ROTORCRAFT TRADESPACE EXPLORATION INCORPORATING RELIABILITY ENGINEERING

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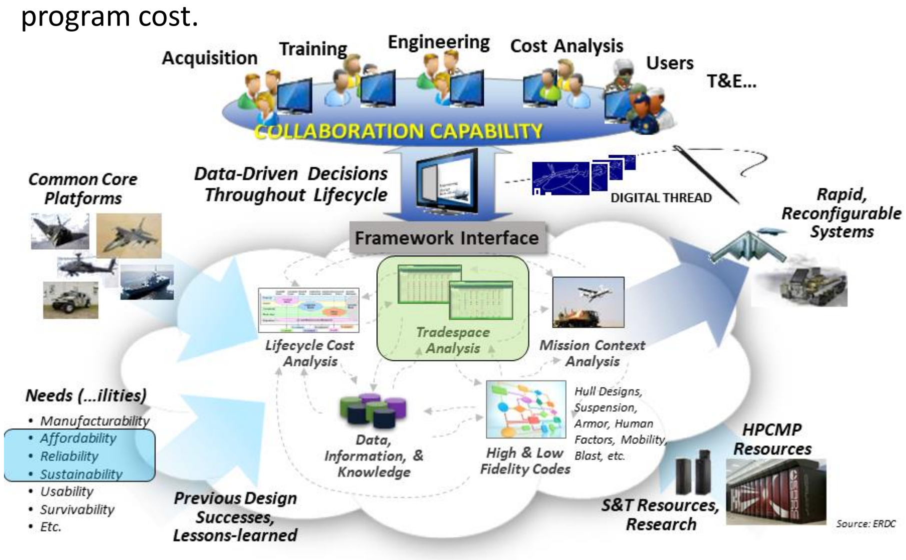
Abstract

- Tradespace analysis and exploration (TSE) is a focus area within the Department of Defense (DoD) Engineered Resilient Systems (ERS) initiative to produce trusted and effective solutions for a wide range of operational contexts.
- Most TSE tools do not explicitly consider the impact of reliability or related quantitative metrics that directly influence operation and support (O&S) costs over the lifecycle.
- This research proposes an approach to incorporate reliability engineering into TSE to improve consider operational effectiveness and suitability.

[2] Tradespace Exploration

- TSE methods offer a more systematic approach to assess alternative candidate designs.
- TSE tools provide environments for stakeholders and designers to explore system tradeoffs, considering existing and future technology.
- Emerging methods and tools will support acquisition modernization, but must also be attentive to factors underlying program cost.



[3] Reliability Modeling

- Expresses mean time between essential function failure (MTBEEF) of subsystem i (M_i) as function of reliability investment (γ_i)

$$M_i(\gamma_i) = \frac{1}{1 - \mu_{d,i} + \dfrac{C_{0,i}\mu_{d,i}}{\dfrac{1}{\lambda_{A,i}} + \dfrac{\mu_{b,i}F^{-1}\left(\dfrac{C_{0,i}e^{\frac{C_{O,i}+CV_i^2\gamma_i}{\mu_{b,i}}}}{\mu_{b,i}}\right)}{\lambda_{B,i}}}}$$

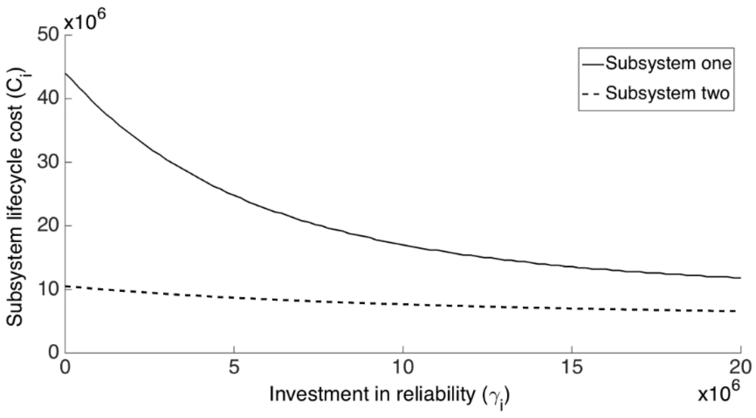
- Maximizing fleet size (η) through reliability improvement

$$\eta = \max\left\lfloor \frac{B - \sum_{i=1}^{n}\gamma_i}{\sum_{i=1}^{n}\left(c_i\left(1 + \left\lfloor \frac{L}{M_i(T_i)} - \varepsilon \right\rfloor\right)\right)} \right\rfloor$$

