Sandia National Laboratories

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Advanced Unmanned Vehicle Remote Autonomous Sustainment (AURAS) – Overview

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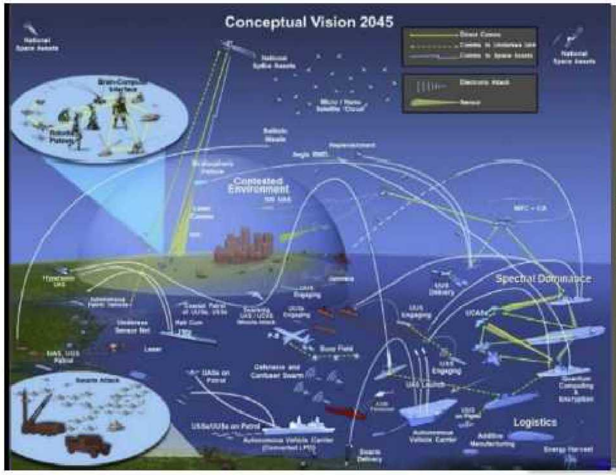
Overview



Proliferation of unmanned vehicles (UXVs) in the future battlespace is inevitable.

UXVs will require an increasing amount of operational energy to sustain them.

Improving sustainment (recharge / refuel) autonomy will enable widespread UXV persistence.

MOTIVATION

The anticipated future proliferation of unmanned vehicles (UXVs) in DoD necessitates advances in autonomous refueling and/or recharging for persistent command and control of battlespace.

The 2016 DoD Operational Energy Strategy highlights area-denial practices – improvised explosive devices (IEDs), mines, and anti-aircraft defenses – will limit feasibility of “logistically-intensive future concepts” required to maintain military superiority

Without careful study, a limiting factor in transitioning advanced unmanned combat capabilities to Operating Forces in high-threat environments will be logistics and manpower required to sustain them.

PROGRAM PLAN/DESCRIPTION

The AURAS study is a one-year effort with goals of identifying operational energy-related capability gaps and providing a methodology to identify S&T investments needed in field of remote, autonomous refueling and recharging of unmanned vehicles.

The study will be broken into 3 operational energy focus areas: *Energy generation and storage, Energy management and optimization, and Energy transfer.* Capability gaps will be identified across each domain, focus area, and power level, and an investment roadmap will be generated identifying S&T investment needs in near-, mid- and far-term to achieve autonomous UXV sustainment.

The diverse team including Carderock, NRL, CERDEC, NREL and SNL brings unique tools and knowledge in realm of UXV operational energy.

MILITARY BENEFIT

- Identification of operational energy capability gaps in near-, mid- and far-term as UVX proliferation increases and energy and autonomy technologies advance.
- Helps DoD identify S&T technology investments to improve energy generation, storage, management and transfer to achieve autonomous sustainment of UXVs.
- Improved UXV persistence, reduced manpower for sustainment

"Technological advances in stored energy are needed to best leverage the capabilities of mid-size and small [UXV], or these systems must harvest energy from the environment, use energy very efficiently, or replenish fuel stocks in situ with a minimum amount of time off station while doing so."
– DoN Strategic Roadmap for Unmanned Systems

Organizational Chart

Matthew Huffman, AURAS PI
James Mulford
Dr. Gordon Waller

NAVSEA
WARFARE CENTERS
Carderock

Carderock Unmanned Vehicle / Autonomous Systems (UV/AS) Working Group

CERDEC
US ARMY–RDECOM

Dr. Tony Thampan
William Rowley
Cao Chung

NAVAL RESEARCH LABORATORY
WASHINGTON, DC

Dr. Richard Stroman
Dr. Robert Walters
Phillip Jenkins
David Scheiman
Dr. Benjamin Gould
Dr. Corey Love
Dr. Paul Jaffe

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Dr. Nancy Haegel
Dr. Donald Jenket
Dr. David Mooney

Sandia National Laboratories

Dr. John Eddy
Alan Nanco
Dennis Anderson
Dr. Stephen Henry
Charles Carter

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Roles and Responsibilities

Naval Research Laboratory

- Advanced and specialty PV solar
- Hydrogen gas generation and fuel cells
- Energy Management optimization
- Autonomy optimization
- Advanced electrochemistry
- Wireless power transfer (WPT)

