Costing for the Future

EXPLORING COST ESTIMATION FOR UNMANNED AUTONOMOUS SYSTEMS

By
CPT(P) Thomas R. Ryan
United States Military Academy

Ricardo Valerdi, Ph.D.
University of Arizona

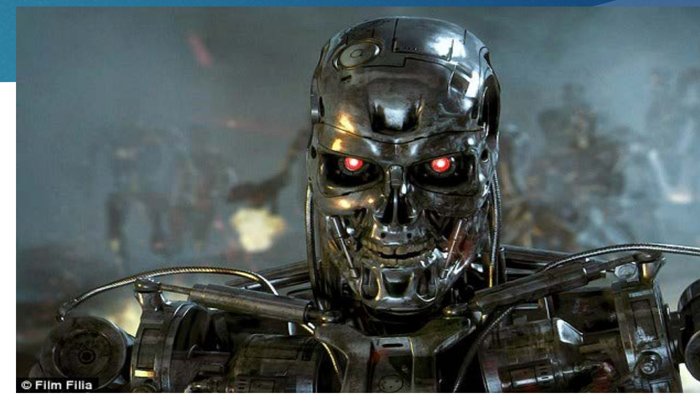
May 5 2016

The views expressed in this article are those of the authors and not necessarily those of the U.S. Army, the Department of Defense, or the U.S. Government.
This material is based upon work supported by the Naval Postgraduate School Acquisition Research Program under Grant No. N00244-15-1-0008. The views expressed in written materials or publications, and/or made by speakers, moderators, and presenters, do not necessarily reflect the official policies of the Naval Postgraduate School nor does mention of trade names, commercial practices, or organizations imply endorsement by the U.S. Government.

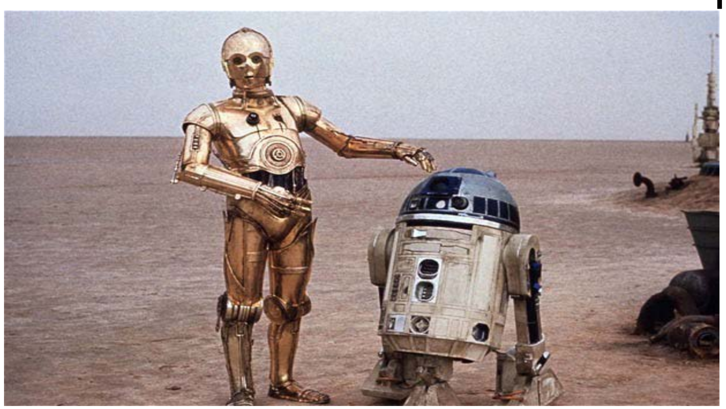
Agenda

- Levels of Autonomy
- Emerging challenges Autonomy
- Research questions
- Autonomy Levels
- Cost hierarchy
- Weight and performance metrics
- Proposed approach
- Case studies
  - Squad Maneuver Equipment Transport, Autonomous Mine Detection System, Autonomous Mobility Appliqué System, Route Clearance Interrogation System

