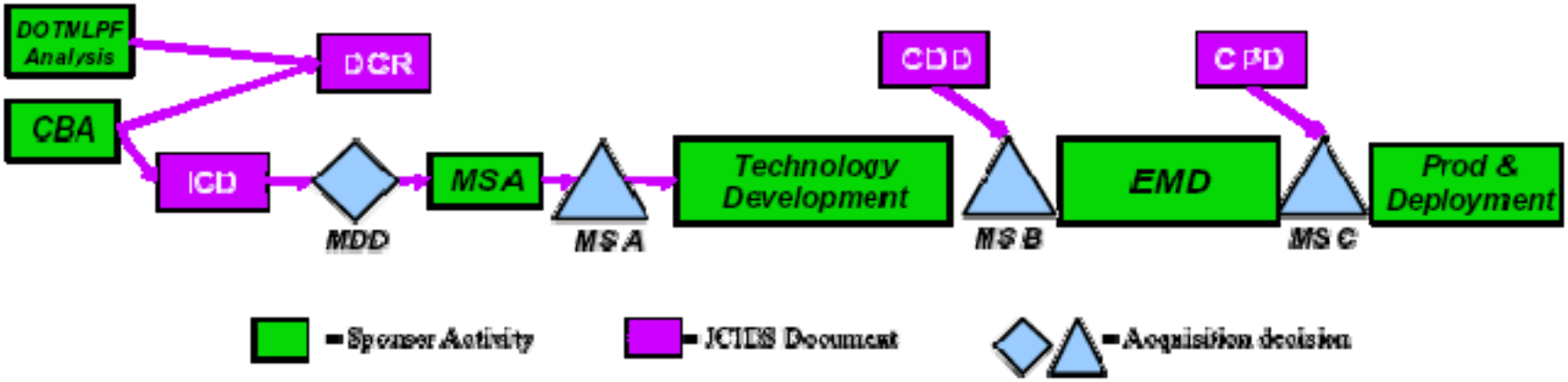
System Dynamics Modeling for Improved Knowledge Value Assessment: A Proof of Concept Study

David Ford Thomas Housel Thomas Housel John Dillard
Texas A&M University Naval Postgraduate School Naval Postgraduate School

Introduction and Context

- "Big A" Acquisition – initiated by JCIDS
  - Aligned with PPBES – Top Down
  - Needs/Requirements for battle "work"



JCIDS Process and Acquisition Decisions

Capability-Based Assessment

- **CONOPS are drivers**
- **DOTMLPF**
- **Often oriented upon costs (old "COEA")**
- **Analysis of (Materiel) Alternatives = BCA**

JROC-Approved Functional Capability Boards

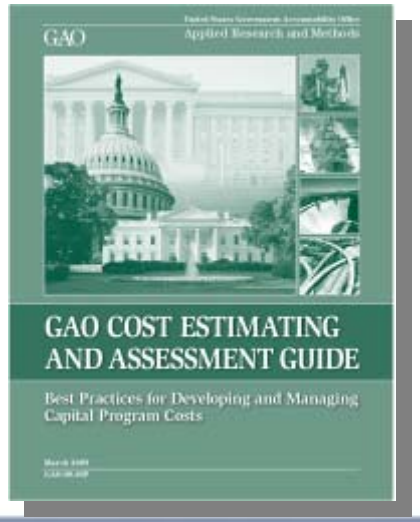
Name	Sponsor
Command & Control	USJFCOM
Battlespace Awareness	J-2
Logistics	J-4
Building Partnerships	J-5
Net-Centric	J-6
Force Application	J-8
Force Support	J-8
Protection	J-8

Valuation of Systems

- **Total Ownership Costs**
  - **Life Cycle Cost Estimate - all colors of money**
  - **Independent Cost Estimates**
- **Key Performance Parameters**
  - **Given Ops Mode Mission Summary Profile**
  - **Expected and Contingency scenarios**
- **Simulations to address uncertainty**
  - **Monte Carlo, Real options, Portfolio optimization, etc.**

Best "Investment" Choices

- **OMB relies upon accuracy and completeness of cost information**
  - **"… credible cost estimates are vital for sound management decision making and for any program or capital project to succeed."**
  - **Following guidelines in *GAO Cost Estimating and Assessment Guide* will help agencies meet most cost estimating requirements."**



Intrinsic Military Value

- **<u>Advanced Anti-armor Weapon System – Medium:</u>**
  - **3 AAWS-M Technical Approach Alternatives**
  - **Competitive Prototypes in TD Phase:**
    - **Laser Beam Rider**
    - **Fiber-Optic Guided**
    - **FLIR**
- **Laser won the COEA, but EMD SSEB chose the FLIR**
- ***Fire & Forget* was mostly about <u>Gunner Survivability</u>**

Q.: How can Program Mangers include diverse benefits in Analysis of Alternatives?

