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When Does It Make Sense to Acquire a Single Weapon System Design That Can Be Used in Both Manned and Unmanned Operational Modes?

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Abstract

There is a strong push to change from manned toward both unmanned and optionally manned systems within the Department of Defense. There are significant open questions about how the manned versus unmanned versus optionally manned options influence costs, adaptability, operational utility, and suitability for missions. The Institute for Defense Analyses developed an approach to address these questions that links underlying physical attributes and engineering relationships to mission attributes and costs. We discuss this approach, where it fits into the acquisition process, and how it can be used to quantitatively inform the unmanned versus optionally manned discussions at both a system level and fleet level.

Background

Today's operational environment is complicated by many requirements that compete against one another for design resources (Freedberg, 2019).[1] Of course, this is not the primary challenge—after all, trade studies have been around for a long time. The primary challenge is characterizing the trades among system attributes (including cost) in a manner that can inform and guide leadership decisions prior to the Analysis of Alternatives (AoA) stage, rather than simply defending the selected alternative after the fact. In the end, this requires methods that leaders understand and visualizations that they can use. These

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[1] "We were under three entirely different organizations previously," Maj. Gen. Cedric Wins said. So RDECOM scientists and engineers would often be eager to offer their expertise to the future concepts teams, but "sometimes, though, quite frankly we might be late to the game," he said. The futurists might have committed to a particular technology without realizing there was a better alternative or, worse yet, without realizing it just wasn't ready for the real world.

methods must expose the implications of choices rather than mask them, long before detailed designs for the alternative approaches exist.

The Institute for Defense Analyses' (IDA's) trade space framework—Deducing Economically Realistic Implications Via Engineering (DERIVE)—links engineering and physics analysis, operational constraints, and semi-parametric cost estimates. The goal is to increase the efficiency of the acquisition process by reducing friction between the program office, the Services, the Joint Staff, and the Office of the Secretary of Defense (OSD), especially at program initiation and during the early stages of development.

IDA designed the DERIVE framework to link important technical inputs to programmatic and operational outputs in a straightforward, traceable, and transparent manner. The framework provides an analytic structure that could be used to build understanding and communicate intent. It could be especially helpful for programs whose complex interactions between requirements, operational restrictions, and technology—rather than any individual issue—drive acquisition outcomes.

Trade Space

The use of trade studies in engineering is not new. It has a long history in the technical community and has now been formally adopted into the Department of Defense (DoD) acquisition decision-making process. Recent experiences suggest that the Services' trade-space tools are being used to inform their internal deliberations. However, several recent new-start proposals have been the subject of follow-on trade studies and amended AoA efforts, suggesting room for improvement. In particular, past trade studies have generally not been able to address high-level trades between competing design families (e.g., conventional helicopters vs. tilt-rotors), or affordability implications of design choices.

Schedule delays associated with follow-on analyses can be avoided if the trade study processes and analytical outputs are structured to support both user and oversight objectives. The outputs of IDA's DERIVE framework are constructed to achieve this goal by enhancing traceability and transparency of inputs, outputs, and decision-making.

Traceability

Traceability is used by systems engineers to manage technically complex endeavors by flowing down program objectives into discrete technical goals. Alternatively, students employ traceability to demonstrate to professors that they have a firm grasp of the nature of problems even if small errors are present in the analysis. Traceability can also be leveraged by the Services and program offices to demonstrate that they have rigorously analyzed the operational environment and have a firm understanding of the technical issues and programmatic consequences of a new program.

The DoD asked IDA to develop and demonstrate DERIVE on a generic infantry fighting vehicle (IFV). The results of that effort will be used below to illustrate how DERIVE's outputs are designed to foster traceability.

Creating traceability requires exposing the objectives of the program, how they relate to technical assumptions, and how the various elements interact to drive results. An output of the DERIVE process traces the desired capabilities to the commensurate technical inputs. shows how key performance and programmatic attributes can be mapped to specific technical requirements for an IFV.

Table 1. Performance and Technical Traceability Matrix

Performance		Specifications (Desires)	Analytical Implication
Force Protection	Ballistic	Trade space	Integral ballistic armor must be able to passively defeat ballistic threats.
	Explosive	Survive an X class of IED and a Y RPG	Supports 45 pounds/square foot (psf) of integral underbody armor and 95 psf of add-on EFP armor.
Passenger Capacity		Trade space	Interior volume scales based on human factors and number of passengers (32 cubic ft/person and 450 lbs/person).
Full Spectrum	Weight	Desire system to be reliable	Structure, engine, transmission, etc. must be sized to support add-on EFP armor.
	Power	Increased exportable power	Has a 50-horsepower generator for electrical power.
Timing		Field system quickly	Uses currently producible armor materials, engines, etc.
Transportability		Transportable by C-17	IDA-defined combat weight limited to 130,000 lbs and must fit inside compartment E of C-17.
Mobility		Speed of X up a grade of Y	Uses an Abrams-like track and has 20 horsepower/ton of engine power.
Lethality		Lethal to a similar class of vehicles	Has a manned turret. Reserved 2.1 tons for non-armored turret weight and 120 cubic feet of volume. Also, 2.5 tons for ammunition and fuel.
Electronics and Sensors			Has sensors/electronics similar to Abrams and Bradley.
General			Includes other fixed vehicle components (e.g., wiring, bolts, weld material). Weight allocated to these types of items is 2.5 tons.