Unmanned Autonomous Systems



Perception



Unmanned Autonomous Systems

Reality

Systems & Industrial Engineering
The University of Arizona

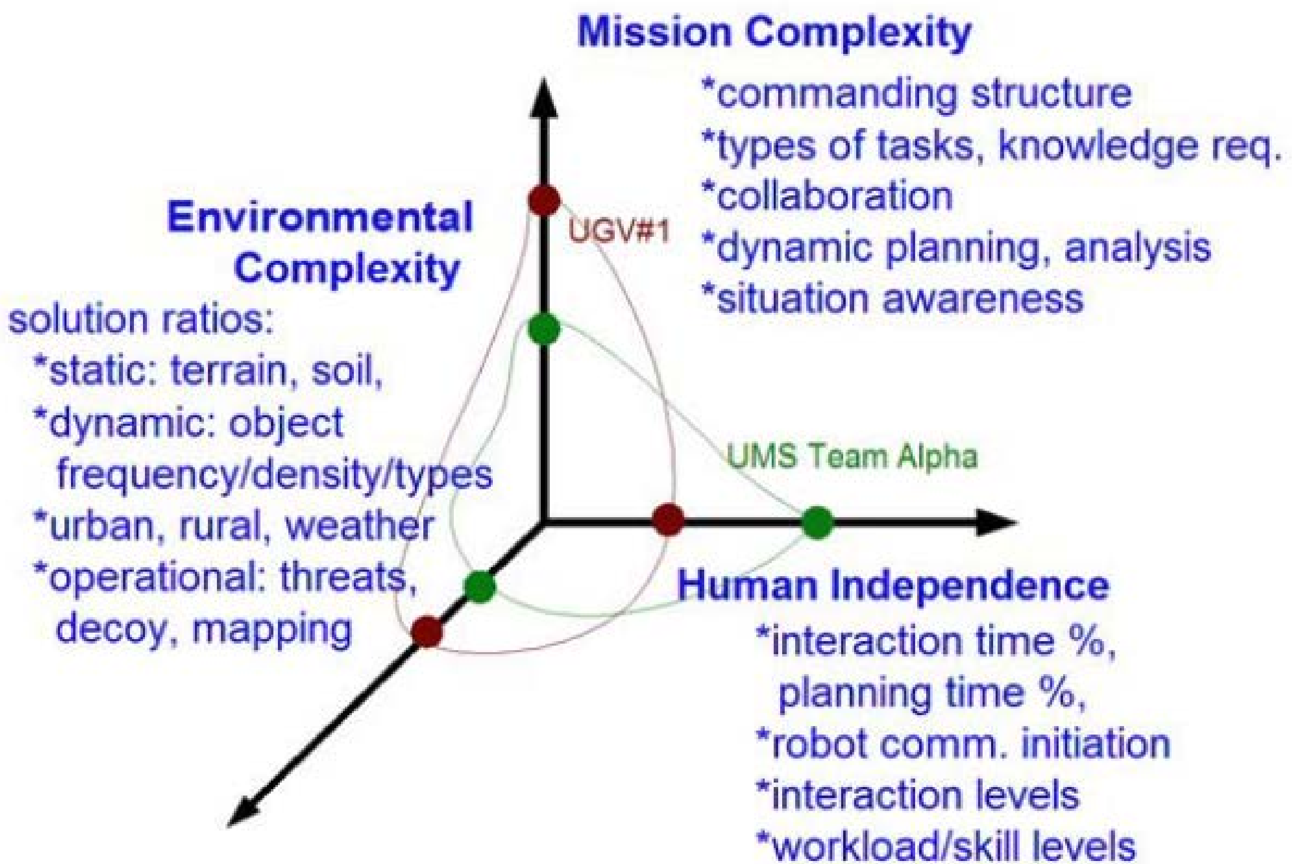
Unmanned Autonomous Ground Systems: Dull, Dirty, Dangerous





- Research Questions
  - From an acquisition perspective, what inadequacies exist, if any, with the tools and methods used to produce cost estimates for emergent UMAS technology?
  - From a monetary and implementation view point, what are the hidden costs of UMAS – specifically when the system has left production and is placed into service?

Autonomy Levels of Unmanned Systems (ALFUS)



NIST Special Publication 1011-II-1.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework Volume II: Framework Models Version 1.0

Levels of Autonomy

Level	Name	Description
1	Human Operated	A human operator makes all decisions. The system has no autonomous control of its environment although it may have information-only responses to sensed data.
2	Human Delegated	The Vehicle can perform many functions independently of human control when delegated to do so. This level encompasses automatic controls, engine controls, and other low-level automation that must activated or deactivated by human input and must act in mutual exclusion of human operation.
3	Human Supervised	The system can perform a wide variety of activities when given top-level permissions of direction by a human. Both the human and the system can initiate behaviors based on sensed data, but the system can do so only if within the scope of its currently directed tasks.
4	Fully Autonomous	The system receives goals from humans and translates them into tasks to be performed without human interaction. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs.

