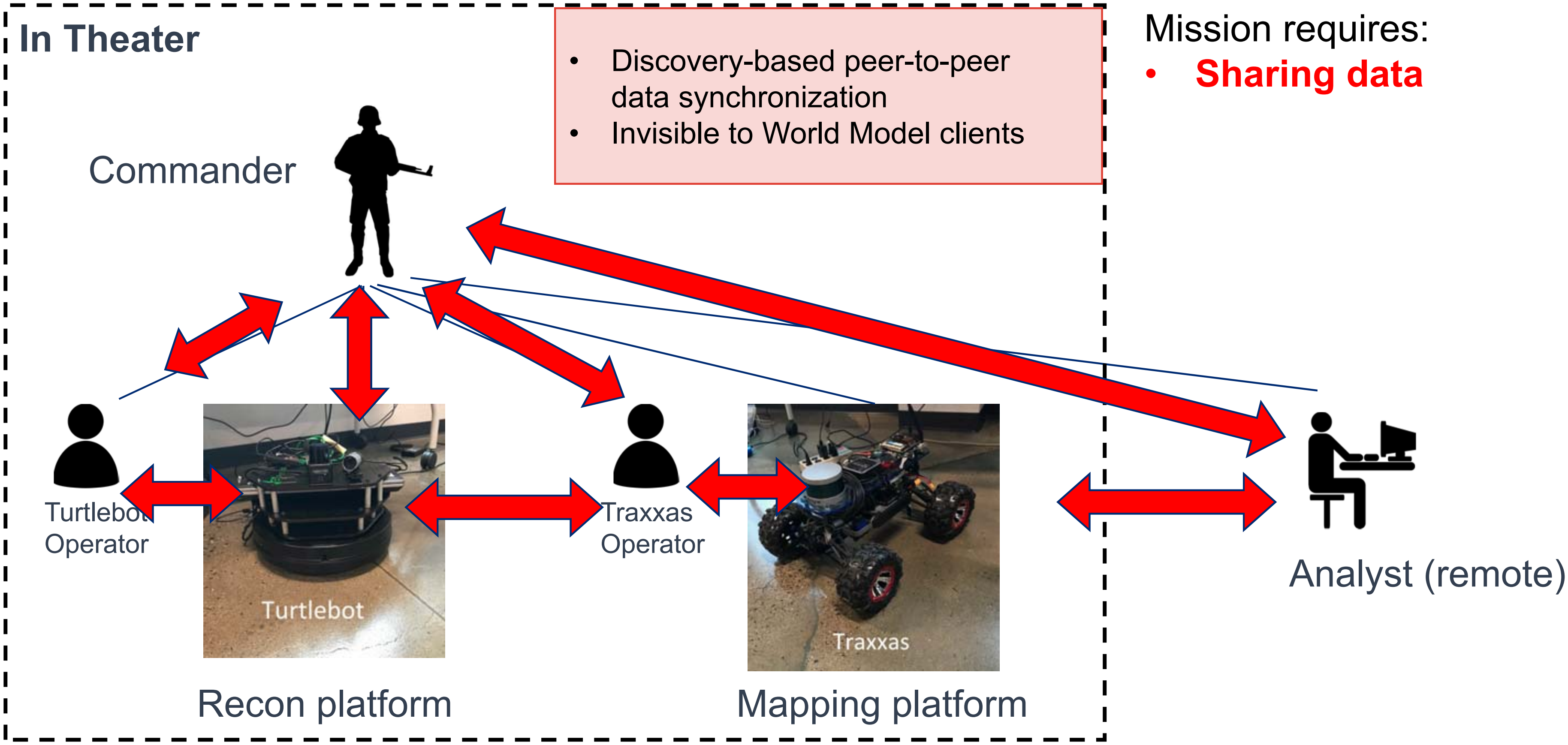
Mapping robot

Analyst (remote)

Mission:

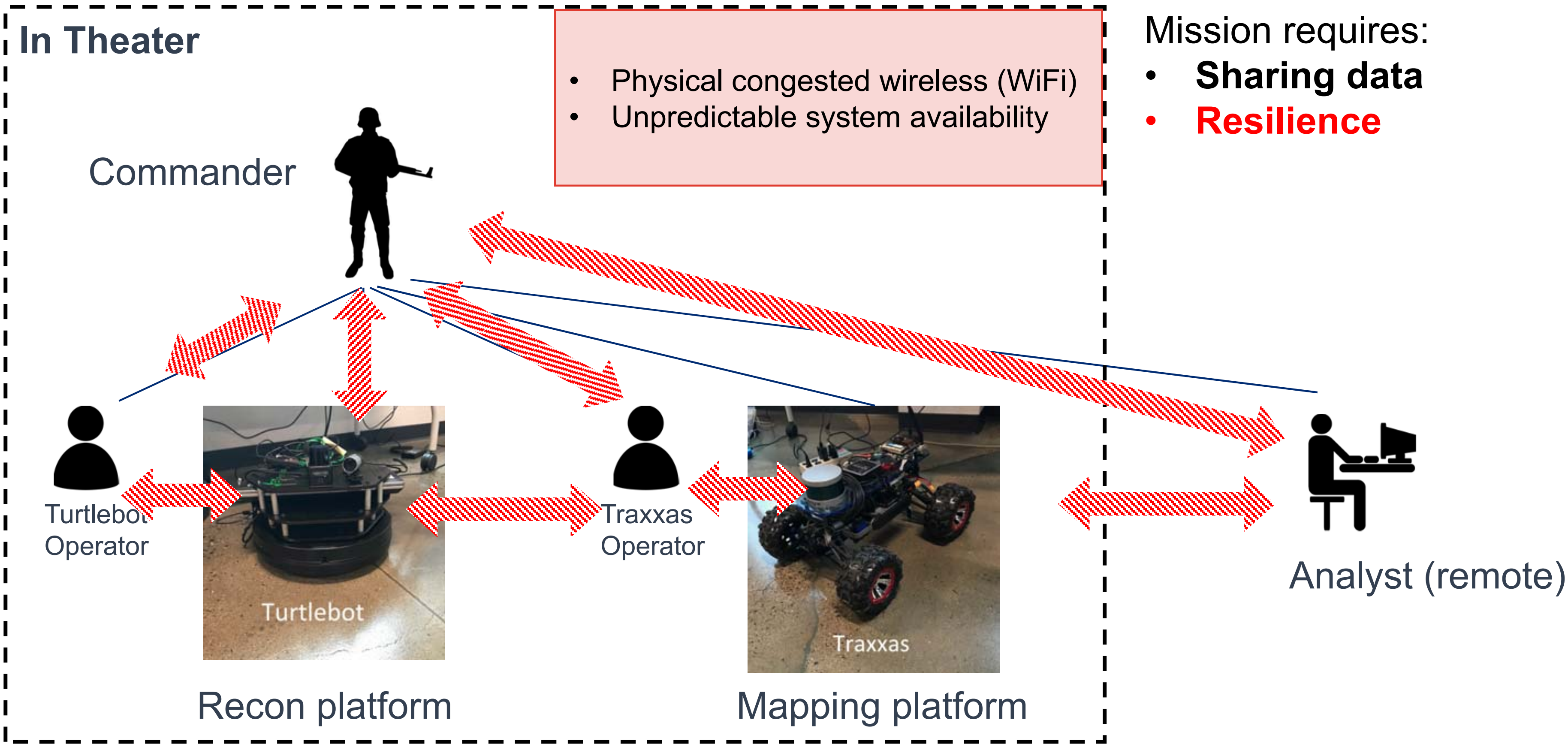
- **Map a building**
  using Mapping robot
- **Examine potential threats**
  using Recon robot
- **Assess threats**
  with help from Analyst

Multi-Agent World Model Demo



Mission requires:
- **Sharing data**

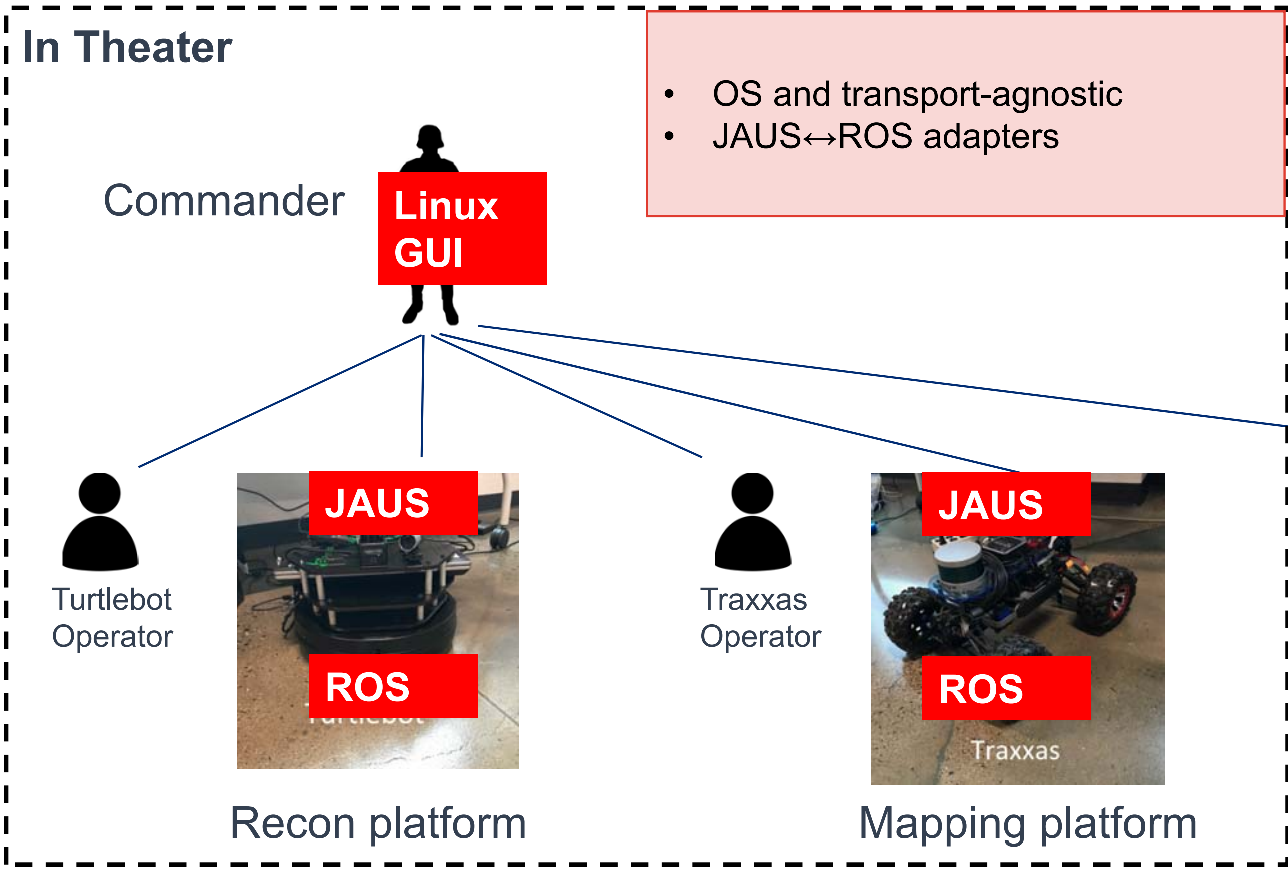
Multi-Agent World Model Demo



Mission requires:

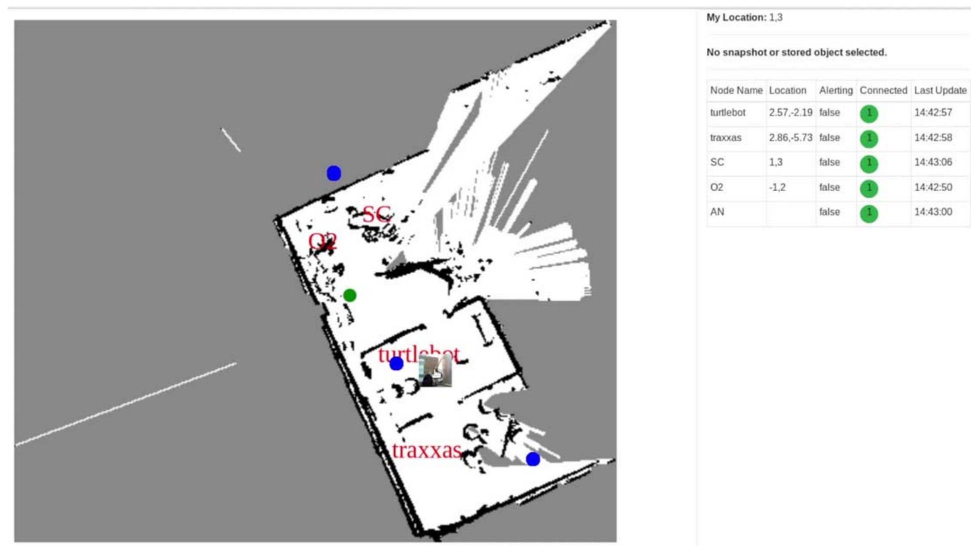
- **Sharing data**
- **Resilience**

Multi-Agent World Model Demo



Mission requires:
- **Sharing data**
- **Resilience**
- **Interoperability**

Multi-Agent World Model Demo



❶ Recon robot uses map generated by Mapping robot

❷ Recon robot visits POI designated by commander, takes snapshots

❸ Commander asks remote analyst for assessment

❹ Analyst gives response

Multi-Agent World Model Demo – Lessons Learned

- Viability of standards-compliant facade
  - Integrated existing ROS-based system into a system of systems through a standards-compliant (JAUS) layer
  - Backwards compatibility with legacy systems

