Advantages of Using Complex Decision Support Tools in Planning Multi-modal Test Programs

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Research Question

We seek to highlight some challenges and approaches for developing alternate test modalities for complex systems. We devise a Multi-modal decision support tool for understanding the usage of these testbeds and evaluate tradeoffs between them.

A specific example is explored for a Space Electronic Warfare test use case.

BLUF

Testing Complexity

- Highly multidimensional problem
- Testing a system is dependent on intended use cases
- Cost, schedule, and performance issues
- Different potential modalities

Value Proposition

- Decision support tools enable traceability
- Multi-modal test tool provides means to evaluate alternatives
- Such tools provide understanding of risks and rewards

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Test Modalities

Over the Air (OTA)

Traditional testing mode in which system is placed in a real-world environment

Hardware in the Loop (HITL)

Testing mode that provides a blend of real-world and digital simulation facilities

Digital Modeling & Simulation (M&S)

Built on digital models of the system, environment, and processes

CubeSat FlatSat (Courtesy: European Space Agency)

Test Objectives

Quality: composed of fidelity, repeatability, and reliability/confidence

Coverage: the part or percentage of the system performance envelope that the test verifies

Difficulty: composed of cost, schedule, and risk

	Quality	Coverage	Difficulty
OTA	High	Low	High
HITL	Moderate	Moderate	Moderate
M&S	Low	High	Low

General trade-offs between the 3 test modes (OTA, HITL, M&S) in terms of the 3 basic test objectives (quality, coverage, difficulty). Rankings are notional.

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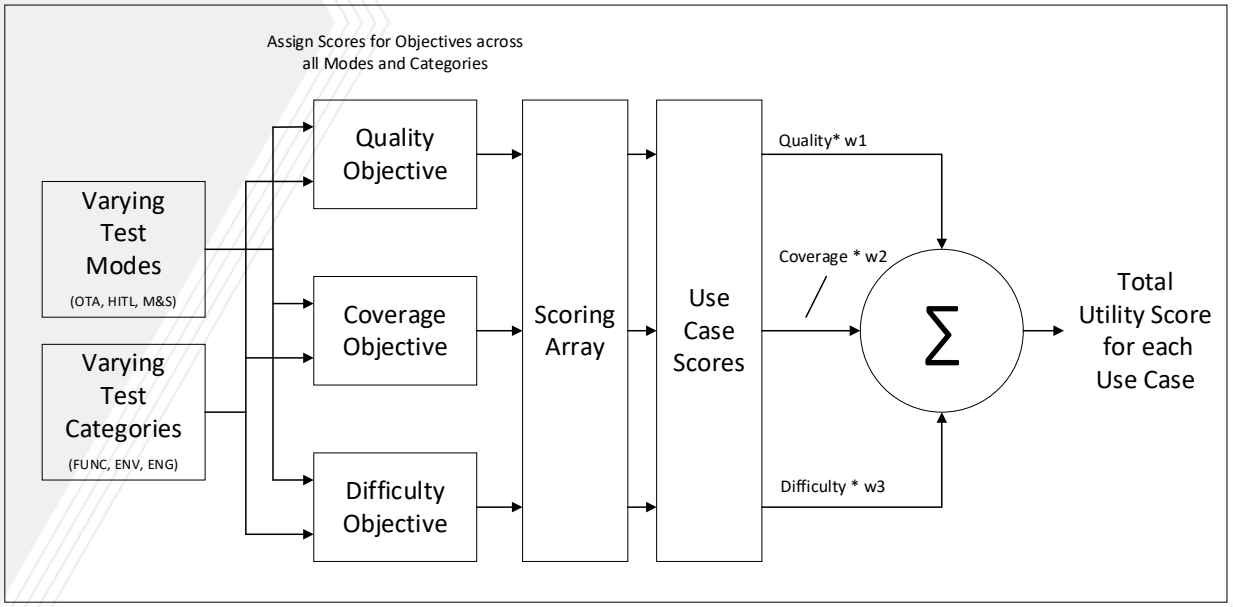
A Starting Framework: Multi-Modal Test Tool

Define Test Categories (the test's functional, environmental, and engagement components)

Define Test Modes (OTA, HITL, M&S)

Define Test Objective (quality, coverage, difficulty)