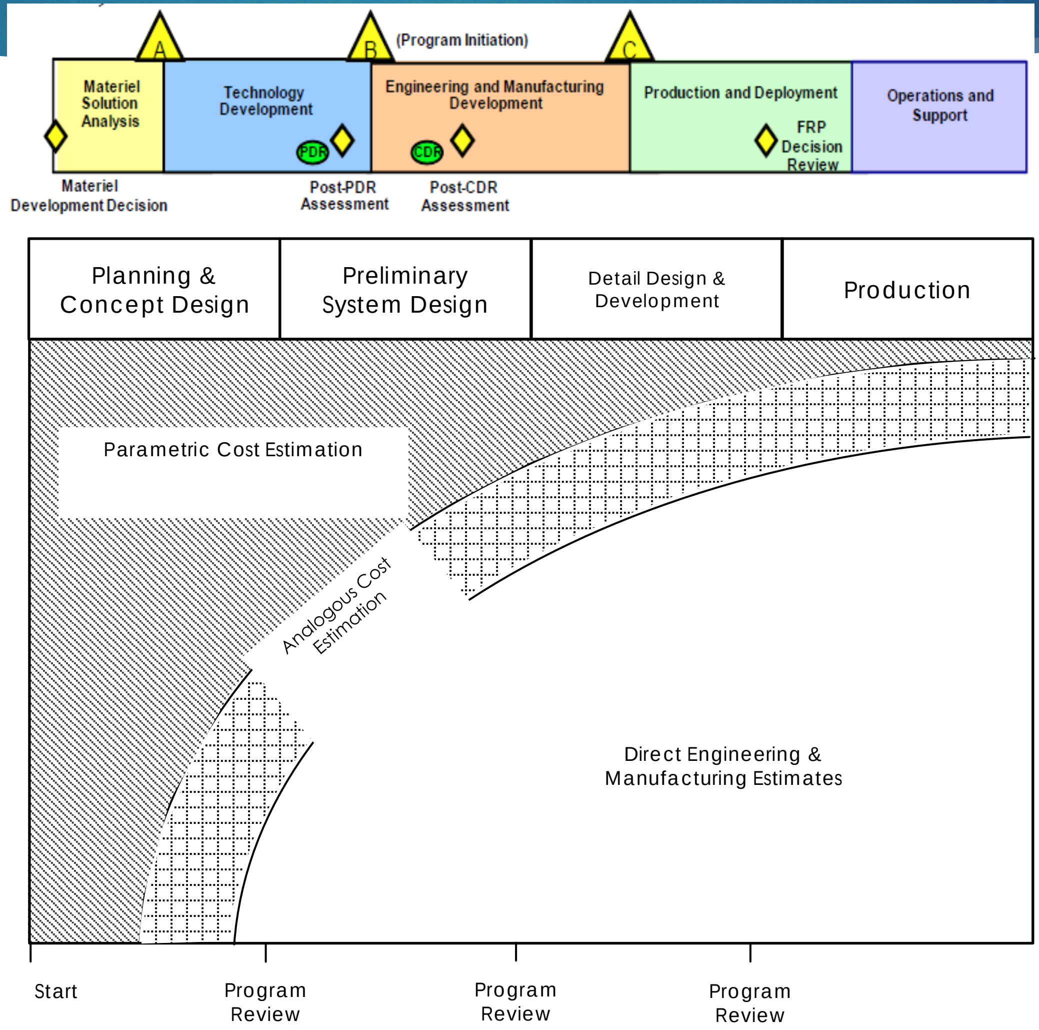
Unmanned systems integrated roadmap FY2013-2038. (2013). Washington, D.C.: Department of Defense.

Levels of Functionality

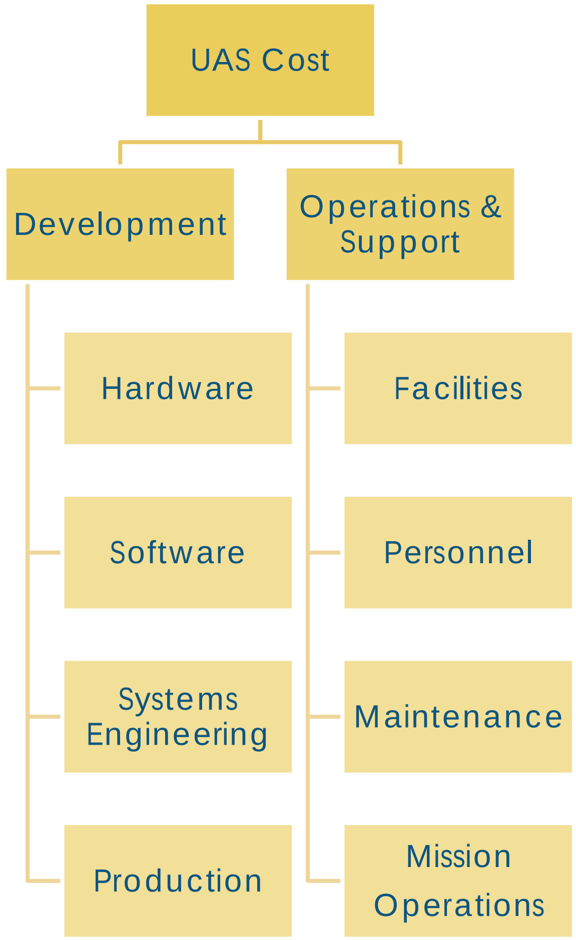
Level	Capability	Comments
0	Pre-programmed	A software radio
1	Goal Driven	Chooses Waveform According to Goal. Requires Environment Awareness.
2	Context Awareness	Knowledge of What the User is Trying to Do
3	Radio Aware	Knowledge of Radio and Network Components, Environment Models
4	Capable of Planning	Analyze Situation (Level 2& 3) to Determine Goals (QoS, power), Follows Prescribed Plans
5	Conducts Negotiations	Settle on a Plan with Another Radio
6	Learns Environment	Autonomously Determines Structure of Environment
7	Adapts Plans	Generates New Goals
8	Adapts Protocols	Proposes and Negotiates New Protocols

Mitola, J. "Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio," PhD Dissertation, Royal Institute of Technology, Sweden, May 2000.