A.: The Knowledge Value Added (KVA) Methodology

- Measures values-added & costs of human and IT assets at sub-process level of operations.
- Uses common units of output to aggregate value-added subprocess operations into numerator of Benefit:Cost ratio
- Uses common units to aggregate subprocess costs into denominator of Benefit:Cost ratio

KVA Methodology Process Steps

1. **Identify core processes and sub-processes.**
2. **Establish common units and level of complexity to measure learning time** (knowledge surrogate).
3. **Calculate/estimate learning time to execute each sub-process. Include technology built into tools.**
4. **Designate operation sampling time period long enough to capture representative sample of the core processes' final output.**
5. **Describe benefits by multiplying learning time for each sub-process by number of times subprocess executes during sample period.**
6. **Calculate cost to execute subprocesses to determine process costs.**
7. **Calculate Return on Knowledge (ROK= Benefits or Revenues/Cost)** and ROI (ROK= Revenue-Cost/Cost).

KVA Limitations

- Estimates often from subject mater experts – limits number of alternatives that can be considered
- Program managers often must consider many alternatives

Q.: How can KVA estimates of ROK be improved to reflect more alternatives more accuracy?

An Approach to Improving KVA Estimates

- A systems dynamics simulation model of the subprocesses that add value and thereby generate benefits and costs
- KVA to combine subprocess benefits and costs into common units of measure
- Integrate for automatic generation of ROK for any alternative
- (Relatively easily, quickly, cheaply) simulate multiple alternatives and ROKs
- Analyze ROK for relative value-added
- Use simulation model to explain differences in ROKs

The current work sought to initially test this approach (a proof-of-concept study).