- Value of open interface
  - Ability to run on multiple systems (Win, Linux),
  - Support for using multiple transports (DDS, ROS, JAUS)

- Importance of testing with physical networking configuration
  - Exercised data distribution and scaling in face of realistic delays and network congestion

Outline

- Our Goal
- Scenario - Multi-Agent/Multi-Domain Squad
- Multi-Agent World Model
  - Definition
  - Requirements
- Our Approach
  - Multi-Agent World Model Demo
  - Standards

Standards Activity - Previous

- Joint Architecture for Unmanned Systems (JAUS)
  - Reference Architecture 3.3 (2007)
    - World Model Vector Knowledge Store
    - Geometric focus rather than flexible metadata
    - Limited cross-platform data-sharing mechanism
  - Environment and World Model Task Group (2013)
    - Effort discontinued

- RCTA Common World Model (2013)
  - Focus on data sharing within a platform, not between platforms
  - APL assessment: Disadvantages of RCTA model outweighed advantages (2014)
    - Restrictive, fixed set of metadata
    - Hardcoded self information

Standards Activity – Current Approach
Working with SAE AS-4 JAUS Committee

- Treat “World Model” as a collection of capabilities (services)
- A Multi-Agent application may
  - Mix-and-match these capabilities
  - Have a different mixture of capabilities on each node
- Identify a **factoring of services** that maintains a good **separation of concerns**. E.g.:
  - Autonomy
  - Data fusion
  - Information sharing and synchronization
  - Transport considerations
- Work on standards for foundational pieces
  - Data storage, transport, synchronization

- Current Status
- Initial proposal to SAE AS-4 Committee in October 2016
- Informal task force established to refine proposal
- Used the proposed standards in our World Model Demo

Standards Activity – Lessons Learned

- **DON'T**
  - Start with detailed ontology definitions
  - Rely on static data definitions
  - Try to boil the ocean (single-shot comprehensive solution)

- **DO**
  - Consider **system-of-systems** from the start
  - Consider **distributed data** from the start
    - Network topologies, discovery, data transfer, replication, …
    - Hard to retrofit multi-system scenario into single-system architecture
  - Design for **extensibility as core principle** ("design the syntax, not the sentences")
    - Self-describing data definitions and ontology
    - Extensible ontology, sensors, algorithms, mission types, capabilities
  - Design for **backward compatibility**
    - Adapters for legacy systems and architectures (or for COTS architectures)

Towards a Multi-Agent/Multi-Domain World Model

Requirements

Shared
- Within and across systems
- Vertically and horizontally
- Timely and relevant

Scalable
- Across many heterogeneous agents
- With differing capacities

Extensible
- New kinds of missions and tasking
- New kinds of domains

Interoperable
- Interoperability of data across lifetime
- Across multiple vendors

Resilient
- Unreliable networks and topologies
- Node failures
- Unexpected tasking (on-the-fly teaming)

Lessons for the Future

Consider system-of-systems from the start
Consider distributed data from the start

Design for extensibility as a core principle

Value of open interfaces
Design for backward compatibility
Viability of standards-compliant façades

Testing with physical multi-agent configurations

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Unmanned System Safety Precepts

NDIA 2018 Ground Robotics Capabilities Conference and Exhibition

Presenters:
Robert Alex, Booz Allen Hamilton
Presenting for: Mr. Michael H. Demmick,
DoD, UxS Safety IPT Chair

UxS Safety IPT Objectives

- ✓ **Updated 2007 Guide and Developed New Precepts**
  - ✓ **Filled critical gaps in AI, Autonomy, V&V**
  - – Subsequent to the 2007 UMS Safety Guide, the DoD perspective on autonomy evolved
  - – 2016 study by the Defense Science Board titled, “The Role of Autonomy in DoD Systems,” highlights need for a dynamic approach to evolving DoD policy regarding autonomous systems
- ✓ **Interfacing with Services**
  - – DOA – integrate Networked Munitions Requirements
  - – DON – interface with DASN UxS & RDT&E
  - – DAF – interface with USAF Safety Directorate
- ✓ **Collaborating with stakeholders**
  - – Collaborating with DOS [*the UN CCW LAWS talks*] and Defense Science Board
  - – Ensure unique interests, capabilities, and concerns are shared, leveraged, and addressed
  - – Integrate other Federal Agencies with similar interests
- – **Institutionalize UxS Safety Guidance**
- – **Align System Safety Engineering Criteria & Requirements with:**
  - – Programmatic, Design, and Operational Requirements

Unmanned System Safety Guide

- **The purpose of this guide is to aid the PM's team, the operational commander, and the systems engineer in recognizing and mitigating system hazards unique to partially or fully autonomous design capabilities.**
- **It augments the tasks within MIL-STD-882 with additional details to address UxSs and the incorporation of greater levels of autonomy and machine learning.**
- **Autonomous capabilities create unique safety challenges beyond those addressed in other safety guidance.**
- **This guide lists safety precepts that must be followed in order to address safety with respect to programmatic, operational, and design considerations**

Guide sets threshold of rules of behavior that manage programmatic, design, & operational characteristics & aligns requirements

Programmatic Safety Precept (PSP) = Program management principles that help insure safety is adequately addressed throughout the lifecycle process.

Operational Safety Precept (OSP) = Directed at system operation setting operational rules to be adhered to. OSPs may generate the need for DSPs.

Design Safety Precept (DSP) = Provides Design guidance & facilitates safety of the system and minimizes hazards. Safety design precepts are intended to influence, but not dictate, solutions.

UxS Safety Challenges

Critical Gaps

[*no substantive safety guidance or policy in place*]

1. Diverging & Missing Definitions
2. Authorized Entity Controls
3. Flexible Autonomy
4. Fail Safe Autonomy
5. Autonomous Function V&V
6. Artificial Intelligence (AI)

- **Highly Complex & Evolving Technologies**
  – Understanding technological complexities associated with Gap areas and their relationship to safety
- **AI technology advancing faster than expected and with less safety assurance**
- **Unmanned Systems (UxS's) cross many boundaries & environmental domains**
  – Cross Service and Cross Agencies - all Department of Defense (DoD) services and operational domains
  – Research & Development and S&T organizations
  – Various Federal Agencies & Industry e.g., DOT, NGA, DOE, DHS, USCG, etc.

– **UxS Lexicon**
  – Taxonomy gap bigger / more central than expected
  – To ensure guidance is effective terminology, lexicon, and definitions must align
    - New and unique terms evolve as a result of on-going scientific research and engineering

- **AI risk mitigation methodologies and techniques are at best immature**
  – E.g., V&V; Probabilistic software analytics; code level analysis techniques; etc.
  – Difficulties exacerbated in a Rapid Acquisition environment

Critical Gaps

#	Critical Gap Name	Rationale for Declaring a Critical Gap, and Gap Description	Impact on UMS Safety Document
1	**Diverging & Missing Definitions**	***Rationale:*** Ensure that safety guidance is interpreted and applied in a manner consistent with the intent of DoD directives and policy, and mindful of international influences. ***The Gap:*** The 2007 UMS Safety Guidance definition of "UMS" diverges from policy. Definitions are missing for: "autonomous system", "semi-autonomous system", "autonomous function", "cognitive autonomy", "LAWS", "LARS", "Human Control", "Human Judgment", and more.	Rewrite Section 1 with best available definitions.
2	**Authorized Entity Controls**	***Rationale:*** Ensure that unmanned systems include Human Control that is appropriate and meaningful, per DoD directive and U.N discussions and in accord with safety precepts. ***The Gap:*** Current guidance allows for any function to be taken over by autonomous systems. There is no guidance ensuring Human in the loop at any level.	Changes throughout document; New PSP, OSP, and possibly DSP.
3	**Flexible Autonomy***	***Rationale:*** a. Enable continued legal use of systems as policies evolve. b. Keep up with evolving technology, adversaries, and CONOPs by enabling safe, rapid insertion and upgrade of autonomous functions. c. Support filling Critical Gaps 2, 4 and 5. ***The Gap:*** No safety precepts to ensure timely system safety upgrades as requirements evolve.	Changes throughout document; New DSP and perhaps OSP.
4	**Fail Safe Autonomy**	***Rationale:*** Mitigate multiple hazards that are new or more critical for autonomous functions** ***The Gap:*** No precepts to mitigate autonomy critical hazards, such as: a. Loss, or suspected loss, of data feed integrity, b. Hack by autonomous system usurping functions that, by law or policy, require human control, c. Hack by enemy, and d. Fail safe on "Terminator Scenario"***	New OSP(s) and DSP(s).
5	**Autonomous Function V&V**	***Rationale:*** S&T efforts indicate that new methods are required for autonomous function V&V, and are developing new methods, such as trust based validation.**** ***The Gap:*** Lack of guidance for safety testing of autonomous functions.	New document section; New DSP, OSP, and edits to SPs added for Critical Gap 2.
6	**Aritificial Intelligence (AI)**	***Rationale:*** Consider new precept[s] that address the use of AI in system decision making; presently UMS precepts focus on Software based logical transitions that are pre-programmed and pre-determined to occur with pre-determined sequencing. AI would potentially impose unpredictability into the equation. ***The Gap:*** Lack of guidance for safety analysis of AI level software or functions	This Gap may have an effect on how Gaps 2 – 5 are addressed, i.e. precepts for 2 – 5 could be written to address AI

* Source of Critical Gap Name: Air Force doc "Autonomous Horizons" (June 2015).
** See MIL-HDBK-516c (Dec 2014) for further discussion regarding such hazards.
*** Term used by RDML Selby at 2nd NSWC Dahlgren Unmanned Systems Integration Workshop and Technical Exchange Meeting.
****Perhaps interact with S&T community to mature new V&V methods for autonomous functionality and with G48 to evolve MIL-STD 882 accordingly.

Safety Issues with UxS

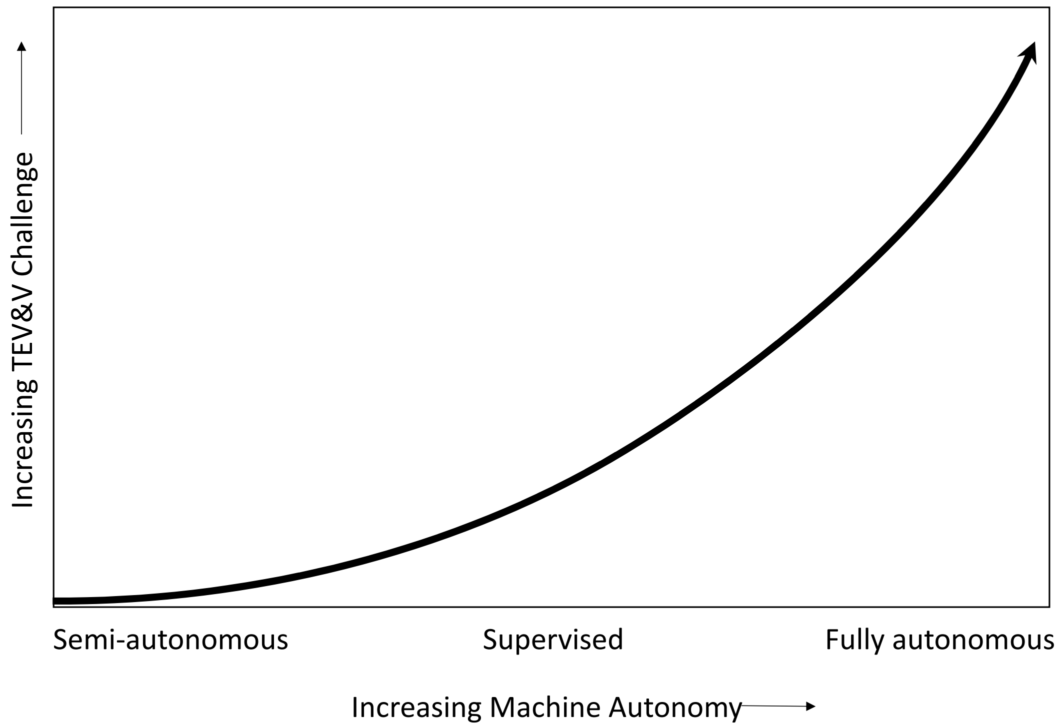
- **Autonomous UxSs inherently introduce potential mishap risk to humans for many different reasons, ranging from unpredictable movements, to loss of absolute control, to potential failures in both hardware and software.**
- **Weaponized UxSs present even more significant and complex dangers to humans.**
- **Typical safety concerns for military UxSs, that apply across semi-autonomous, supervised, and fully autonomous UxSs include:**
  - Loss of control over the UxS
  - Loss of communications with the UxS
  - Loss of UxS ownership (lost out of range or to the enemy)
  - Loss of control of UxS weapons
  - Unsafe UxS returns to base
  - UxS in indeterminate or erroneous state
  - Knowing when an UxS potentially is in an unsafe state
  - Unexpected human interaction with the UxS
  - Inadvertent firing of UxS weapons
  - Erroneous firing of UxS weapons
  - Erroneous target discrimination
  - Enemy jamming or taking control of UxS