Cross-referencing the technical assumptions and desired capabilities in a single, compact form provides two benefits. First, it allows the program developers to articulate clearly the user's goals and the technical requirements necessary to achieve those goals. Second, it allows the oversight community to understand the potential loss of capability if there are technical shortfalls during development.

Similarly, shows how cost traceability can be achieved. Various cost categories are mapped to the data sources and assumptions used in generating the cost estimate. This traceability matrix allows oversight organizations to qualitatively assess the riskiness and fidelity of the estimate.

Table 2. Cost Elements and Costing Assumptions and Data Sources

Cost Element	Description / Sources / Methodology
Hull/Frame	Cost estimating relationship depends on material type and weight. Assumed a buy-to-fly of 1.
Suspension, Engine, Transmission, Auxiliary Automotive, Integration, Assembly, Test, and Evaluation	Army Ground Vehicle Systems Bluebook (2006).
Add-on EFP armor	Estimated as cost per ton from budget data and publicly reported contract values.
Electronics/sensors	Estimated from President's Budget submissions for ground vehicle upgrade programs. Focused on sensors and electronic upgrades.
Contractor non-prime mission product cost elements	Estimated using historical contractor cost data reports. Applied as a multiplication factor on the prime mission product.
Support	Estimated using Selected Acquisition Reports. Applied as a factor on contractor costs.
Deflation/inflation rates and conversions	Joint Inflation Calculator (http://www.asafm.army.mil/offices/office.aspx?officecode=1400).

Finally, the logic used to estimate the costs and performance of the IFV trade space is described in Figure 1. In sum, the DERIVE framework helps program developers and the acquisition oversight community build a common understanding of the key technical, operational, and cost drivers of new capabilities being sought by the department.

- Determine the size of the box (volume under armor)
    - # dismounts and crew; soldier space claim
    - Interior mission equipment and auxiliary automotive space claim
- Determine the weight of the box
    - Front, side, rear, ballistic force protection; underbody and EFP protection
    - Areal density of protection technologies
    - Other - radios, seats, steering, soldiers, etc.
- Determine the weight and size of subsystems that move the box
    - Drivetrain, suspension, support structure
    - Engine track/tires based on mobility requirements – hp/ton, ground pressure, etc.
- Cost the system based on identified materials and components
    - Scale contractor and program costs
- Prune infeasible solutions
    - Impose constraints such as transportability weight restrictions

Figure 1. Outline of Process Used in Creating Infantry Fighting Vehicle Trade Space

Transparency

The DERIVE framework improves the transparency of the analyses supporting acquisition decisions. Figure 2 shows an output of the DERIVE framework for the IFV example. It enhances transparency by illustrating the entire trade space rather than a few point designs. Showcasing the full trade space demonstrates the thoroughness of the investigation and reduces the possibility of having to include additional cases. Also, instead of using a value function, the analysis simply highlights the desired point solutions and lists the rationale for the decision and the relevant trade-offs that were considered and accepted as part of the decision-making process. Showing trade space data, the rationale, and the resulting decision together serves to enhance trust, convey thoroughness, and reduce institutional friction.