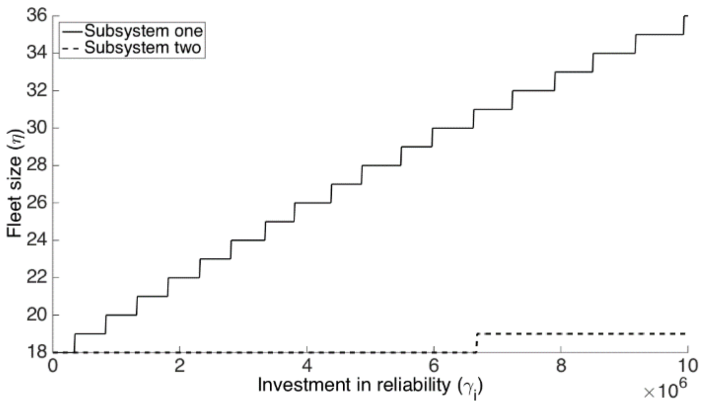
where,

- μ_d – Average success rate of corrective actions
- C_0 – Cost to operate test, analyze, and fix (TAAF)
- μ_b – Cost increments incurred by corrective action
- F^{-1} – Inverse of Lambert W-function
- CV – Coefficient of variation in B-mode failures
- λ_A – Rate of A-mode failures
- λ_B – Rate of B-mode failures
- B – Total budget
- c_i – Cost to replace subsystem i once
- L – Length of system lifecycle

[4] Equations Illustrated



Impact of reliability investment on lifecycle cost



Marginal utility of reliability investment

[5] Example

Parameter	Interpretation	No Reliability Investment	Optimal Reliability Investment
M_1	MTBEFF of subsystem 1	90.92	444.66
M_2	MTBEFF of subsystem 2	142.86	270.39
P_1	Number of part replacements	219	44
P_2	Number of part replacements	139	73
C_1	Subsystem lifecycle cost	44,000,000	9,000,000
C_2	Subsystem lifecycle cost	10,500,000	5,550,000
C_s	System lifecycle cost	54,500,000	14,550,000
η	Fleet size	18	62
	Fleet Cost	981,000,000	902,100,000

- Fleet size of $\eta = 62$ without reliability investment: \$3.379 billion (=62×54,500,000) >300% of original budget.

[6] Future Research

- More realistic cost modeling assumptions informed by DoD.
- Assess fleet size and cost sensitivities to model assumptions.
- Consider multiple quantitative "-ilities" such as reliability, availability, and maintainability, and impact on affordability.

References

1. Kendall, F. Better Buying Power 3.0 White Paper, OUSD (AT&L), September 19, 2014.
2. U.S Government Accountability Office, "DEFENSE MANAGEMENT: DOD Needs Better Information and Guidance to More Effectively Manage and Reduce Operating and Support Costs of Major Weapon Systems, GAO-10-717, July 2010. Available at: www.gao.gov/assets/310/307408.pdf
3. Long, E., Forbes, J., Hees, J., and Stouffer, V., "Empirical Relationships between Reliability Investments and Life-Cycle Support Costs," LMI Report SA701T1, 2007.
4. Richards, M., "Multi-Attribute Tradespace Exploration for Survivability," Massachusetts Institute of Technology, PhD dissertation, Cambridge, MA, June 2009.
5. Spero, E., Avera, M., Valdez, P., and Goerger, S., "Tradespace Exploration for the Engineering of Resilient Systems," Procedia Computer Science, Vol. 28, 2014, pp. 591-600.
6. Crow, L., "On tracking reliability growth," In Proc. Annual Reliability and Maintainability Symposium, 1975, pp. 438-443.
7. Ellner, P., and Hall, J., "AMSAA maturity projection model based on Stein estimation," Army Materiel Systems Analysis Activity Aberdeen Proving Ground, TR-751, MD, 2004.

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