Key Autonomy Safety Focus Points

- **Achieving Safety with Autonomy**
  - When tasks are assigned, the assigner bounds the assignment when issuing the task, and checks the bounds when the plan is generated
  - When autonomous functions are operating in a semi-autonomous mode, the human does the bounds checking
- **Bounding Autonomous Functionality**
  - Once the human is out of the loop (fully autonomous), deterministic bounded software becomes a real-time validator of the autonomous function or a notification for a human that an autonomous activity is taking place
  - Without separate deterministic bounding software, hazards may increase and trust may decrease when novel solutions are offered by the autonomous functions
- **Managed Machine Learning & Learning Mode**
  - A side effect of machine learning is the potential to execute unsafe decisions
  - The use of machine learning is expected to increase
  - Managed machine learning, or the concept of "Learning mode", provides a tool to enable or disable machine learning and a mitigation to associated potential risk
- **Flexible Autonomy**
  - Flexible autonomy allows, without reprogramming, rapid safe reconfiguration of the system based on validation results, field experience with the system, changing mission parameters or rules of engagement, DoD policy and more.
  - It allows people to rapidly grant the system more autonomy as trust is developed. It also allows people to rapidly revoke autonomy where trust has been compromised.

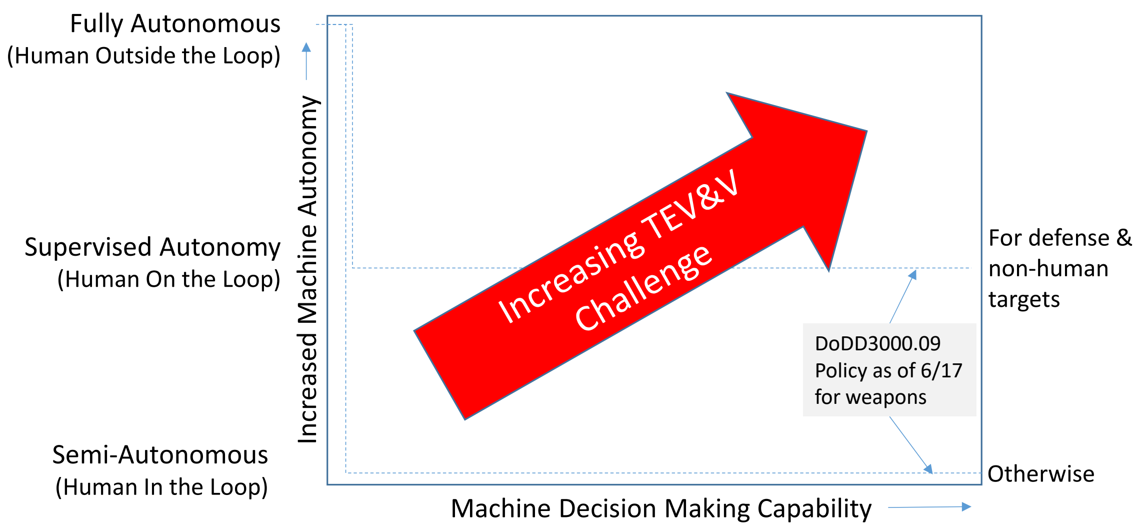
TEV&V Challenges

- **The relative magnitude of the challenge as a function the extent of autonomy in the system has been estimated as being exponential due to state-space explosion and increasing lines of software**



TEV&V Challenges

- **The challenge to make the system capable and safe while meeting policy and passing the TEV&V portion of the acquisition process increases both as the machines decision making capabilities increase and as the degree of autonomy that it is provided increase.**



	Automatic	Automated	Autonomy	
			Behavioral	Cognitive
V&V	Verifiable	Technically Verifiable	Non-Verifiable	TBD
Sample Technology	Data Processing	Expert System	Machine Learning	TBD
Complexity	Simple	Complex	Highly Complex	TBD
Outputs	Deterministic		Probabilistic	TBD

Programmatic Safety Precepts

- **PSP-1**
  - Establish and maintain a Systems Safety Program (SSP) in accordance with MIL-STD-882 (current version) for all life cycle phases.
- **PSP-2**
  - Establish consistent and comprehensive safety precepts across all UxS programs under their cognizance to ensure:
    - Mishap risk is identified, assessed, mitigated, and accepted
    - Each system can be safely used in a combined and joint environment
    - That all safety regulations, laws, and requirements are assessed and addressed
- **PSP-3**
  - Ensure that off-the-shelf items (e.g., COTS, GOTS, NDI), re-use items, original use items, design changes, technology refresh, and technology upgrades (hardware and software) are assessed for safety, within the system.
- **PSP-4**
  - Ensure compliance to and deviation from the UxS safety precepts are addressed during program reviews such as System Safety Working Groups (SSWG), System Readiness Reviews (SRR), Preliminary Design Reviews (PDR), & Critical Design Reviews (CDR) and Internal Program Office Reviews (IPR).

Programmatic Safety Precepts

- **PSP-5**
  - Ensure the UxS complies with current safety policy, standards, and design requirements.
- **PSP-6**
  - Ensure that the UxS, by design, does not allow subversion of human command or control of the UxS.
- **PSP-7**
  - Ensure that safety significant functions and components of an UxS are not compromised when utilizing flexible autonomy where capabilities or functions can be added, removed, enabled or disabled.
- **PSP-8**
  - Prioritize personnel safety in unmanned systems intended to team with or operate alongside manned systems.
- **PSP-9**
  - Ensure authorized & secure control (integrity) between platform and controller to minimize potential UxS mishaps and unauthorized Command and Control (C2).
- **PSP-10**
  - Ensure that software systems which exhibit non-deterministic behavior are analyzed to determine safe employment and are in compliance with current policy.

Operational Safety Precepts

- **OSP-1**
  - The control entity of the UxS should have adequate mission information to support safe operations.
- **OSP-2**
  - The UxS shall be considered unsafe until a safe state can be verified.
- **OSP-3**
  - The control entity of the UxS shall verify the state of the UxS to ensure a known and intended state prior to performing any operations or tasks.
- **OSP-4**
  - The UxS weapons should be loaded and/or energized as late as possible in the operational sequence.
- **OSP-5**
  - Only authorized, qualified and trained personnel using approved procedures shall operate or maintain the UxS.
- **OSP-6**
  - Ensure the system provides operator awareness when non-deterministic or autonomous behaviors are utilized in the various phases of the mission.

Operational Safety Precepts

- **OSP-7**
  - The operator should establish alternative recovery points prior to or during mission operations.
- **OSP-8**
  - Weapon should only be fired / released with human consent, or control entity consent and in conjunction with preconfigured criteria established by the operator.
- **OSP-9**
  - When the operator is aware the UxS is exhibiting undesired or unsafe behavior, the operator shall take full control of the UxS. [manual override]
- **OSP-10**
  - The operator must have the ability to abort/terminate/kill the mission of the UxS. [Terminate system]
- **OSP-11**
  - During mission operations the operator shall enable or disable learning mode to avoid hazardous or unsafe conditions. [learning mode]
- **OSP-12**
  - The control entity must maintain positive and active control of the UxS when any transfer of control has been initiated.

Design Safety Precepts

- **DSP-1**
  - The UxS shall be designed to minimize the mishap risk during all life cycle phases.
- **DSP-2**
  - The UxS shall be designed to only fulfill valid commands from the control entity.
- **DSP-3**
  - The UxS shall be designed to provide means for C2 to support safe operations.
- **DSP-4**
  - The UxS shall be designed to prevent unintended fire and/or release of lethal and non-lethal weapon systems, or any other form of hazardous energy.
- **DSP-5**
  - The UxS shall be designed to prevent release and/or firing of weapons into the UxS structure itself or other friendly UxS/weapons.
- **DSP-6**
  - The UxS shall be designed to safely initialize in the intended state, safely and verifiably change modes and states, and prevent hazardous system mode combinations or transitions.
- **DSP-7**
  - The UxS shall be designed to be able to abort operations and should return to a safe state.

Design Safety Precepts

- **DSP-8**
  - Non-deterministic software, as well as safety critical software, shall be physically and functionally partitioned.
- **DSP-9**
  - The UxS shall be designed to minimize single-point, common mode or common cause failures, that result in high and/or serious risks.
- **DSP-10**
  - The UxS shall be designed to mitigate the releasing or firing on a friendly or wrong target group selection.
- **DSP-11**
  - The UxS shall be designed to transition to a pre-configured safe state and mode in the event of safety critical failure.
- **DSP-12**
  - The UxS shall be designed for safe recovery if recovery is intended.
- **DSP-13**
  - Use of the UxS newly learned behavior should not impact the UxS' safety functionality until the newly learned behavior has been validated.

Design Safety Precepts

- **DSP-14**
  - Autonomy shall only select and engage targets that have been pre-defined by the human.
- **DSP-15**
  - Common user controls and display status should be utilized for functions such as: Manual Override (OSP-9), Terminate Mission (OSP-10), and Learning Mode (OSP-11).

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Modular Mission Payloads for Manned/Unmanned Ground Vehicles

Dr. Richard Pettegrew
General Manager
IEC Infrared Systems/Precision Remotes

Agenda

- Company Background
- Defining Modularity
- Purpose
- Design Methodology/Approach
  - Core Elements
  - UGV used for illustration: GD-MUTT
  - Modular Payload Blocks
- Configuration
  - CUAS
  - Situational Awareness: Short Range
  - Situational Awareness: Long Range
  - Lightweight ROWS
- Summary

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Company Background

IEC Infrared Systems LLC

- Founded in 1999: NASA Spinoff company
- In-house engineering & manufacturing of tactical surveillance systems
- Complete surveillance and sensor systems integration
- Intuitive command & control middleware

Precision Remotes LLC

- Founded in 1997
- In-house engineering & manufacturing of remotely operated weapon systems (ROWS)
- Lethal and non-lethal threat mitigation solutions

Defining Modularity

What is meant by the term 'modularity'?

Broadly speaking, 'modularity' can be defined as the degree to which a system's components can be separated and re-combined, providing flexibility and variety of usage.

Clearly, a 'modular' approach to mission payloads would be beneficial to both manned and unmanned (robotic) military platforms….

What might that look like?

Purpose

IEC/PRL have develoed flexible (reconfigurable) mission payloads for unmanned ground vehicles, to include:

- 360° Situational Awareness
- Long Range Surveillance for ISR
- CUAS capability
- Lightweight Remote Weapon Station with heavy machine gun (M2)

All of these are adapted variants of our proven products.