Test Case: Uplink Survivability (ULS)

Value:

Dependence of terrestrial missions on reliable SATCOM (downlink effects)

Prototype for DoD space EW T&E

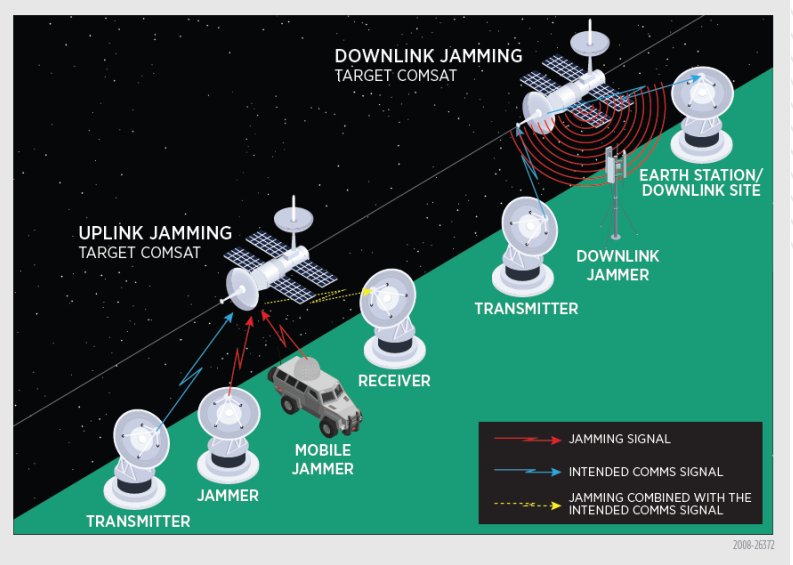
Difficulties:

Connecting test environment to actual orbital conditions

Mission orbit access throughout lifecycle

EMCON issues with EW

How to test for system of system resilience?



Source: "Challenges to Security in Space." *Defense Intelligence Agency*, www.dia.mil/Military-Power-Publications/.

Description: satellite under test experiences interference of data or TT&C on the uplink from the ground segment which denies or degrades

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Tool Applied to the ULS Test

A ULS use case is composed of the possible categories:

Function: **data link** or telemetry, tracking and control (TT&C)

Interference Type: **basic**, advanced

Environment: **clear**, obscured

Engagement: **1v1**, MvN

Example use case: {datalink, basic interference, clear environment, 1v1 engagement}

Quality score = 9 + 9 + 7 + 7 = 32

	Use Case Category																							
	Link						Interference						Environment						Engagement					
	Data			Control			Basic			Advanced			Clear			Obscured			1v1			MvN		
Objective	O	H	M	O	H	M	O	H	M	O	H	M	O	H	M	O	H	M	O	H	M	O	H	M
Quality	9	5	3	9	5	3	9	5	3	9	7	3	7	5	3	3	7	3	7	5	3	1	5	5
Coverage	3	5	7	3	5	7	3	5	7	3	5	7	3	5	7	3	5	7	3	5	7	1	1	9
Difficulty	1	5	7	1	5	7	3	7	5	1	7	5	1	5	7	1	5	7	3	5	7	1	1	9
Scoring:	Rate 7,5,3 with 7 = best; allow extremes for edge cases (9,1)																							

Example notional scoring array for different use cases. Entries should be informed by test designers familiar with the modes and domain.