Communications-Electronics Research, Development and Engineering Center (CERDEC)

- Energy generation
- Wireless power transfer (WPT)
- Army / ground CONOPS

National Renewable Energy Laboratory (NREL)

- Technoeconomic analysis of mature renewable energy sources
- System-level and theater-level PV analysis / optimization
- Battery lifetime analysis tool

Sandia National Labs

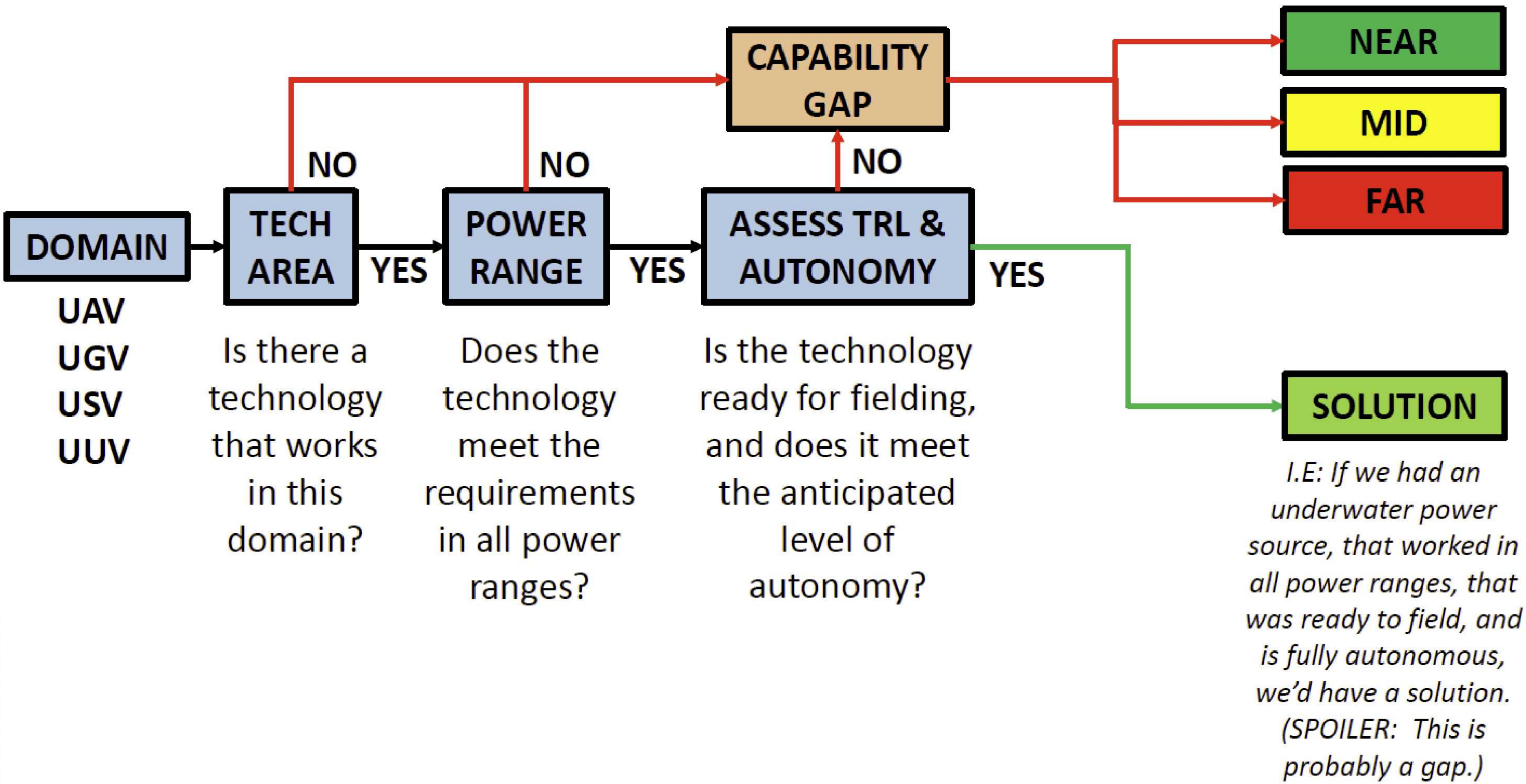
- Technology Management Optimization (TMO) for roadmap planning
- System of Systems Analysis Toolset (SoSAT) modeling
- Whole System Trade (WSTAT) tool for system design, autonomy

Consultants

- US Army TARDEC, ARMDEC, and ARL
- US Navy PACOM
- US Air Force AFRL

Capability Gap Identification – Approach A

Approach A: Conduct exhaustive analysis across each domain, technology area, and power capability.