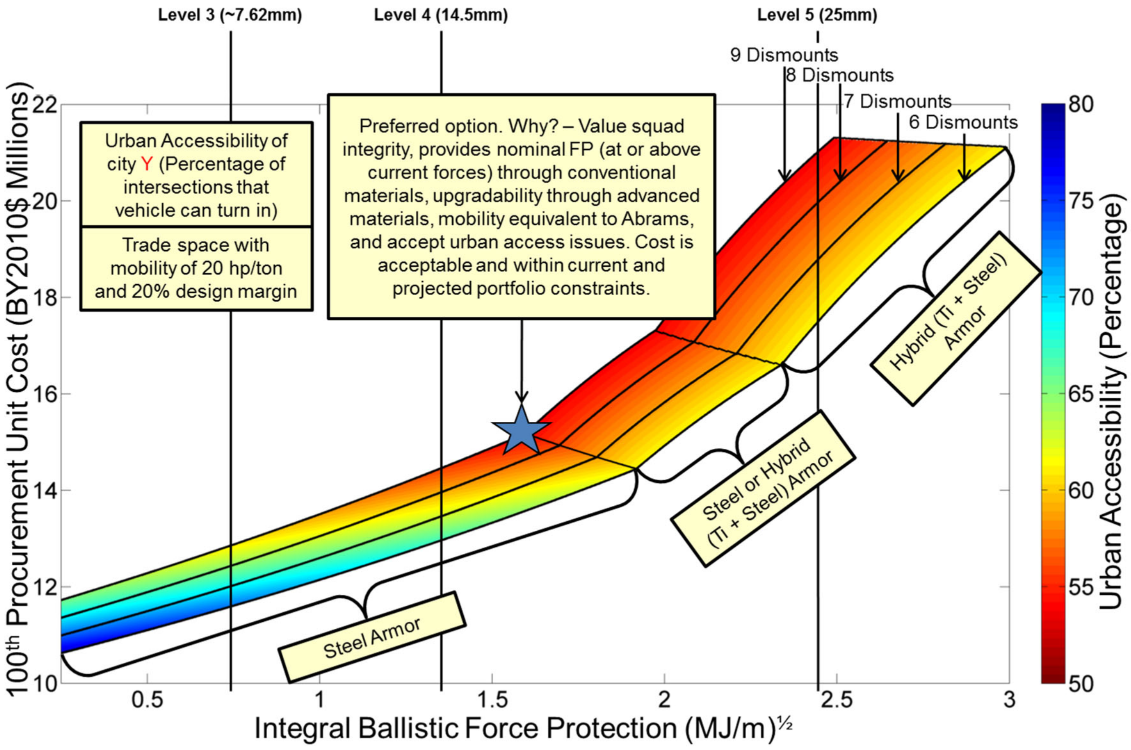

Figure 2. Infantry Fighting Vehicle Trade Space with Logic for Decision

The outputs from DERIVE also make certain difficult trades obvious. For example, it is clear from Figure 34 that no vehicle carrying six or more dismounts can provide both full urban trafficability and force protection level 3 or higher. If there is a mission need for well-protected fighting vehicles in urban environments, they will need to carry fewer personnel per vehicle. Similarly, force protection level 5 can only be obtained using advanced armors, with corresponding unit cost consequences.

Thought Experiment 1: Urban Counterinsurgency

Given mission need for a fighting vehicle that can maneuver in 90% of urban terrain and provide force protection level 3 or higher, what are the available options? Figure 2 shows that such a vehicle cannot carry very many people; the space claim of human passengers induces a positive feedback on required cubic feet, and thus on areal surface to be armored, and thus on weight. This has consequences for concepts of operations—if it is not possible to preserve squad integrity in urban environments while preserving force protection levels, either squads will need to be divided or force protection levels will need to be reduced. Either of these leads to changes in how the force will fight. They key is that exposing these issues early puts the warfighter in charge of making the decision of what they value, since they ultimately have to manage the consequences.

Thought Experiment 2: Optionally Manned Vehicles

Recent advances in remotely piloted vehicle technologies and artificial intelligence (AI)–enabled autonomy have increased interest in optionally manned vehicles—that is, vehicles that are typically operated as manned vehicles with a human driver, but can sometimes be operated as remotely piloted or even autonomous vehicles. What are the costs and benefits of optional manning? Under what circumstances would an optionally manned design be preferable to an unmanned design, or to a mixed fleet of manned and unmanned designs? We can use DERIVE to investigate these questions.

In general, the principal benefits of unmanned systems arise from the absence of those requirements related to the presence of human passengers. Human beings and their equipment are heavy; they occupy space; they require environmental conditioning and protection against threats. Unmanned systems can thus avoid the weight associated with humans, their equipment, additional armor, heating and air conditioning systems, air purification systems, doors, seats, visual displays, manual controls, and so forth. They can be smaller than manned systems, potentially able to operate in more confined spaces and with lower observability.

Optionally manned systems do not share these benefits. Instead, they incur all of the weight and space penalties of manned vehicles, plus additional requirements to support remote operation. This might include additional sensors, communications links, and onboard computational power. These added systems must also be configured so as not to interfere with manned operations—so that, for example, any cameras that provide the “driver’s view” for remote operation must not interfere with the driver’s sight lines during manned operations.

In the end, the business case for an optionally manned platform must rest on the mix of missions the system is envisioned for, and the concept of operations that would make a mixed fleet of manned and unmanned systems impractical. DERIVE could be used to quantify these trades, informing decision-makers about the operational and cost consequences of design choices and force mixes before committing significant resources.

Conclusion

DERIVE and similar approaches provide a framework that can be used to engage and improve acquisition outcomes. DERIVE fuses a variety of information sources (capabilities, operational, technical, and cost) to enable more thorough analyses in support of decision-making and to reduce friction between program developers and the acquisition oversight community. DERIVE can also serve to make fundamental trades more apparent to senior decision-makers, avoiding misunderstandings about what is feasible and focusing the discussion on the relevant warfighter values.

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