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Results

Use Case					Intermediate Scores									Total Utility Scores		
					Quality			Coverage			Difficulty					
Use Case #	Function	Interference	Environment	Engagement	OTA	HITL	M&S	OTA	HITL	M&S	OTA	HITL	M&S	OTA	HITL	M&S
1	Data Link	Basic	Clear	1v1	32	20	12	12	20	28	8	22	26	260	310	330
2	Data Link	Advanced	Clear	1v1	32	22	12	12	20	28	6	22	26	250	320	330
3	Control Link	Basic	Clear	1v1	32	20	12	12	20	28	8	22	26	260	310	330
4	Control Link	Advanced	Clear	1v1	32	22	12	12	20	28	6	22	26	250	320	330
5	Data Link	Basic	Obscured	1v1	28	22	12	12	20	28	8	22	26	240	320	330
6	Data Link	Advanced	Obscured	1v1	28	24	12	12	20	28	6	22	26	230	330	330
7	Control Link	Basic	Obscured	1v1	28	22	12	12	20	28	8	22	26	240	320	330
8	Control Link	Advanced	Obscured	1v1	28	24	12	12	20	28	6	22	26	230	330	330
9	Data Link	Basic	Clear	MvN	26	20	14	10	16	30	6	18	28	210	270	360
10	Data Link	Advanced	Clear	MvN	26	22	14	10	16	30	4	18	28	200	280	360
11	Control Link	Basic	Clear	MvN	26	20	14	10	16	30	6	18	28	210	270	360
12	Control Link	Advanced	Clear	MvN	26	22	14	10	16	30	4	18	28	200	280	360
13	Data Link	Basic	Obscured	MvN	22	22	14	10	16	30	6	18	28	190	280	360
14	Data Link	Advanced	Obscured	MvN	22	24	14	10	16	30	4	18	28	180	290	360
15	Control Link	Basic	Obscured	MvN	22	22	14	10	16	30	6	18	28	190	280	360
16	Control Link	Advanced	Obscured	MvN	22	24	14	10	16	30	4	18	28	180	290	360

Test Objective	Weight
Quality	5
Coverage	5
Difficulty	5

Quality *w1 + Coverage*w2 + Difficulty*w3 =
32*5 + 12*5 + 8*5 = 260

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Challenges

Weights
- Must be devised by a test planners and resource gatherers
- Scoring is sensitive to weight scheme

Test Modes
- Continuum of test modes
- Bias to existing infrastructure and historical methods

Lifecycle
- Growing popularity of digital twins necessitates consistent testing in different contexts

Case		Weight			# Modes w/Highest Utility Score		
		Quality	Coverage	Difficulty	OTA	HITL	M&S
1	Evenly weighted	5	5	5	0	2	16
2	Quality weighted	8	2	2	8	8	0
3	Coverage weighted	2	8	2	0	0	16
4	Difficulty weighted	2	2	8	0	0	16
5	Operational Test	8	2	3	4	10	2
6	Developmental Test	7	4	3	2	6	8

ULS Test Case sensitivity analysis

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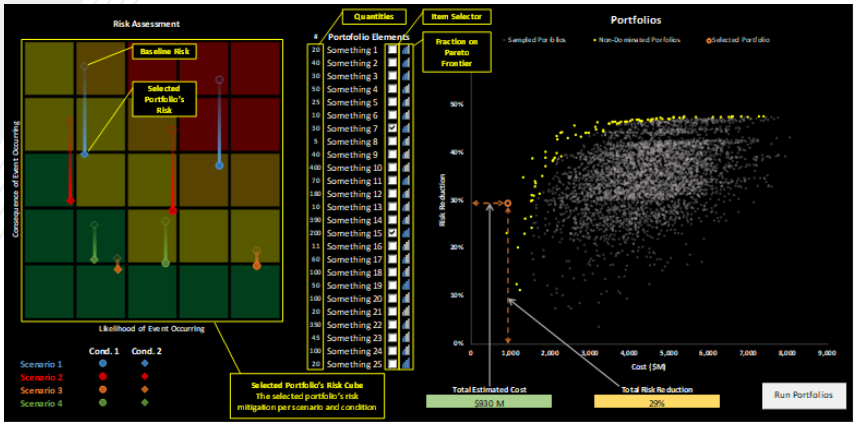
Further Work

Leverage existing decision support tools

Tie in to multidimensional decision frontiers to provide insight into contextually-relevant studies

Address challenges

Working with test resource planners and designers for informed inputs for tool development and scoring



Example Decision Support Tool including multidimensional decision frontier. (Source: Patterson, Fullmer, Browne, & Balestrini-Robinson, 2023)

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References

"Challenges to Security in Space." *Defense Intelligence Agency*, www.dia.mil/Military-Power-Publications/.

Image, https://www.esa.int/ESA_Multimedia/Images/2021/10/CubeSat_FlatSat

Patterson, F., Fullmer, D., Browne, D., & Balestrini-Robinson, S. (2023). Chapter 36 Portfolio Management and Optimization for System of Systems. In D. C. Verma, *Systems Engineering for the Digital Age.*