Capability Gap Identification – Approach B

Approach B: Use scenario-based analysis and determine what capability gaps emerge as the desired autonomy increases.

We will define and investigate several scenario-based vignettes based on:

- War games and studies of future warfighting scenarios
- Autonomous vehicle roadmaps
- DoD Operational Energy Strategy
- U.S. Marine Corps S&T Strategic Plan

Ideas for scenarios:

- Persistent ISR **UAVs**, which require on-board power generation & management and far-field wireless power transfer to extend range. When they do have to land, they refuel / recharge autonomously from a ground-based sustainment facility.
- **UGV** logistics network, driving between logistics hubs and forward deployed locations to deliver food/water/ammo/fuel/etc
- **UUV** submerged docking station for refueling / recharging
- **USV** logistics network delivering bulk fuel and supplies from ship-to-shore

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Road-mapping Framework

	Current	Near-Term	Mid-Term	Far-Term
LEVEL OF AUTONOMY	LIMITED TO NONE	SEMI	NEAR	FULL
Energy Management	No system-level management	Analytical tools guiding human decisions	UXVs manage their energy	UXVs and facility collaborate as a system
Energy Generation and Storage	Energy transported to operating area	Energy transported and harvested	Local energy harvest w/human support	Local energy harvest w/no human support
Energy Transfer	Manual refuel/recharge	Semi-automated refuel/recharge	Automated refuel/ recharge w/human oversight	Fully automated refuel/recharge from remote sustainment facility w/no human oversight

Sandia's Analysis Role

- Sandia will use information provided by the AURAS team to develop a trade-space of efficient technology development and deployment roadmaps to address the OE capability gaps

- A roadmap is a description of the time phased roll-out of new or modified technologies over time simultaneously addressing various OE capability gaps as a system of systems

Sandia's Technology Management Optimization (TMO) will be the primary decision analytics tool employed for this effort

Integrated Military Systems
Defend & Defeat

TMO Capability

Sandia developed and has used the Technology Management Optimization (TMO) capability and tool to support various US Army's modernization programs for the past 10+ years

Its genesis was rooted in work done for the Joint Strike Fighter (F-35) program, to create optimal technology insertion roadmaps over the life of the program

Technology Management is the process of dealing with obsolescence, diminished manufacturing sources, and capability gaps with technology investments for existing and planned systems.

Technology Management is a challenging problem

- Large-scale, architecturally complex systems with multiple interdependent sub-systems
- Multiple competing objectives and constraints… reliability, survivability, cost, weight, fuel consumption, etc.
- Schedule uncertainty
- Situation changes… obsolescence, diminished manufacturing sources, technological advances

TMO Process

Define System of Systems

UXV

Capability Gaps & Technologies

30 yrs

Specify Design Options

Capability Gap 1:

Technology	Cost	TRL	...
Technology A			
Technology B			

Capability Gap 2:

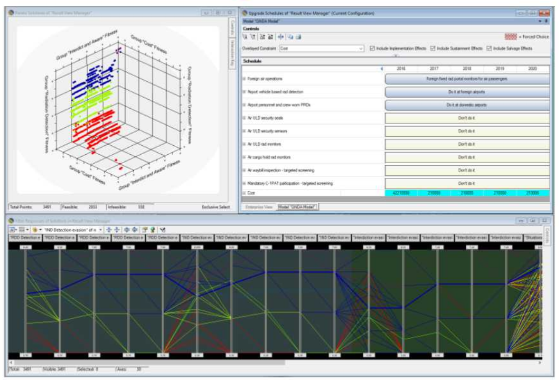
Technology	Cost	TRL	...
Technology A			
Technology B			