Cost Estimation Methods



Life Cycle Cost Hierarchy



Weight and Performance Metrics

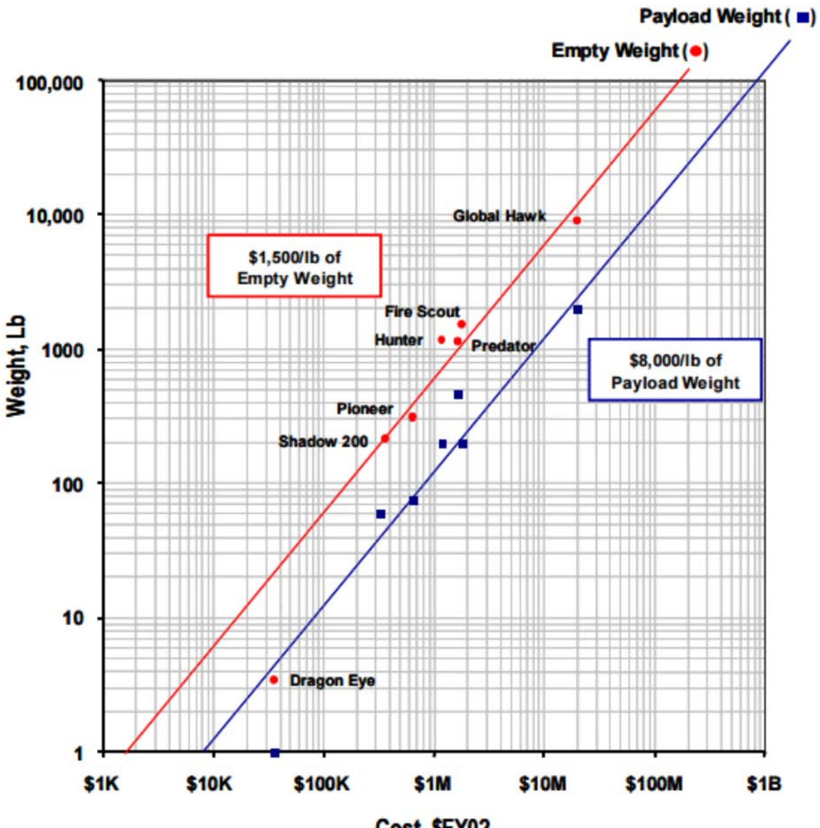


Figure 4. UAV Capability Metric: Weight v. Cost[1]

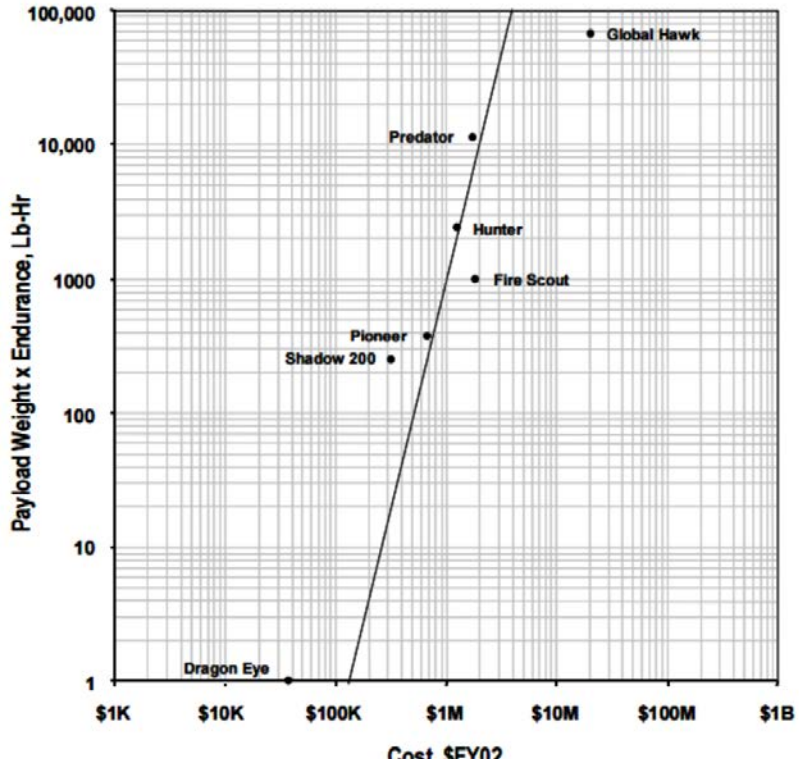


Figure 5. UAV Performance Metric: Endurance v. Cost[1]

UAV Roadmap, "Unmanned Aircraft Systems Roadmap: 2005-2030," Office of the Secretary of Defense, August 4, 2005.

Proposed Methodology

$$Cost\ (convert\ all\ individual\ outputs\ to\ \$K) = (SEER-HDR) + (COCOMO\ II) + (COSYSMO) + (WeightBased\ CER) + (PerfomanceBased\ CER)$$

- Hardware – Best understood space with respects to UMAS.
- Software – Most complex space at both the lowest levels of UMAS WBS, and at integration of sub-systems
- Systems Engineering/ Program Management – Not as precisely quantified as other effort categories.
- Weight Based CERs – Different UMAS will require different goals. Less may not always be better in this category.
- Performance Based CERs – This requirement will allow a system's need to remain the main driver, preventing "scope creep."