Design Methodology/Approach

- To achieve 'modularity', must use common 'module' interfaces:
  - Mechanical
  - Software
  - Electrical
- Systems should be built around common, core elements, then "mission-tailored" with specialty modules, to the greatest degree possible*.
- Connections/Interfaces should be fast and easy to change

***In some cases, core elements may need to change as well, but interfaces to vehicle must remain common**

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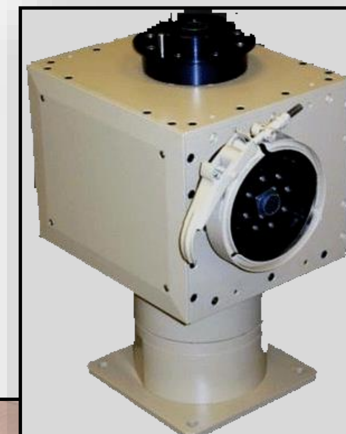
Design Methodology/Approach

Core Elements:

Positioner is common to most configurations

- IEC's 'WereWolf positioner
- Three payload mounting positions
- Tools-Free, Blind-Mate Payload mounts, allowing for quick re-configuration



Common Electronics Module

- power management
- Video Processing
- Payload control

Common Control Software

- Controls most payloads

Design Methodology/Approach

UGV used for illustration: GD-MUTT

- For purposes of this presentation, all configurations are illustrated on General Dynamics' MUTT (wheeled version).
- IEC/PRL have experience with the MUTT in several experimental exercises, but used here as illustration: other vehicles also very feasible

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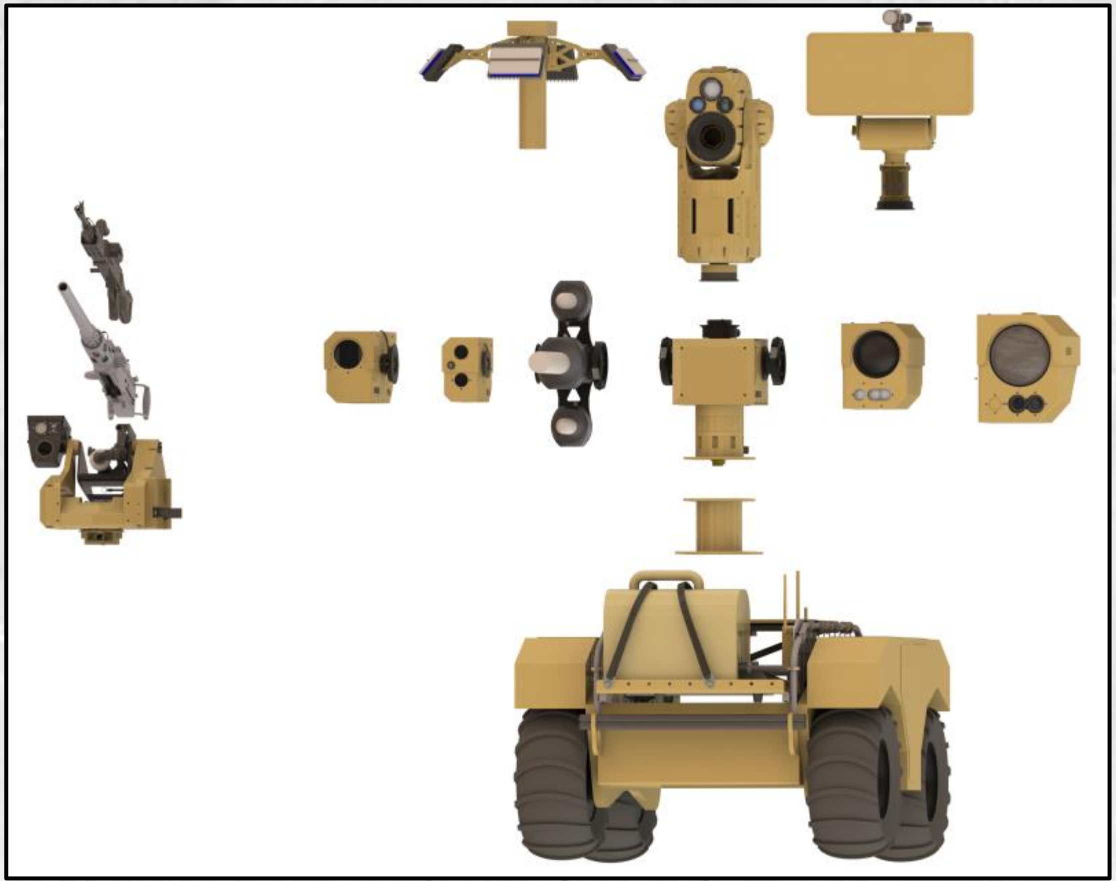
Design Methodology/Approach

Modular Payload Blocks



- Payloads reconfigured using modular blocks
- Most payloads built around common positioner

Configuration: CUAS

- Detection of Class I UAS up to 700 meters
- Thermal/visual imaging for target assessment, optical tracking
- AI engine for clutter rejection
- Tri-band RF jamming (control, video, nav)

Built on common WereWolf positioner

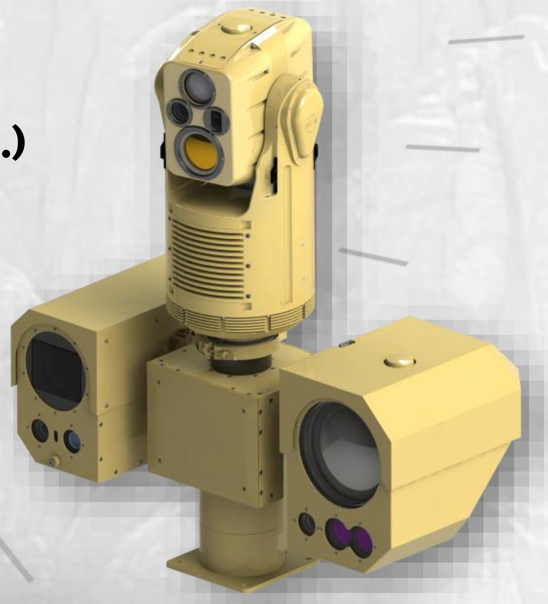
Configuration: CUAS

Built on common WereWolf positioner

Configuration: Situational Awareness
(short range panoramic surveillance)

Panoramic thermal/visual imaging & detection system
- 360° Day/night Situational Awareness
- Completely Passive (Thermal/Visual)
- 1 Hz update rate (360o)
- 2 km upright human detection (with clear L.O.S.)

Co-Located Assessment Imager
- LWIR 225mm & 120mm visual imager
- Target recognition beyond 2 km
- LRF & GPS for target geolocation



Built on common WereWolf positioner

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Configuration: Situational Awareness (short range panoramic surveillance)

Built on common WereWolf positioner

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Configuration: Situational Awareness (Long range surveillance)

Ground Surveillance Radar Detection System

- 12 km upright human detection
- 18-20 km vehicle detection

Co-Located Assessment Imager

- 825mm MWIR & 2000mm Visual imager
- Target recognition beyond 8 km
- LRF & GPS for target geolocation

Built on common WereWolf positioner

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Configuration: Situational Awareness
(Long range surveillance)

Built on common WereWolf positioner

Configuration: Lightweight ROWS

- T360 platform from Precision Remotes
- Positioner <75 lbs (without gun & ammo)
- Light weight provides easy payload change, easy logistics/maintenance
- Can support M2 0.50 cal, M240
- Brings heavy firepower of M2 to M2 to dismounted infantry
- Weapon can be fired remote or manually

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Configuration: Lightweight ROWS

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Summary

- Modularity requires:
  - Commonality (mech, elec, sw)
  - Quick change capability
  - Easy reconfiguration
  - Simplified Logistics
- IEC/PRL have developed modular mission payloads for a variety of missions, with these requirements in mind
  - CUAS
  - M2 ROWS
  - Short Range ISR/SA
  - Long Range ISR

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End of Briefing

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Autonomy
Robotic Research, LLC

Abstract

Autonomous systems excel at some tasks and are poor at others, especially when compared to humans. Automatically computing line of sight from a-priori data and measuring distances are some tasks in which autonomous systems excel, but doing subtle recognition tasks, like finding humans in a vegetated environment or differentiating between non-combatants and the red team, are not tasks that the state of the art has yet to achieve. Robotic Research is uniquely placed to perform this research.

Robotic Research's software and hardware autonomy kits have autonomously driven large vehicles (with no passengers) for thousands of miles on civilian roadways, with civilian traffic on the unstructured roads of Afghanistan for Special Forces Programs (Figure 1).

***RR Proprietary-* Figure 1. Autonomous vehicle driving in civilian roadways with nobody onboard successfully deployed for road clearing.**

These systems – deployed in 2013 – represent the first completely autonomous ground vehicle systems for the DoD, and the government community in general. It was also a first for the DoD's Army Test and Evaluation Center (ATEC) to provide an "acceptable risk" level for autonomous driving with nobody on board. To our knowledge, this has not been repeated by any program since.

Robotic Research is also the prime for two keystone programs for autonomous mobility: AGR and ExL/F. AGR is developing the de facto autonomous mobility kit (A-Kit) for the next generation of army trucks and logistic vehicles. Robotic Research is therefore defining algorithms, interfaces, and architectures that will become the requirements for the next generation of DoD vehicles. But even more relevant to this effort, the ExLF program builds on the progress demonstrated during the Autonomous Mobility Applique Systems (AMAS) Joint Capability Technology Demonstration (JCTD) and AGR programs to develop unmanned prototype systems that address the needs of the Leader Follower Directed Requirement and Program of Record. ExLF will equip existing military ground vehicles and will conduct an Operational Technical Demonstration with scalable autonomy technology showcasing the integration of modular kits, common interfaces, and a scalable open architecture. The AGR architecture is being developed to become the de-facto autonomous architecture for all foreseeable ground robotic vehicles.

Robotic Research has fully demonstrated autonomous mapping and search missions with groups of vehicles. Although the utility functions of those coordination efforts are different from the ones needed for this topic, the underlying structure of the distributed localization and coordination engine is being leveraged for SubT and urban warfare applications.

Robotic Research has a rich history of success in autonomous mobility, as our timeline of autonomy, Figure 2, shows.

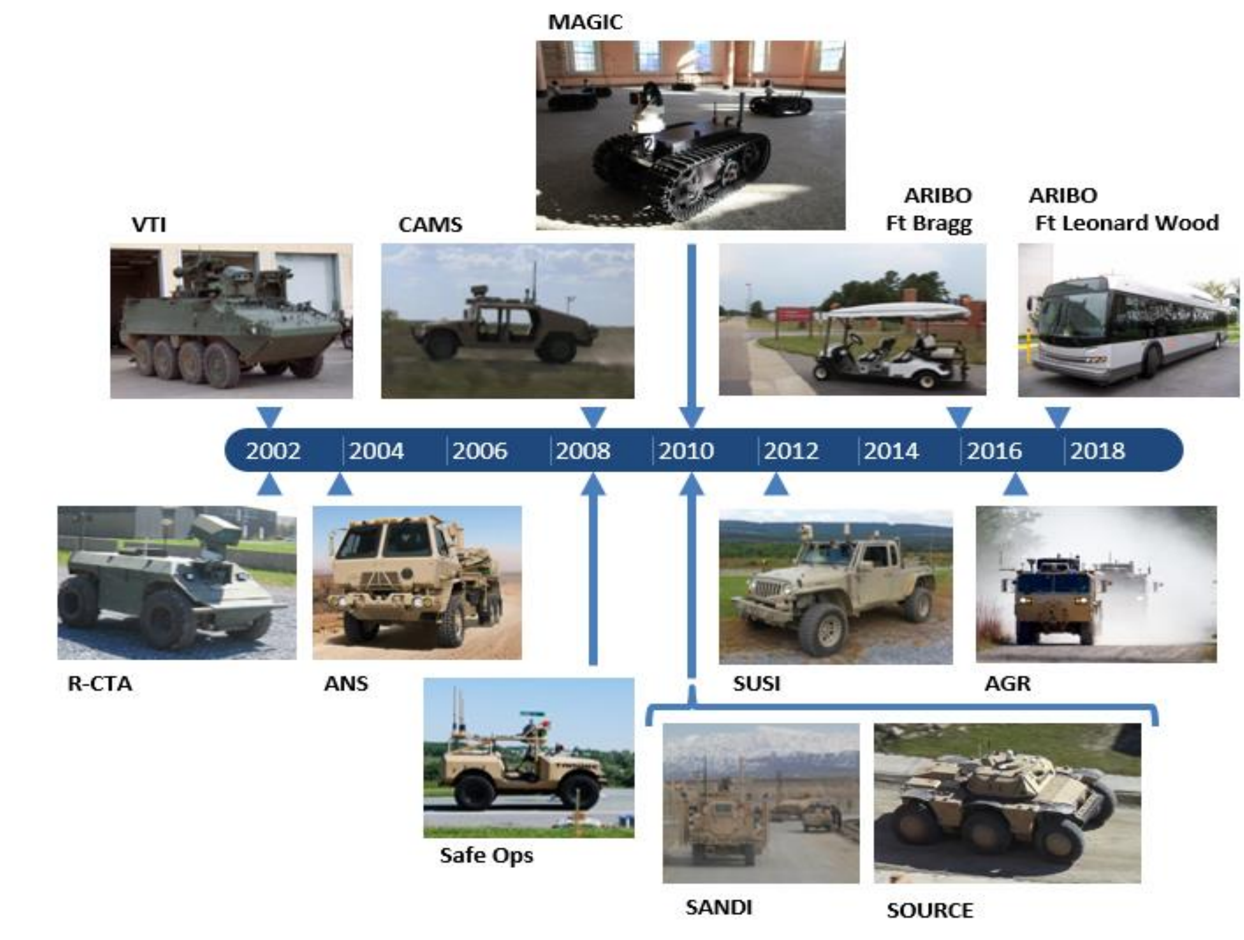

Figure 2. Robotic Research history of autonomous programs.