Define Design Objectives

Metric	Threshold	Objective
Cost	$1.2B	$700M
Schedule Certainty (2030)	93%	100%
# Vehicles Supported (2030)	175	310

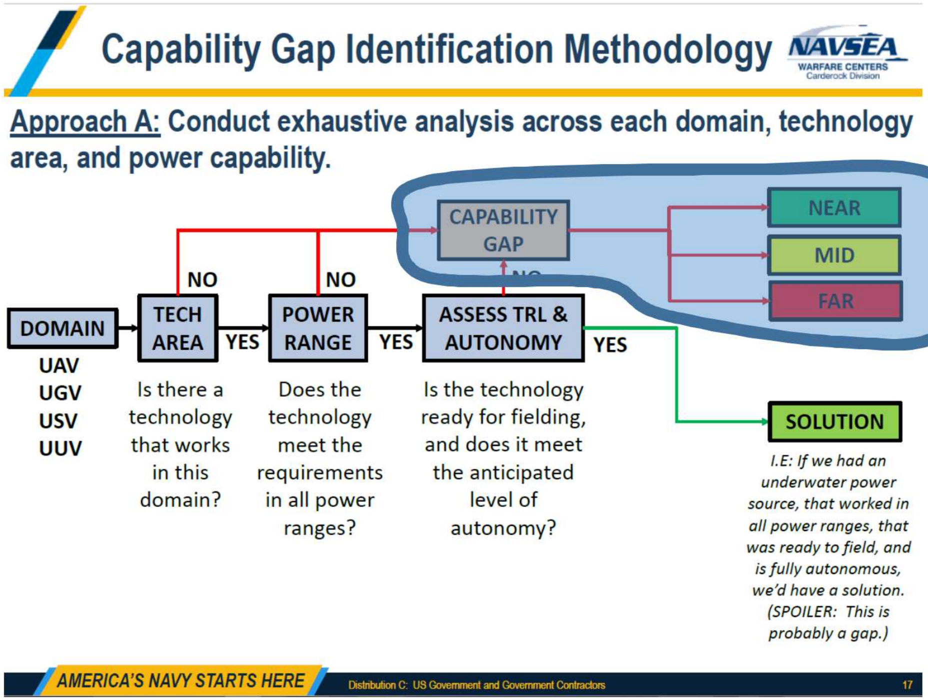
Optimize

Investigate Results



TMO

TMO Application to Capability Gap Identification Methodology



Capability Gap 1:

Technology	Cost	TRL	...
Technology A			
Technology B			

Capability Gap 2:

Technology	Cost	TRL	...
Technology A			
Technology B			

Performance Objectives

Roadmaps

Schedule

		2016	2017	2018	2019	2020
Foreign air operations		Foreign fixed rad portal monitors for air passengers				
Option Total		25100000	100000	100000	100000	100000
Foreign fixed rad portal monitors for air passengers	Subtotal	25100000	100000	100000	100000	100000
	Implementation	25000000	0	0	0	0
	Sustainment	100000	100000	100000	100000	100000
	Salvage	0	0	0	0	0
Airport vehicle based rad detecton		Do it at domestic airports				
Option Total		10100000	100000	100000	100000	100000
Do it at domestic airports	Subtotal	10100000	100000	100000	100000	100000
	Implementation	10000000	0	0	0	0
	Sustainment	100000	100000	100000	100000	100000
	Salvage	0	0	0	0	0
Airport personnel and crew worn PRDs		Do it at foreign airports				
Option Total		7010000	10000	10000	10000	10000
Do it at foreign airports	Subtotal	7010000	10000	10000	10000	10000
	Implementation	7000000	0	0	0	0
	Sustainment	10000	10000	10000	10000	10000
	Salvage	0	0	0	0	0
Air ULD security seals		Don't do it				
Option Total		0	0	0	0	0
Don't do it	Subtotal	0	0	0	0	0
	Implementation	0	0	0	0	0
	Sustainment	0	0	0	0	0
	Salvage	0	0	0	0	0
Air ULD security sensors		Don't do it				
Option Total		0	0	0	0	0
Don't do it	Subtotal	0	0	0	0	0
	Implementation	0	0	0	0	0
	Sustainment	0	0	0	0	0