A System Dynamics Model of Mobile Weapons Use: Moving Weapons Sector

Core Process

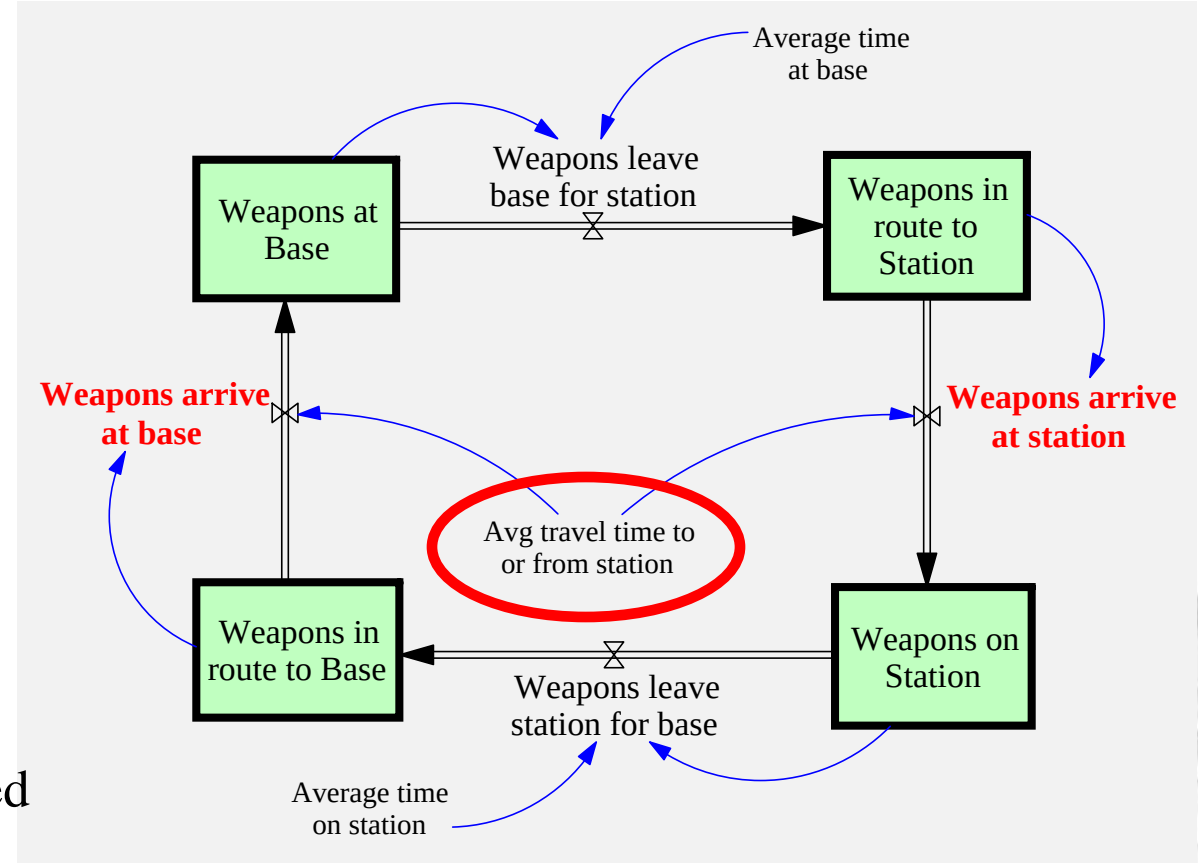
Mobile weapons fleet operations

Moving weapons to & from base & station is a **value-adding subprocess**

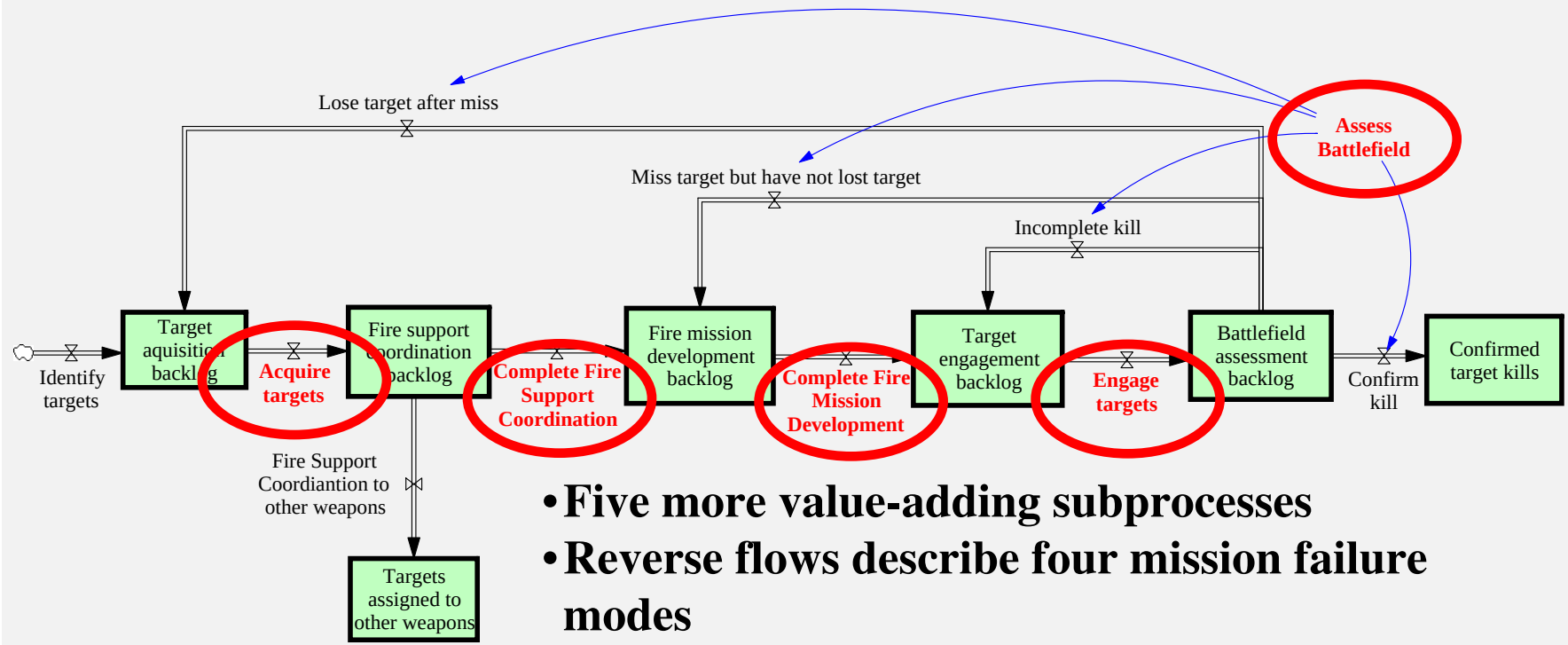
Common units of measure

Benefits: Time required to learn how to develop technologies and skills to move weapon

Costs: Average time required to move weapon



A System Dynamics Model of Mobile Weapons Use: Target Evolution Sector



<u>Weapon capabilities</u> and *environments* descriptors include:

- p(kill if hit) driven by (<u>payload</u> / *lethal payload*)
- p(hit) driven by (<u>dash speed</u> / *target speed*)
- p(not lose if miss) driven by (<u>range</u> / *target distance from base*)