1 Purpose

Automating the coordination between humans and robots for a variety of missions in both GPS enabled and GPS-denied environments. The autonomous robotic system needs to communicate with humans in a way that does not overwhelm or significantly increases operator/team member loads. A variety of missions with tactical validity can be implemented:

- ***Loose cooperation*** allows to have the operators go about their mission without worrying about mapping or clearing and let the robots clear the areas that have not been covered by the humans. For example, the humans will go through the main tunnel shaft, and the robots will clear all areas surrounding the operator's trajectories.
- ***Autonomous horizon sentry*** will have robots automatically discover the horizons of the explored areas and automatically find locations where to provide persistence surveillance so that the team could is not surprised by enemies coming from the horizon of unexplored areas.
- ***First encounter*** is where the robots automatically explore the operational areas and mark specific areas that have been cleared so that the warfighter can know of, and more safely move into, areas that do not have line of sight to unexplored areas, therefore reducing risk and speeding operation tempo.

- ***Suspicious interrogation.*** Robots can be used to automatically discover movers in the field of view and approach them before the movers get closer to the humans. Non-lethal warnings and deterrents can be used to discourage enemies or noncombatants from approaching the warfighters and the team.
- ***Perimeter sentry*** is a mission where robots are constantly patrolling the perimeter (e.g. opening to a tunnel or a clearing), protecting warfighters while they perform a task. The robots can automatically generate random routes to patrol.
- ***Follow the group*** similar to perimeter sentry, but the group is on the move.

2 Theme

The Robotic Research, LLC research and development addresses autonomous operations of multi-domain robotic systems providing advances in situational awareness, assured robotics communications/control, and human-robot interface for the warfighter.

3 Design/Methodology/Approach

Localization as a Distributed System

Localization is usually thought of as an individual functionality. In other words, navigation units in the market provide localization for a single vehicle or person. Even if all vehicles in a convoy have a navigation unit (they know their own position and a general position of other vehicles), that localization knowledge is not optimally shared and used to create a better localization solution for all unit members. Robotic Research's working during UMAPS (a Phase II and III SBIR supported by ARDEC) turned that common practice upside down. For our approach, localization on a coordinated battlefield became a group functionality, with emphasis on relative positioning between the team members. This relative positioning is the fundamental enabler of coordination. Commands and targeting at the unit level rely on the relative positioning capabilities of its members, especially in GPS denied areas. A warfighter in a building is more likely to say "go to the door to my right" than specifying at Northing and Easting locations of the door. This relative positioning is only possible if the sensors/systems providing the positioning (worn by each unit member) work together to provide this information (Figure 3). Robotic Research has already developed a family of meshing localization products. These devices track friendly forces' positions relative to each other, even in GPS denied environments. This family of systems include the WarLoc™ for dismounts, the RR-N-140 for vehicles, and the SR-Nav, LR-Nav, and RR-140 for small, medium, and large sized UAVs and UGVs. The systems have been tested outdoors, indoors, in subterranean environments, and even perform well under attempts at jamming. The location of each person, vehicle, or unmanned system is shared with all of the other nodes in the mesh.

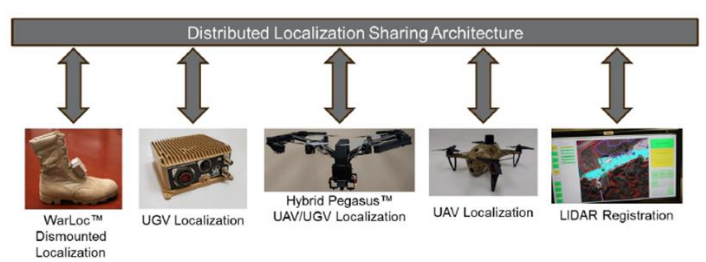

Figure 3. A subset of Robotic Research's family of distributed localization systems.

The ARDEC supported UMAPS SBIR developed the architecture necessary for the distributed filtering of this positioning information. The filtering works across platforms (dismounts and vehicles) to include: inertial measurements, SLAM, ultra-wide band and Bluetooth ranging and GPS when available. The filtering is treated as a distributed filtering network of "springs" (Figure 4). Measurements from odometry, SLAM, ultra-wide band, and GPS are synchronized across platforms and filtered in each node given the communications available to each node. Nodes that lose communications with the rest of the group continue filtering the information that has reached their radios and synchronize the information once they return to communication with the rest of the group. The resulting localization benefits have already been demonstrated in a variety of tests for the Special Forces Community.

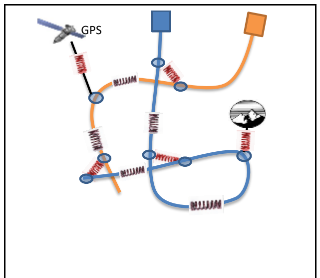

Figure 4. Spring solver.

The advantage of the coordinated localization becomes obvious when we examine the missions/capabilities that it enables. Figure 5, below, shows some examples of mission types Robotic Research has been working on with ARDEC to improve operations through the use of Robotic Research's "Spring Network":

- **Human-Human accurate relative positions** are important for the operational unit. In the figure, as warfighters explore the tunnels, the relative position ("where are my buddies?") is important to coordinate movement, or to help to find a wounded team member. For these cases, the absolute positions are almost irrelevant.

- **Robotic Leader-Follower operations** in GPS denied areas. When GPS is jammed or not available, in order to have groups of robots relay or follow each other, synchronization between their units is necessary.
- **"Follow me" modalities**. Once again, the relative location of the warfighter and the robot are necessary to accurately follow. In this case the LS3 robot (legged) was demonstrated to accurately follow the pedestrian on a complex multipath environment.
- **Multi-robot 2D and 3D map building** can only be accomplished if the maps are registered and "stretched" to fit each vehicle's errors in localization. This registration (SLAM) must be performed to assemble the maps. The coordinated localization synchronization was used to build the maps at the Ft. Hood site.

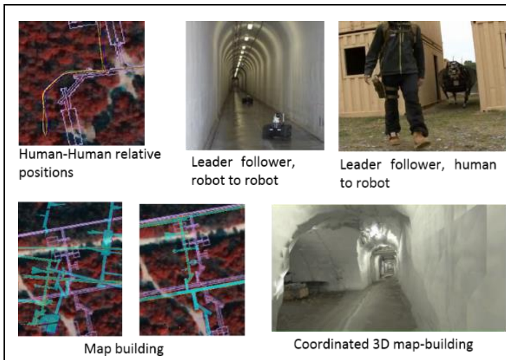

Figure 5. The synchronization and common filtering of the navigation units allow for a number of missions: Accurate relative positions of warfighters in GPS denied areas, robot convoying in tunnels, Human-robot leader followers, coordinated map-building, and 3D map building.

Localization

As mentioned earlier, at the core of every coordination mission, there is always a need for localization. Localization can be absolute or relative. Absolute localization means that the system needs to know where its assets are in the world. Relative means that the systems or individuals know where they are with respect to each other, or with respect to markers left in the field. Of course, if absolute location is known, relative can be derived.

The opposite, of course, is not true. Interestingly, for accurate coordination missions, only accurate relative localization is needed. For example, two humans can coordinate their motion to carry a sofa without knowing their Latitude and Longitude, but they will fail miserably if they cannot determine where they are with respect to each other. The proposed family of systems will work even if the absolute location of the members is not known, as it only requires having relative positions. Moreover, it builds an infrastructure that allows the family to deploy and expand a relative localization infrastructure.

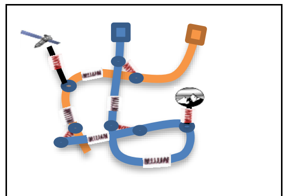

Figure 6. Spring solver depiction of how the filter works.

At the core of this infrastructure is a series of IMU (inertial navigation units) and ranging radios (direct point to point measurement of range) and a distributed filter that allows the system to accurately determine the location of all its members.

Figure 6 shows a depiction on how the distributed localization filter works. The blue vehicle and the orange vehicle are at the beginning of their tracks. The springs in the image show measurements that collaborate towards determining the location of each device. There are springs along the path that represent dead reckoning (encoders, accelerometer, visual odometry, etc.). There are springs shown when vehicles recognize each other and the ranging radios perform a measurement between the two vehicles. There are springs between the orange vehicle and GPS, and there are springs between the position of the blue vehicle and some landmark that it discovered. The stiffness of each spring represents the confidence of the measurement.

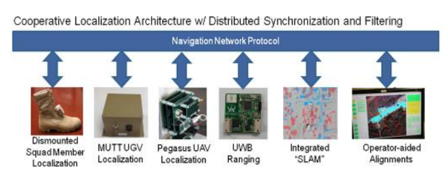

Figure 7. The cooperative localization architecture includes a variety of odometry sources and measurement updates for heterogeneous assets in a distributed framework that is resilient to communication dropouts.

For example, the error of the ranging radios is approximately 10cm creating a stiff spring, while the errors accumulated by reckoning could be significantly larger depending on the distance traveled, therefore, creating very soft springs. The same is true with GPS and other measurements. The "spring solver" then solves the overall solution by optimizing the network and finding the position of the family of systems.

Figure 7 shows some of the devices used for providing these measurements and already incorporated into our localization infrastructure.

4 Findings

Coordination and SA of all systems can create a significant cognitive load on operators as the number of platforms being controlled grows. In particular for search and mapping missions, where the missions for each robot are not easily described by waypoints.

Robotic Research, LLC has developed a SA coordination system that maps and searches areas utilizing large number of assets utilizing different control techniques. In particular, we assign areas to groups of robots and the robots partition these areas to minimize an overall cost function. An outline of this algorithm will be presented in the next section. These techniques were developed for the MAGIC 2010 and were successfully tested to map a variety of locations (see Figure 8) including an exhaustive test at the USG underground testing facility. Figure 9 shows a 2D and 3D map generated by three assets autonomously coordinating and subdividing the space among themselves. The total length of the tunnel is approximately 3 km. This mission was conducted in a GPS denied environment.

Figure 8. Pegasus™ II-e hybrid UAS/UGV first assembled platform flown off a MUTT UGV.

Robotic Research's coordination layer resides on each robotic system and on each OCU. Our overall philosophy embeds coordination capabilities on each robot in the architecture. The communications between robots is kept to a minimum by only propagating bounds of the solutions found in the nodes called "contracts." When communications connect the UGVs and the OCUs; the coordination layer benefits from the larger number of computational units. In those cases, the greater number crunching capabilities of some nodes, such as OCUs, will provide search bounds to the rest of the robot team. When communications are poor and SUGVs are isolated, they can still coordinate in their local communication neighborhood. It has been shown that this system is guaranteed to outperform an auctioning coordination strategy. The Robotic Research MPAC library (MPAC is software and system developed for autonomy of small unmanned surface vehicles) provides the search engine in the Coordination Layer Planner. MPAC is already integrated into Fire Effects software, and it will be migrated into ATAK.

Figure 9. A group of three autonomous robotic systems generated without operator intervention a map of this underground facility. The system autonomously coordinated and merged the resulting map. Both 2D maps and 3D textured maps were generated.

5 Practical Applications

The research and development results demonstrate new and innovative approaches to teamed robotic systems autonomously operating in support of the warfighter in GPS-denied environments enabling the warfighter to focus on critical tasks more effectively. This is accomplished through improved situational awareness and reduced risk to warfighters in SubT and urban warfare. The research results are applicable to a "Family of Systems" of autonomous unmanned ground and air vehicles to include transformable hybrid UAS/UGV that can both fly and drive as needed.

Because these efforts can be leveraged, the full objectives of this program can be more prudently implemented. We expect that the Family of Systems will be able to perform a variety of missions very relevant to the Army. In particular: Cooperative SA, Coordinated effects, and counter UAV.

Figure 20, below, shows a Multi-Utility Tactical Transport (MUTT) autonomous ground vehicle and Robotic Research's Pegasus IIe, a transformable UAV/UGV vehicle. These two autonomous vehicles are part of the current Family of Systems.

Figure 20. An autonomous MUTT (behind the fence) deploys a Pegasus vehicle that "hops" over the fence. Pegasus transforms from its aerial modality to its ground modality.