Performance Objectives

- We can develop roadmaps based only on considerations like cost, technology maturation schedules and system completion date targets – assuming that all technology solutions considered will attain sufficient performance to fill a capability gap

- Typically we are provided the measures of performance, driven by requirements, indicating degree to which functional objectives are satisfied – which is more demanding (data intensive) and requires performance metrics which could be identified and explored during the OE capability gap identification phase and the investigation and identification of potential OE technology solutions

Required Capability Gap Information

For each capability gap, we need to have data for each technology under consideration that could potentially mitigate or fill the gap and possible maturation processes and schedules

Gap

Technology	TRL	Potential Maturation Schedules (including cost profiles)	Power (?)	…
T1	2			
T2	5			
T3	3			
T4	7			
…				

Values of Power, Weight, etc. (performance metrics) are not required but result in more complex and potentially informative trade-space solution sets

Technology Maturation Schedules

Each technology will have a current TRL. We need to know all the ways that it can be matured to the needed TRL (for deployment) and what that entails. For example:

"Technology A is at TRL 2. It can be matured to TRL 8 by 2025 with 90% confidence, 2026 with 95% confidence, etc. if we invest $2M per year between now and then.

Alternatively, it can be matured to TRL 8 by 2031 with 99% confidence if we invest $1M per year between now and then."

Cost and Performance Data

- If R&D costs, acquisition costs and/or O&M costs are critical to the technology investment selections, then that data will be needed for each technology as well

- If any technical performance measures are to be included (recommended), then supporting data will be needed and may be time dependent (power requirements may grow over time, etc.)

TMO Exemplar

OE Capability Gaps

Gap: Energy Storage for UUV Charging @300 ft. below sea level

- Storage Solution 1 – TRL 1
  - $2M/year investment
  - $1.5M/year investment
- Storage Solution 2 – TRL 3
  - $2M/year investment
  - $1.5M/year investment
  - $500K/year investment

Gap: Energy Transmission for Autonomous UGV Charging

- Transmission Solution 1 – TRL 3
  - $2M/year investment
  - $1.5M/year investment
- Transmission Solution 2 – TRL 2
  - $2M/year investment
  - $1.5M/year investment

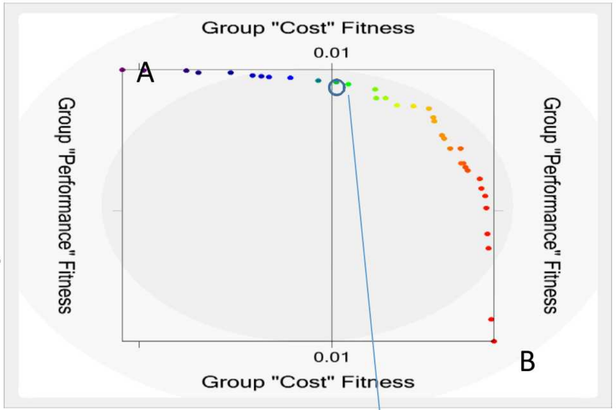
Metrics

Performance Objectives and Design Criteria

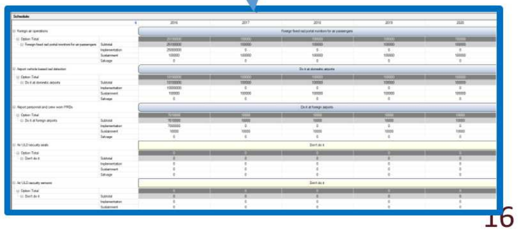
- Development, Deployment & Sustainment Costs
- Maturation Schedule including uncertainty
- Completion Dates & Goals
- Potential Key Performance Parameters (SWaP-C, energy generation metrics, maintenance/manpower requirements, recharging speed, efficiency, etc.)

Pareto Frontier of Solutions

Trade space Results



Technology Investment Roadmaps



TMO Results

- TMO optimal trade-space results can be used to identify relationships between technologies, the best individual solution to a technology gap, deployment trends within a system of technologies and more
- Sandia team will iterate with the AURAS team to refine and understand the results
- These results support the SMEs tasked with decision making within the AURAS project – combining a data driven analytic approach with experienced SMEs results in more effective decision making when addressing complex problems

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