PWBS Estimation Breakdown Matrix – with type of estimation approach recommended

Ref. #	WBS Element	SEER – HDR	COCOMO II	COSYSMO	Weight	Performance
1	UMAS System					
1.1	Vehicle					x
1.1.1	Vehicle Integration			x		
1.1.2	Vehicle Sub-systems	x			x	x
1.1.3	Autonomous Capabilities		x	x		x
1.1.4	Vehicle Electronics		x	x		
1.1.5	Navigation Capabilities				x	x
1.1.6	Communications		x		x	x
1.2	Remote Control System				x	
1.2.1	Ground Control Center Subsystem			x		
1.2.2	Operator Control Unit (OCU) Subsystem				x	

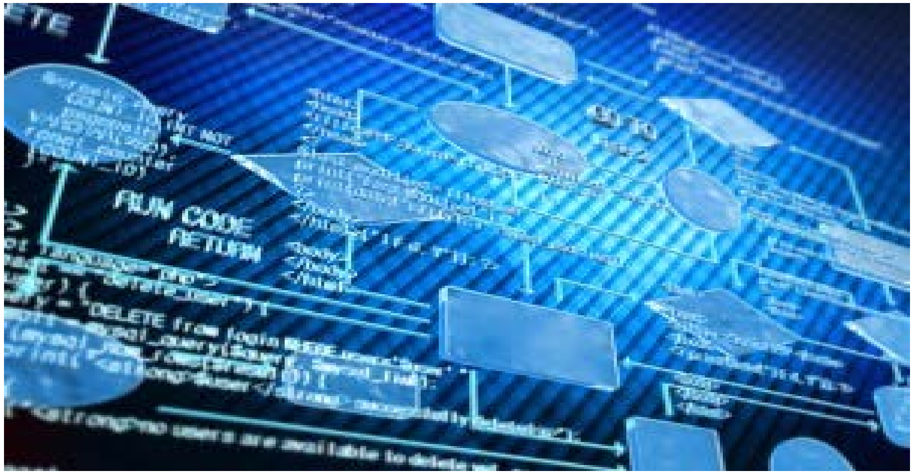
Unique Cost Considerations

- **Software –** Programming for operational environment interaction as well as adapting and evolving may be the biggest challenge for Autonomy.

- **Test & Evaluation –** We currently test UMS in similar fashion to MS. For UMAS we will need to collect different data points, change interpretations, create autonomous test environments, and change paradigms.

- **HRI and MUM-T –** Focusing on integration of UMAS with the end user and the operating environment. Issues are current human capacity, cultural acceptance, ethical dilemmas, most of the engineering "-ilities"

Potential Solutions Software Size – OOFP



Object Oriented Function Points (OOFP) – Suggested Augmentation for COCOMO II
COCOMO II currently uses the International Function Point Users Group (IPFUG) standard for unadjusted function points (UFP). Traditional function point estimators view the final function point count through the lens of the end-user or the system itself, and what is not accounted for in that viewpoint is the SOS or lens of the customer. OOFPs can be used to calculate size that encompasses both the individual system and its integration, interoperability, and capacity as an SOS – creating a more robust estimation.

Potential Solution T-VED

Test, Validation, Evaluation, and Demonstration (T-VED) – Suggested Augmentation for COSYSMO

This cost driver rates the scale of requirements test worthiness at each level of the system. As the source of test worthiness increases the effort required to test, validate, evaluate, or demonstrate a requirement is lessened.

Very Low	Low	Nominal	High	Very High
No TVED methods currently available to certify requirement success. Requires full development of any TVED.	TVED methods are being developed and should be employable within the near term (0-2 years).	Current TVED methods are available and meet varying levels of standards.	Current TVED methods are in place and are standard compliant.	TVED methods are proven and reliable. These methods are also consistent with respective standards.

Potential Solution HRI-T

Human Robot Interaction and Teaming (HRI-T) – Suggested Augmentation for COSYSMO

This cost driver counts the number of input/interactions required between a system and the number of unique users/teams that ensure mission success. As the number of counts decreases for HRI the effort estimation from a systems integration perspective increased. This is inversely applied for MUM-T, for as teaming capabilities increase (or the number of other systems it successfully cooperates with increase) the effort to integrate also increases.