Example Results: Return on Knowledge Ratios

Predator

- Model was calibrated to four existing weaponized UAV
- Simulated (sub)processes , core process, & KVA analysis

		Weaponized UAV			
		Predator	Reaper	Sky Warrior	X-47B
Subprocess Productivity	Acquire targets	377	377	377	377
	Fire support coordination	189	189	189	189
	Fire mission development	943	3122	1222	3962
	Move weapons	50	23	44	607
	Engage targets	5094	70761	15212	254736
	Battlefield assessment	377	377	377	377
	Weapon	705	907	954	1067

- KVA ratios are relative values for comparison across subprocesses

Example Model Use

- Hypothetical program to upgrade Predator UAV to engage opposing UAV targets
- KVA ROK that reflect overall performance improvement
- KVA ROK that reflect relative improvement in individual subprocesses

		Subprocess KVA ratios			Weapon System	
		Develop fire mission	Move weapons	Engage targets	KVA ratio	% Change from Base Case
	Predator Base Case					
Improvement Alternative	Increase fuel capacity 100%					
	Increase fuel capacity 50%					
	Increase Power plant 100% for payload					
	Increase Power plant 50% for payload					
	Redesign transmission for 100% faster dash speed					
	Redesign transmission for 50% faster dash speed					
	Increase Power plant 100% for dash speed					
	Increase Power plant 50% for dash speed					
	Reduce time at base 50%					
	Reduce time at base 100%					

Example Analysis of Alternatives:
Hypothetical Predator Upgrade Program

Reaper

- KVA-based AoA indicates that increasing fuel capacity 100% improved overall performance most (34% weapon improvement).
- If other acquisition constraints (e.g. available funding, approvals) are met AoA recommends this alternative.

Q.: How can the program manager best explain and justify this recommendation?

  - Increasing fuel capacity by 100% improves performance most by improving the "Develop fire mission" subprocess.
  - ***From simulation model analysis***, improvement is due to increasing range/target distance from base, which reduces targets lost if missed, increasing opportunities to retarget after misses.

- Analysis also identifies what subprocesses to monitor during development and operations to assure and verify that the forecasted improvements occur.

Conclusions

X-47B

Analysis of Alternatives based on an integrated System Dynamics / KVA model provides program management teams with several kinds of valuable information:

- Quantified measures of improvement that include benefits
- Overall system improvement estimates
- Subprocess improvement estimates
- Guidance for alternative selection in Analysis of Alternatives
- Help in justification of Analysis of Alternatives decisions
- Guidance for further investigation

Neither a System Dynamics model nor a KVA analysis alone can produce these improvements. Only by integrating System Dynamics and the KVA approach are the improvements above available.

Impacts on Practice

Sky Warrior

- More alternatives can be analyzed, therefore more robust AoA decisions
- Stronger AoA decision justifications
- More consistent AoA results - single, integrated model of operations and KVA.
- Better product performance baselines during acquisition

<u>Bottom Line:</u> Program management will select better alternatives. This will generate more effective and potentially cheaper materiel solutions.

Potential to improve CONOPS: Javelin case study:

- Operators surprised that range was twice of the weapon replaced
- Increased range initiated improvements to tactics, techniques, and procedures (ttp), i.e. IED
- Improved Javelin ttp can generate changes to strategies

Accurate forecasts of product subprocess performance (e.g. accuracy at longer range) can also be used to plan CONOPS improvements before product delivery.

Future Work

- Model specific acquisition program in support of its Analysis of Alternatives process – operationalize the approach tested here.
- Incorporate important uncertainties to generate distributions of KVA productivities and use in real options analysis
- Improve product life cycle management
  - Forecast performance and KVA ratios during acquisition
  - Compare forecasts with actual operations
  - Use results to improve the model fidelity with the system
  - Use improved model to analyze proposed changes or replacement of the system throughout its life cycle.
- Model and analyze portfolios of assets for improved portfolio management

Questions?
Comments?
Discussion?

Related Research

- FY07: Housel, *AEGIS Platform: Using KVA Analysis, Risk Simulation and Strategic Real Options to Assess Operational Effectiveness*
- FY08: Housel and Mun, *Potential Impact of Open Architecture on AEGIS Using KVA and Real Options Analysis*
- FY08: Housel, *Potential Impact of Collaborative and Three-dimensional Imaging Technology on SHIPMAIN*
- FY07: Dillard and Ford, *Modeling the Risks of Spiral Development*
- FY08: Dillard and Ford, *Modeling the Integration of Open Systems and Evolutionary Acquisition in DoD Programs*
- *National Research Council. Optimizing U.S. Air Force and Department of Defense Review of Air Force Acquisitions Programs. http://www.nap.edu/catalog/12673.html*