6 Original Value

This generalized formulation allows other types of missions to be performed in addition to search-only missions. The ability to plan for multiple types of sensory capabilities is made possible by abstracting the tasks into the starting conditions, ending conditions and resources required for completion. Through this basic formulation, a wide variety of pertinent missions can be managed on-the-fly by a group of human robot teams. A new algorithm was developed by Robotic Research and tested with robotic only teams to perform this same mission. This algorithm is called K-means Line-of-sight (KML) and computes the countries and capitals given initial information about the building layout.

Robotic Research has developed a situational awareness tool that provides SA during the mission and stores data for use in detecting changes in the environment, called Flashback™. Flashback™ is an intelligence and reconnaissance tool that captures, time tags, geo-references, and stores data (such as camera imagery) for use in mission planning, intelligence analysis, and aids warfighters to detect changes in the environment. Flashback™ achieves this by storing data to a spatiotemporal database, and provides and intuitive user interface to query, display, annotate, and compare data over time, thus providing superior target detection of existing and emerging threats. Robotic Research has also integrated Flashback with ATAK, providing the government with time-tagged panoramic imagery and navigation data. Flashback™ provides the warfighter a superior advanced real-time analysis framework (Figure 11).

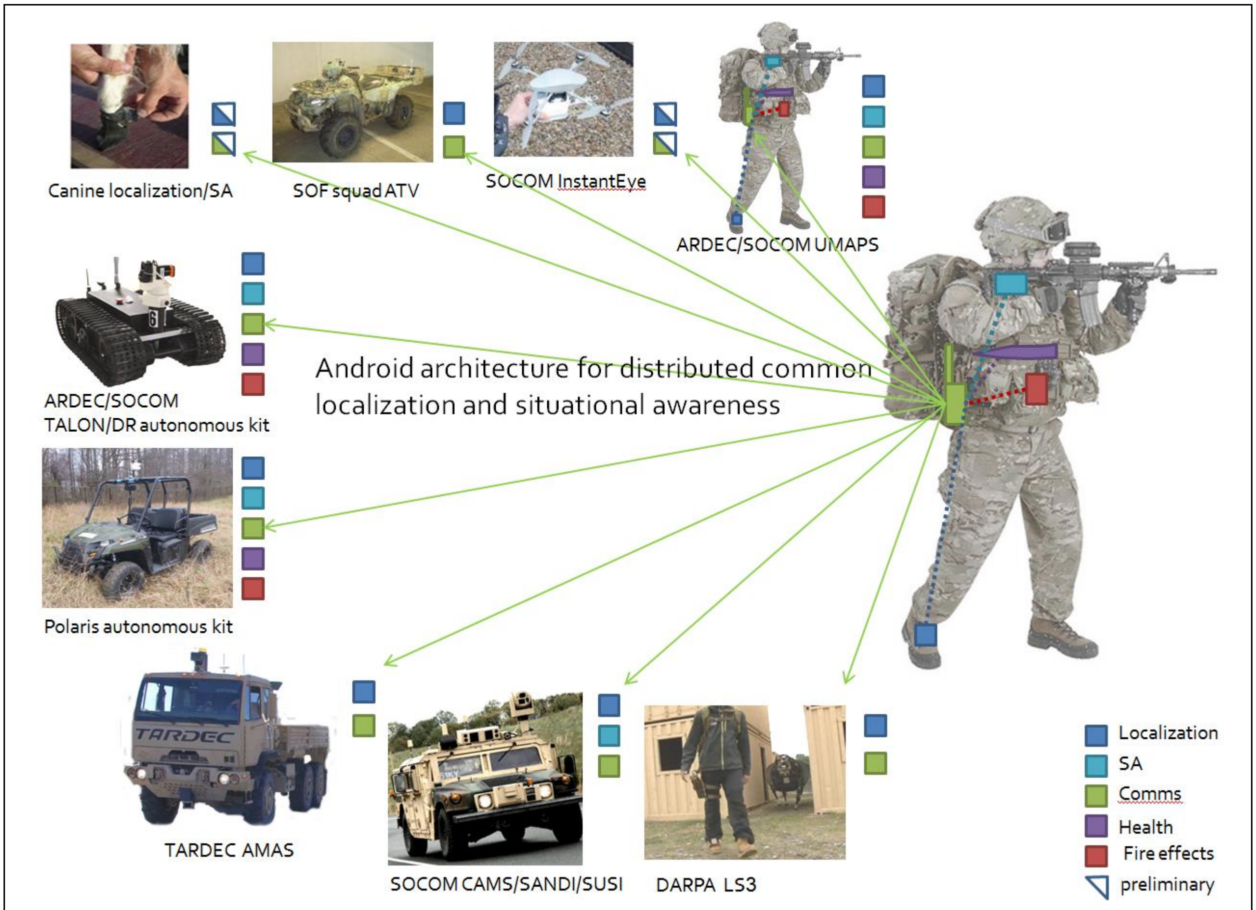

Figure 11. The connected battlespace starts by having common localization, situational awareness and fire-effects tools. Family of Systems in development and testing.

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PME Overview

Celyn Evans – Technical Director

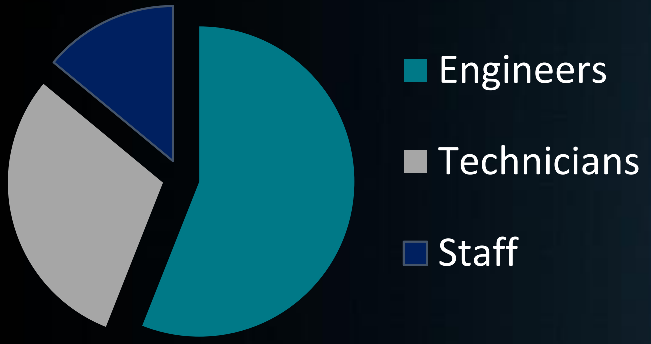
Tom Waligora – Chief Robotics Engineer

May 2019

Who We Are

ABOUT US

- ESTABLISHED 1989
- PRIVATELY OWNED S-CORPORATION
- NON-TRADITIONAL QUALIFICATION
- FACILITY SECURITY CLEARANCE



Pratt & Miller uses a proven formula of attracting and retaining talented people, developing robust processes, and investing in advanced technology to achieve the highest level of customer and employee satisfaction.

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RESEARCH & INNOVATION | ENGINEERING & DESIGN | PROTOTYPE BUILD | TEST & DEVELOPMENT | PRODUCTION

Customers

PRATT & MILLER DEFENSE

Motorsports

GM — Exclusive to General Motors since 2005

Defense

Mobility

Innovation

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Defense Specialties

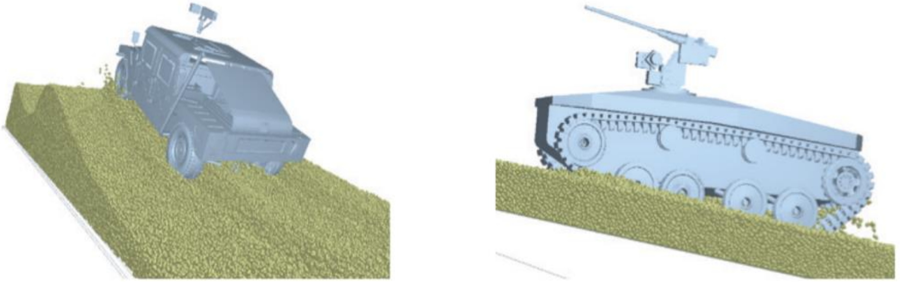
Design and Build Winning Ground Vehicle Solutions

Mobility
- Wheeled & Tracked Vehicles
- Chassis & Suspension
- Mobility Analysis
- Testing and Development
- Hybrid/Electric Systems
- Software Development

Survivability
- Lightweight Systems
- Blast Analysis
- Occupant Protection

Robotics
- Autonomous Systems
- Robotic Mobility Platforms
- Software Development – Controls

Complete Vehicle Integration
- Prototype Builds
- Concept Development
- Trade Studies
- Requirements Management



Discrete Soft Soil Modelling

Robotics, Autonomy, Electronics & Controls

Building the Best Ground Robotic and Autonomy Platforms

Robotic Platform Development

- Vehicle Design Prioritizing Performance, Modularity & Affordability
- Early Co-Simulation for Architecture Determination (tool chains)
- Custom High Voltage System Design
- High Mobility Tracked & Wheeled Systems
- Drive-by-wire design & integration
- In-Wheel & Shaft Coupled Drive Motor Configurations
- Hybrid & Electric Propulsion Systems
- Full Vehicle Build & Test

Mobility Controls and Software Development

- Dynamic & Kinematic Model-Based Control
- Advanced Traction & Force Control Design
- Bimodal Enabling Actuation System Design

Autonomy Integration

- Integration of Partner Autonomy Applique
- Electrical Architecture Design
- Sensor and Perception Layer
- Path Planning Integration

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Relevant Robotic Platforms

Expeditionary Modular Autonomous Vehicle

Customer

Marine Corps Warfighting Laboratory

Specifications

- TRL 7
- Diesel Electric Series Hybrid (JP8, zero oxygen, silent)
- 7,000 lbs GVW /14,000 lbs GVWR
- 30 MPH with upgrade to 55 mph
- 3 kW (Driving); 6 kW (Generator Mode)
- Overall Size: 12'7" x 5'0" x 3'0" (with CROWS II)
- Supervised autonomy, tele-op, follow me, obstacle avoidance
- GPS way-point following, Follow-me capability
- GPS denied environments

Links

https://vimeo.com/298432618/9608b909d8

Trackless Moving Targets (TMT-V and TMT-I)

Customer

US Army/PEO STRI

Specifications

- TRL 9 for “TMT-V” and TRL 7 for “TMT-I”
- Full electric with 4-wheel steer and independent drive
- 5,400 lbs GVW /11,200 lbs GVWR and 820 lbs/ 1300 lbs
- Top Speed TMT-V 35 MPH / TMT-I 12 mph
- “V” 181 in x 80 in x 32 in
- “I” 49.6 in x 42.8 in x 19.6 in
- GPS way-point following, reactive behavior, automated-emergency-braking

Links

http://www.tracklessmovingtargets.com/

https://vimeo.com/301915160

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Development Process: Enabling Success

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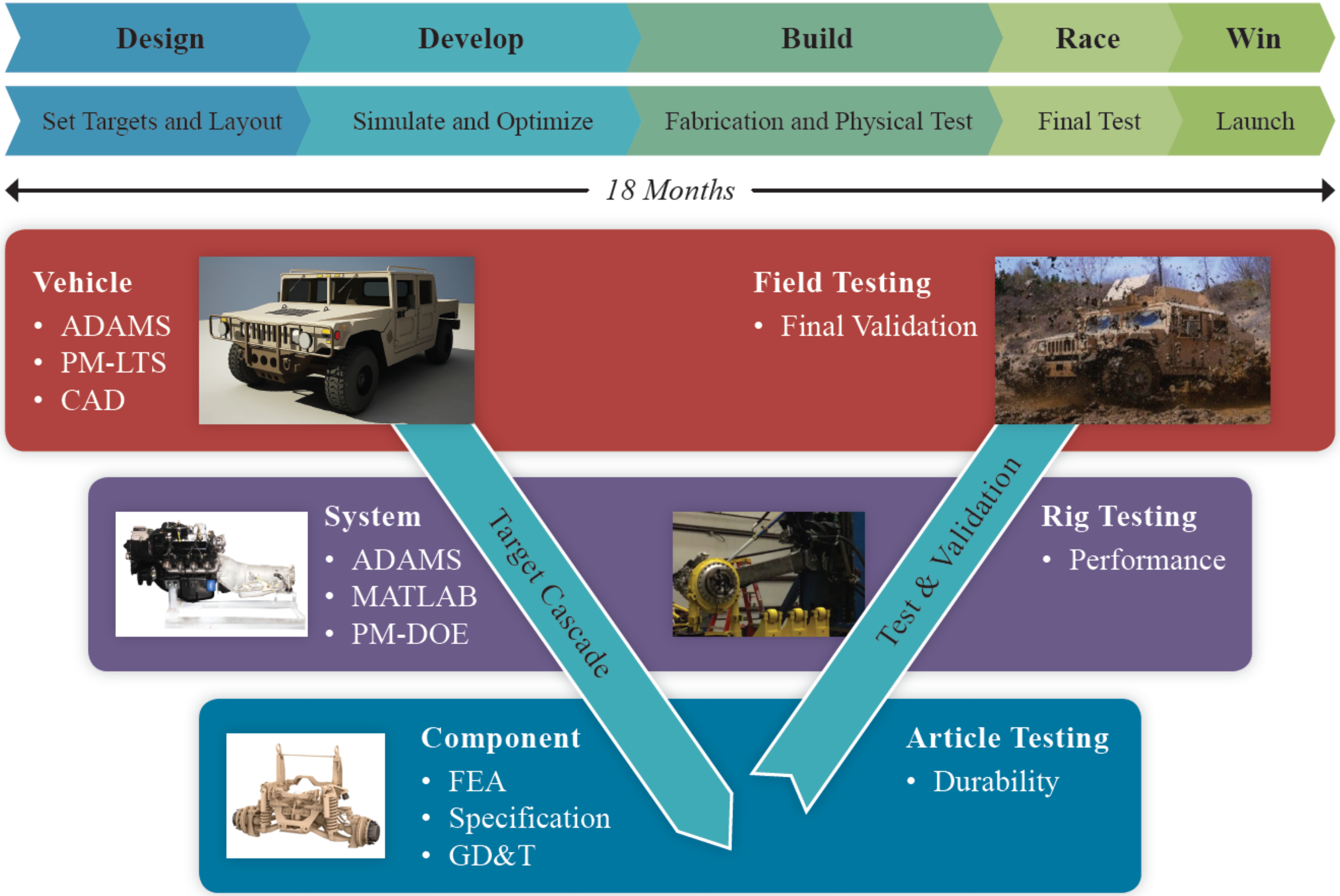
System Development Process