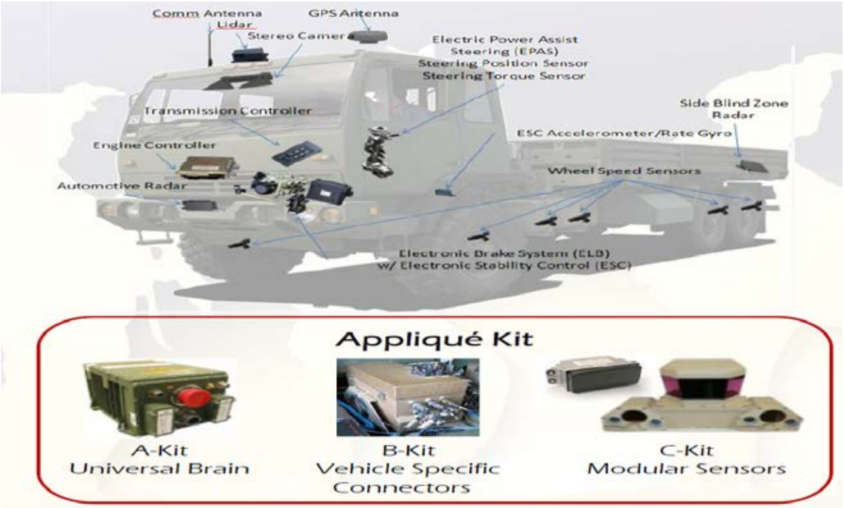
	Very Low	Low	Nominal	High	Very High
HRI Count	10+	10-5	4-3	2-1	0
HRI	System is holistically dependent on human/user interaction.	System requires interaction intermittently throughout total mission profile.	System requires interaction only in critical phases of a mission profile.	System is capable of completing mission without interaction.	After initial calibration system requires zero interaction during a mission.
MUM-T Count	1	2-3	4-5	6-10	10+
MUM-T	System currently exists in a team with a singular manned system with established procedures.	System currently exists in a team with a multiple manned systems with established procedures.	System exists in a team with manned and unmanned systems; all systems are controlled by humans.	System exists in a team with manned and unmanned systems; some systems may controlled by humans.	Team exists in a swarm with mission parameters calibrated prior to execution.

Case Studies: Squad Maneuver Equipment Transport, Autonomous Mine Detection System

The **SMET** will lighten the Warfighter's load and sustain the force during operations. The SMET will maneuver with the dismounted force and enable Warfighters to conduct continuous operations without the individual Warfighter carrying the equipment required to conduct 96 hours of dismounted operations. (Roberson, 2014)

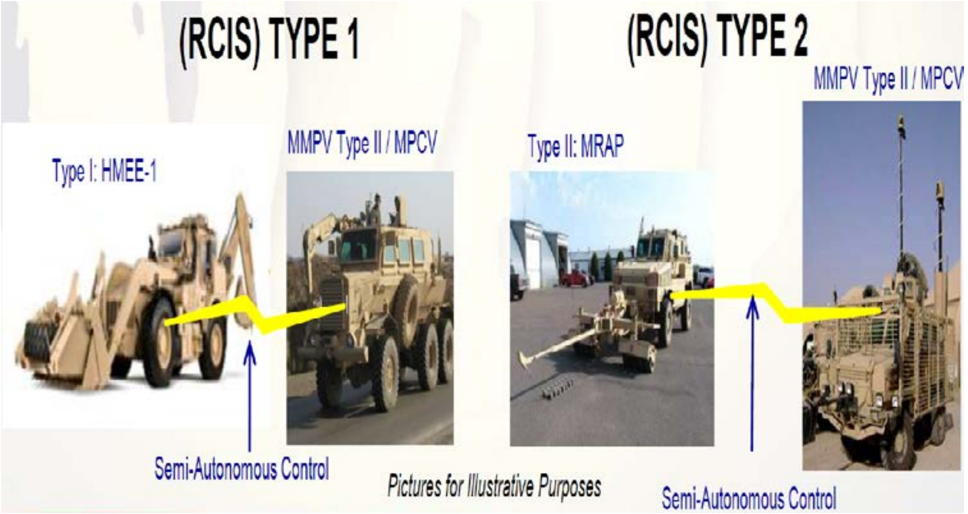
The **AMDS** is a team of 3 unique autonomous robots that when deployed together will provide the Army with unprecedented capability to detect, mark, and neutralize explosive hazards in virtually all environments. The platform for the collection robots is the MTRS and includes cutting edge detection technology like AN/PSS-14 and Ground Penetrating Radar (GPR). (Army, 2015)

Case Studies: Autonomous Mobility Appliqué System, Route Clearance Interrogation System