Product Development V-Model:

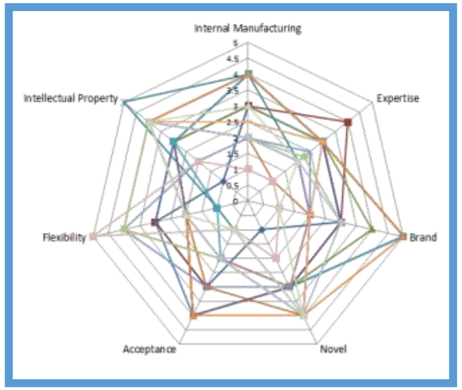
- Translating the broad vision
- Decomposing requirements/interdependencies
- Creating analysis and model driven designs
- Trading features, modularity and cost
- Architecture trades have lasting effect
- Validation of assumptions
- Concept to production

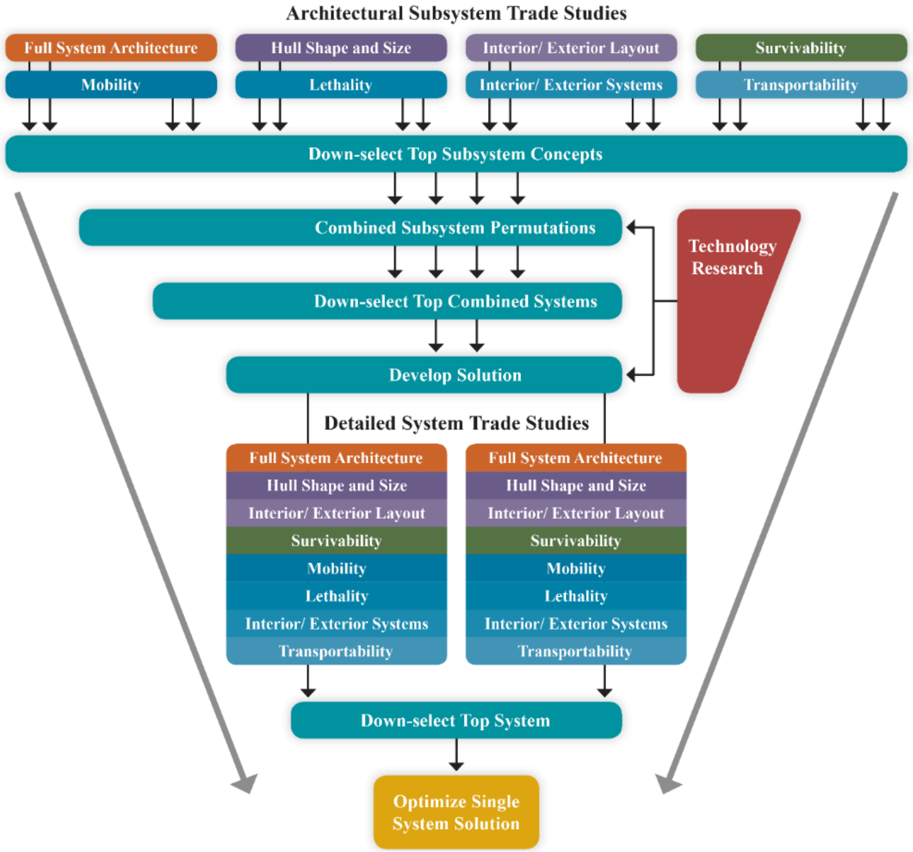


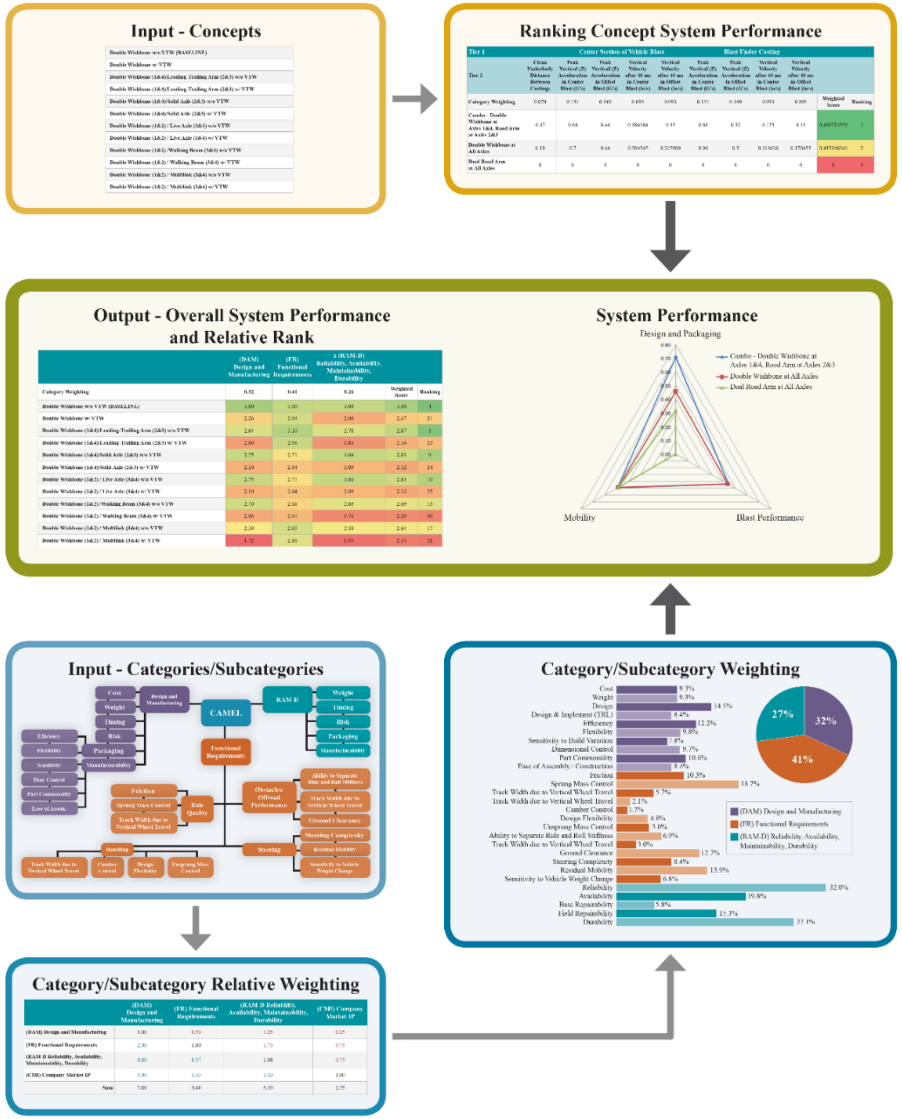
System Development Process

Analytical Hierarchy Trade Study Process

- Decompose what customer wants
- Features/Capability
- Subjective/Objective
- Creates non-intuitive solutions
- Custom







Modular Architecture

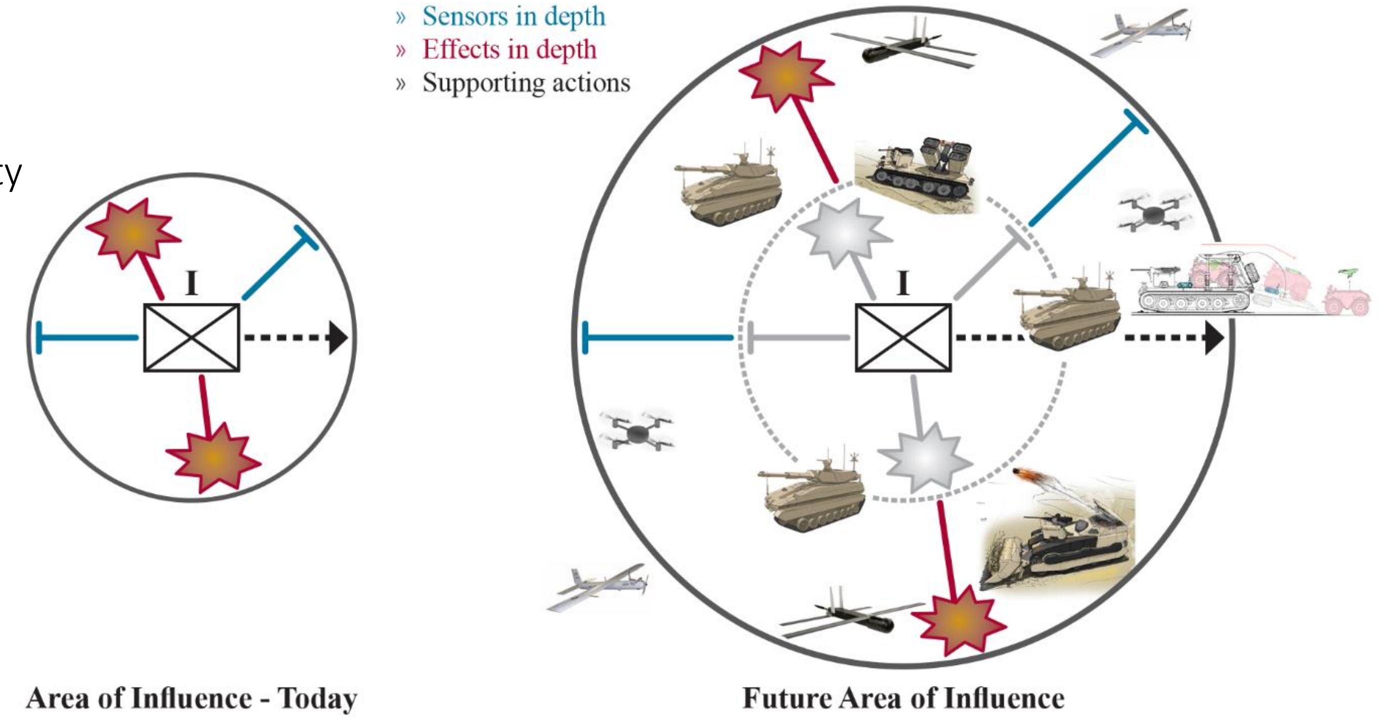
Modularity Concept to Execution

Enable combined capabilities to expand area of influence

Realization of Modular Design:

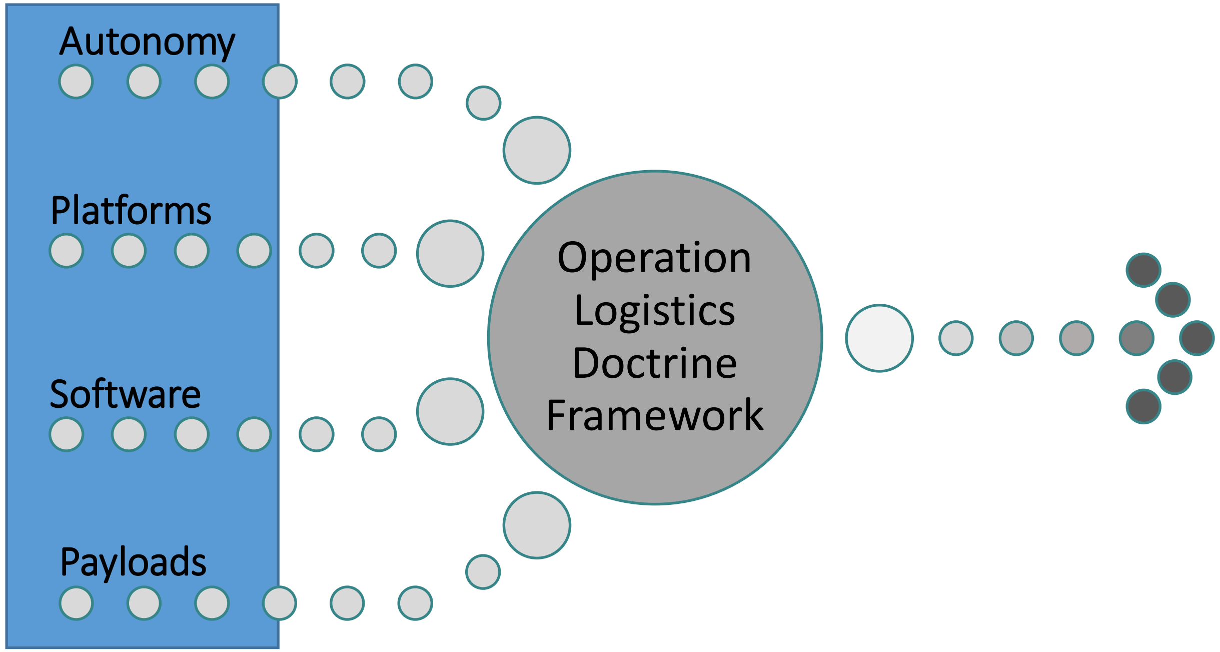
- Idea of modularity is limited in the ability to get to the future capability desired
- Full mission asset management to solve a problem
- Combining modular capabilities payload, interface, operability

Limited View



Capability Modularity

Combined levels of modularity and operational context to meet future needs



Require modularity

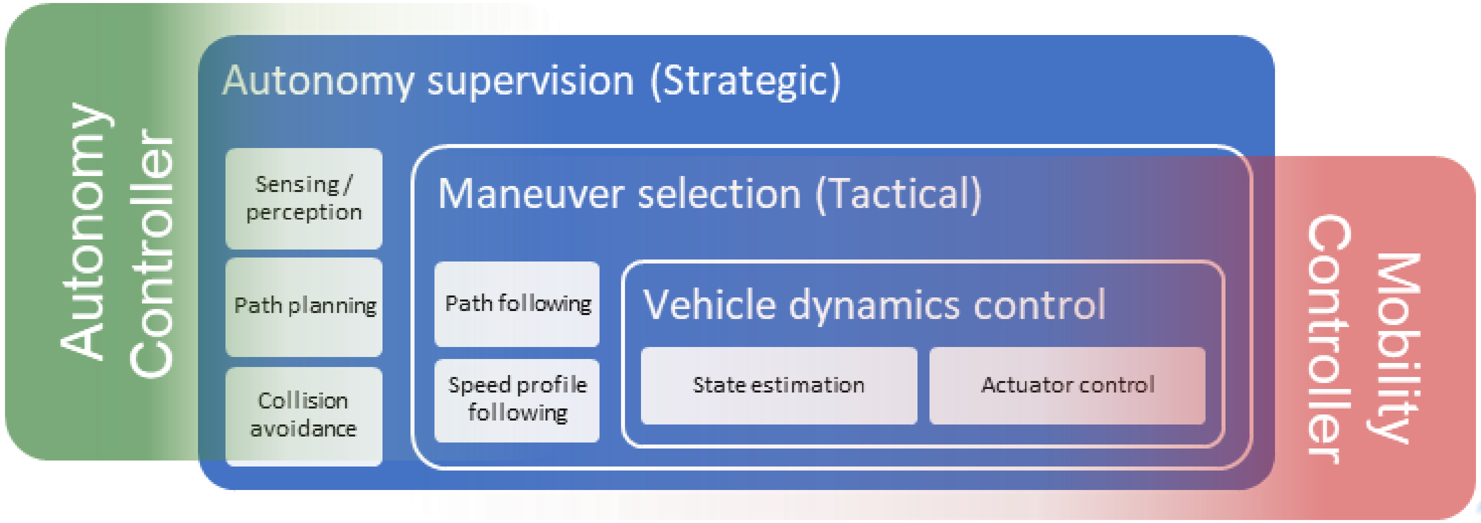
Multi-Domain Asset Management

The country needs and, unless I mistake its temper, the country demands bold, persistent experimentation. It is common sense to take a method and try it: If it fails, admit it frankly and try another. But above all, try something.

- Franklin D. Roosevelt

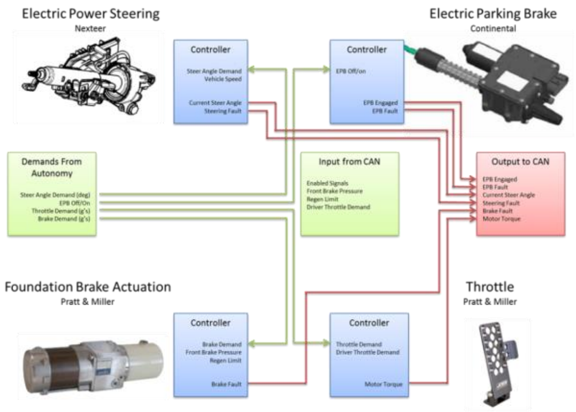
Spectrum of Modularity: Autonomy

Autonomy stack and mobility stack are part of the solution



Human Machine Interface

Actuation System Enabling



Demonstrators: Test the Theory

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Spectrum of Modularity: Platforms

Vehicle definition of modularity can enable or hinder success

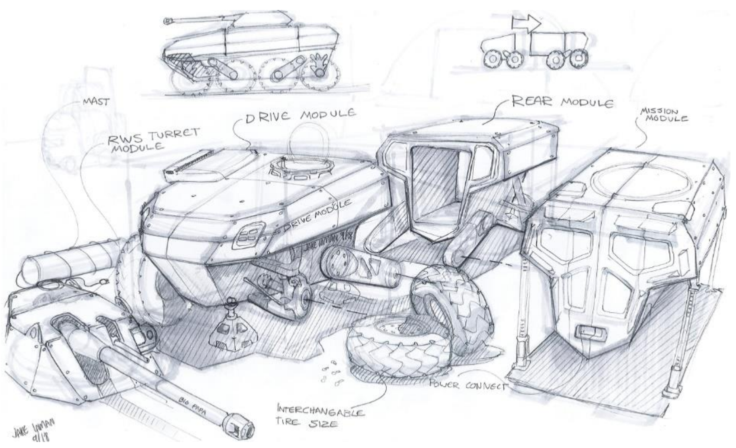
Vehicle Modular Design:

- Simple to complicated
- Evaluate based on speed of change
- Move beyond “flat deck”
- Powertrains, size, power adaptable
- Wheels and tracks
- Armor and sensors

Rebuild
- Essential all new

Modules
- Swap key components

Rolling Chassis
- Separated “cabs”



Infinite
- “Lego” blocks

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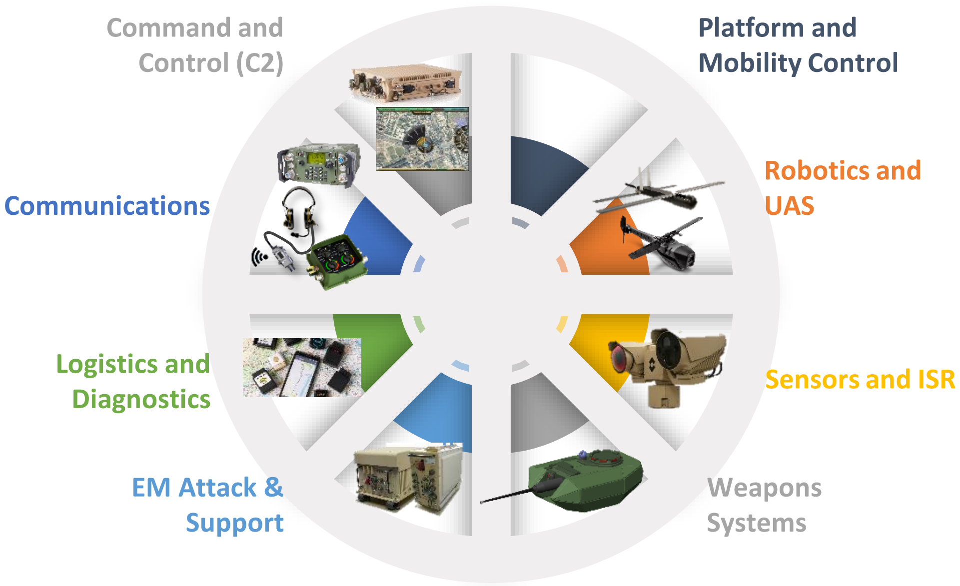
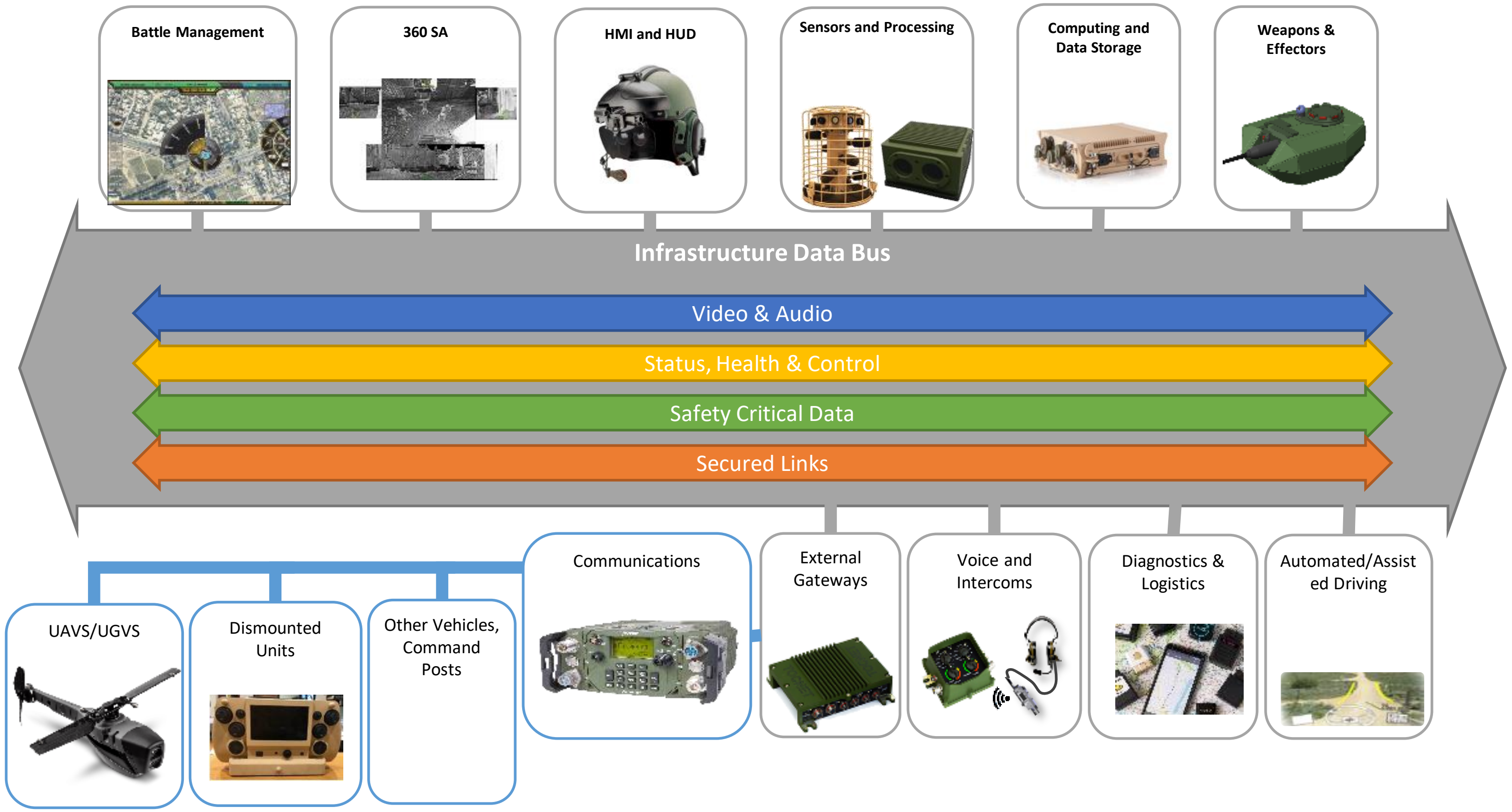
Modular Software & Payloads

Operational effectiveness involves many disparate systems

Defense is complicated:

- Mission planning, Battle Management Systems
- C4ISR, Communication
- Payload controls and cyber hardening
- Soldier information systems





Development Arc

View of Defense development path

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P O R T F O L I O

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