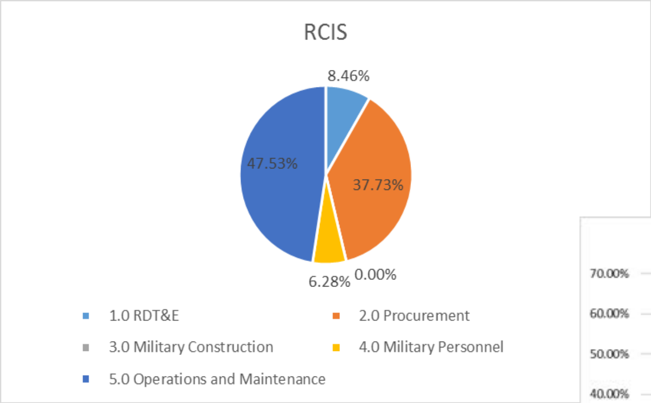


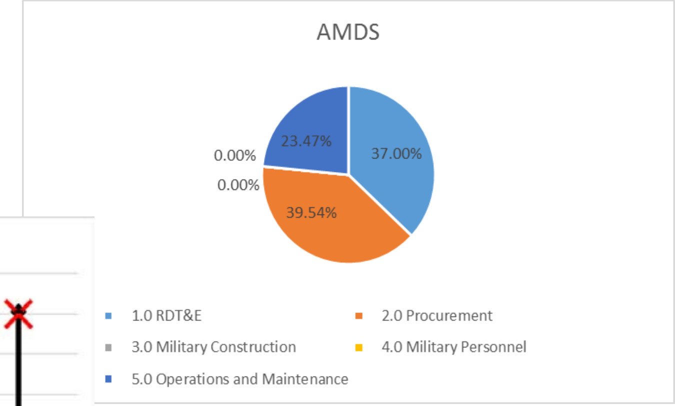
The **AMAS** interfaces between the "Autonomy Kit" and mission payload and the host platform's environment - enabling manned vehicles to be operated with autonomous capabilities. (Roberson, 2014)

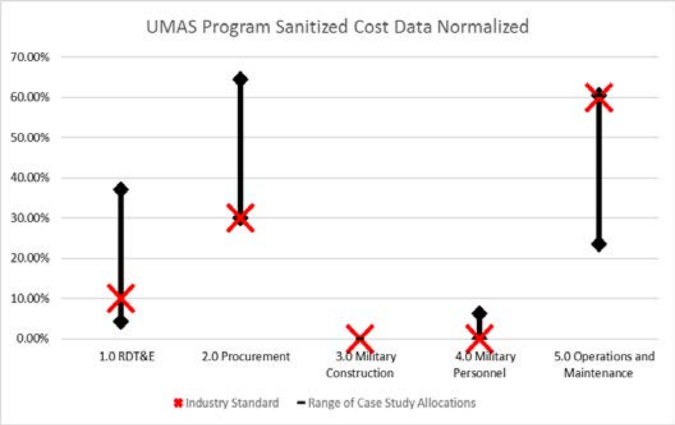
RCIS does not procure any additional platforms, it will utilize existing HMEEs and RESET RG-31s. RCIS' main purpose is to develop and field a Semi-Autonomous Control Capability that provides standoff interrogation and neutralization capabilities for Route Clearance. (Roberson, 2014)

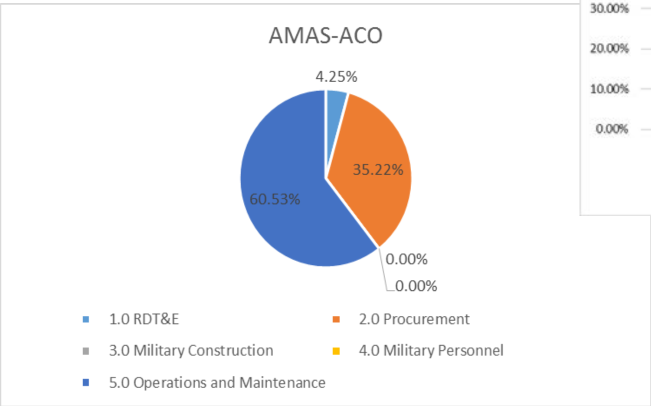


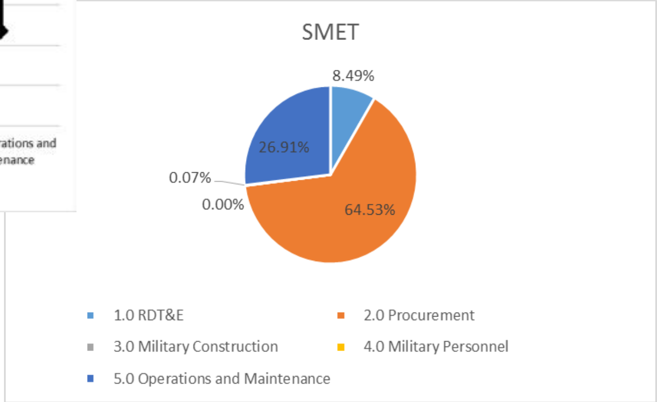
Cost Distributions for Army Systems









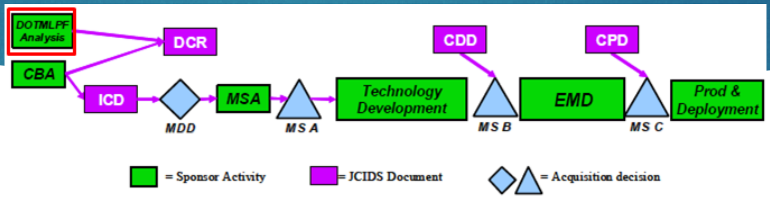


Case Study

Cost Element Allocation	RDT&E	Procurement	MILCON	MILPER	O&M
Current Industry Standard	10%	30%	0%	0%	60%
Range for Autonomy	5-37%	35-65%	0%	0-6%	23-60%
Recommended Standard	15%	45%	0%	0%	40%

- RTD&E – The individual story line for each UMAS factors into the data's distribution. A new industry standard for systems with autonomy in the RDT&E phase could be expected to be more than 10%.
- Procurement – Three of the UMAS are re-using existing vehicular platforms keeping the allocation smaller than SMET, which is a completely new system. As new systems are not COTS based we should see Procurement become more than 30%
- MILPER/MILCON – most programs assume that their system is engineered to "fit-in" to the existing infrastructure and existing operating environment. This assumption will have to change as autonomy becomes prevalent. And we could see this cost category become utilized more often.
- O&M/O&S – The O&M cost element is the hardest element to estimate for. As UMAS infrastructure is built and exiting systems are supportive of this technology we will see a decrease in allocation – which does not equate to a smaller price tag.

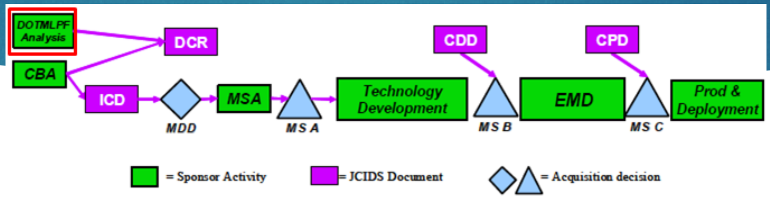
DOTmLPF-Pǂ



- Gap Analysis tool used when a military requirement is generated by one of the services
- Used unconventionally in this research as a way of analyzing how UMAS will impact these same areas after implementation
  - Doctrine – Capacity exists to generate early concept style doctrine. Current method is to issue emergent systems and let Soldiers innovate through trial and error (sometimes in real-world situations)
  - Organization, Training, Leadership , Personnel – Recommend initially exploring an Army Special Forces structure of humans to robot ratio. Eventually expanding to regular Soldiers where incoming candidates train with their systems at entry level training then both Soldier are aligned by specialty

ǂ Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Policy

DOTmLPF-P (Cont.)

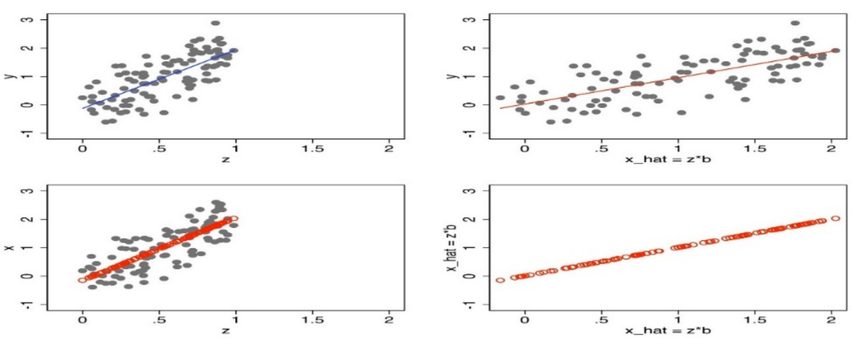


- Materiel – adjusting our understanding of how emergent systems will be mass produced should impact how we eventually field UMAS
- Facilities – Recommend initial focus be on upgrading Test and Evaluation Centers (Yuma Proving Grounds, White Sands Missile Range, etc.) Secondly upgrade national military training centers (this could be both physical training infrastructure and with simulation training capacity)
- Policy/ Acquisition – newest change is dated 7 January 2015 – not able to quantify impact yet; however, this new policy introduced 4 unique acquisition strategies that could empower Project managers to be more agile in the process. (Hardware, Software, Incrementally deployed Software, and accelerated)
- Policy/ Implementation – Focus is on ethical use, rule of law, and unintended consequences. Provoke thought – the systems we build/use are never perfect.

Next Steps in Research

Autonomous Model Validation

- Continue to seek program data to build and validate a parametric model
- Focus on critical areas of Test & Evaluation, User and System of Systems integration, and Sustainment
- Discuss and Contribute to a common language for Autonomous Systems



Next Steps

- Delphi Survey based on research
- Expand portfolio
- Examine sub-system and sub-component autonomy
- Continue to refine the process for UMAS – embrace the coming paradigm shift