A Generalized Options-Based Approach to Mitigate Perturbations in a Maritime Security System-of-Systems

Nicola Ricci, Adam M. Ross, Donna H. Rhodes
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Atlanta GA
What is the Paper about?

The more a word was used in the paper, the bigger
Outline

• Motivation

• Generalized Approach
  – Options Generation Process
  – Options Evaluation Process
    • Metrics for Evaluation of Options
  – Options Selection Process

• Discussion & Next Steps
MOTIVATION
The world in which Systems Engineers practice has undergone a significant metamorphosis over the past twenty years

• **Advent of the internet** → great increase in amount of resources available
• **Information travels at the speed of light** → instantaneous communication
• **High-speed computation** → Performance of very complex analyses

**Systems are subject to highly dynamic operational environments**

- A multitude of **exogenous uncertainties** can impact a system
  — *Geo-political shifts* (e.g., policy/regulation changes)
  — *Disruptive technologies* (e.g., advent of GPS)
  — *Market variations* (e.g., price & demand variations)

- **Unanticipated shifts in stakeholder needs**
  — Change of *preferences*
  — Change of *mission objectives*

- **Many options-based approaches for risk management**
  — Conceptually attractive, but with challenging effort and data requirements
  — May not be appropriate or difficult to apply to system of interest

If focused solely on the present state of the world, engineers may encounter the problem of designing systems that may not be well positioned in the future, forced to operate in contexts for which they were not conceived, and delivering capabilities no longer of interest to stakeholders.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Perturbations introduce the <strong>RISK</strong> of interruption of value delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution</td>
<td>In the design of the system, include “<strong>options</strong>” that reduce the risk of interruption of value delivery</td>
</tr>
</tbody>
</table>
**Options**

**Problem**

Perturbations introduce the **RISK** of interruption of value delivery

**Solution**

In the design of the system, include **“options”** that reduce the risk of interruption of value delivery

---

An **option**, in general, is the ability to execute a design feature that will change or prevent change to the system in order to respond to perturbations and avoid interruption of value delivery

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**GENERALIZED OPTION**

- **Resistance Option (RO)**
  - Path Inhibitor (PI)
  - Resistance Mechanism (RM)

- **Change Option (CO)**
  - Path Enabler (PE)
  - Change Mechanism (CM)

**Having __________ allows you to __________**

(path variable) (mechanism)

X = bad state

A, B = acceptable state

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The socio-technical environment in which such systems are architected (and will eventually operate) can change rapidly, and therefore, in most cases, the identification and evaluation of options must occur in a timely manner.

Q1. How should we generate a list of interesting options?

Q2. How should we evaluate them? What metrics should we use?

Q3. How should we select the best options among those evaluated?
GENERALIZED APPROACH

- Resist + Change
- Breath of Consideration
- Scalability w.r.t. Effort and Time
High-level Operational Needs Statement:

Provide *maritime security* for a particular littoral Area of Interest (AOI)

Stakeholders want a *system (SoS)* that:

- Detects, identifies and boards boats entering AOI
- Is capable of carrying out *search and rescue* missions upon request

Design variables and levels have already been defined…

**Form**
- Hermes
- Shadow
- Prop Plane
- Helicopter
- Manned Patrol Boat
- Satellite Relay
- Land Sensors

**ConOps**
- Tech Level Upgrade
- Info Sharing Use
- Task Assignment
- Geographic Segmenting
- Operators Per UAV
- Workforce Buffer
- Authority
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- Tech Level Upgrade
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**BUT…**

We expect perturbations to occur and undermine the SoS value-delivery

It is now desired to find options that can be added to this current design space
Inputs to Approach

Value Sustainment

Survivability

Design Principles

• Preemption
• Avoidance
• Defensive Posture
• Deflection
• Hardness
• Heterogeneity
• Failure Mode Reduction
• Fail-safe
• Modification
• Containment
• Stable Intermediate Instances

... (Richards)

Disturbances

Serious Attack Occurrence
Asset Unavailable
Information Attack
Storm
Tsunami

Shifts

Technology Level
Workforce Availability
Info Sharing Availability
Boat Arrival Rate
Pirate Percentage
Smuggler Percentage
Search and Rescue
Jamming (Bad Com)

Perturbations

desiredilities

design principle

path enabler/inhibitor

change/resistance mechanism

Option
Generate a extensive list of options to be considered
# DP to Perturbation Mapping

## 1. DP to perturbation mapping

**Brainstorming activity:** Perturbation-mitigating instantiations of design principles are considered options for systems engineers to include in the system design.

Generate as many options as possible

### 3 steps in this process

1. **Generate as many options as possible**

### VALUE SUSTAINMENT

<table>
<thead>
<tr>
<th>DESIGN PRINCIPLES</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
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</tbody>
</table>

**Option**

Having **_______** allows you to **_______**

(path variable) (mechanism)

**Desiredilities**

**Design principle**

**Path enabler/inhibitor**

**Change/resistance mechanism**

**Option**
# VALUE SURVIVABILITY FOCUS

## Design Principles

<table>
<thead>
<tr>
<th>Value Survivability</th>
<th>Serious Attack</th>
<th>Asset Unavailable</th>
<th>Storm (decreased situational awareness)</th>
<th>Tsunami (SoS seriously damaged)</th>
<th>Information Attack</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prevention</strong></td>
<td>Only use boats for intercept</td>
<td>Buy spares</td>
<td>Water repellant layer on windshield</td>
<td>Bring assets back to base promptly</td>
<td>Higher altitude</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Vary flight paths and speeds</td>
<td></td>
<td>Enhanced control system</td>
<td>Move to non-affected region</td>
<td></td>
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<tr>
<td><strong>Concealment</strong></td>
<td>Higher Altitude</td>
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<tr>
<td><strong>Deterrence</strong></td>
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<tr>
<td><strong>Preemption</strong></td>
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</tr>
<tr>
<td><strong>Avoidance</strong></td>
<td>Vary flight paths and speeds</td>
<td></td>
<td>Fast planes</td>
<td>Move to non-affected region</td>
<td>Vary flight paths and speeds</td>
</tr>
<tr>
<td><strong>Defensive Posture</strong></td>
<td>Only use boats for intercept</td>
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<td>Bring assets back to base promptly</td>
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<tr>
<td><strong>Deflection</strong></td>
<td>Decoys</td>
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<tr>
<td><strong>Authentication</strong></td>
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<td><strong>Reserves</strong></td>
<td>Spares</td>
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<tr>
<td><strong>Hardness</strong></td>
<td>Armor</td>
<td></td>
<td>More stable structure</td>
<td></td>
<td>Double authentication</td>
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<tr>
<td><strong>Redundancy</strong></td>
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<tr>
<td><strong>Margin</strong></td>
<td>Increase wing coefficient of lift (fly on one wing)</td>
<td>Use UAVs that are able to change role (detection/identification, etc.)</td>
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<tr>
<td><strong>Heterogeneity</strong></td>
<td></td>
<td>Multi-role asset</td>
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<td>Satellite and direct links</td>
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<tr>
<td><strong>Failure Mode Reduction</strong></td>
<td></td>
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<td></td>
<td>Distribute/decentralize authority</td>
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<tr>
<td><strong>Decentralization</strong></td>
<td>Geographical distribution</td>
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<td>UAV flight path change</td>
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<tr>
<td><strong>Stable Intermediate Instances</strong></td>
<td>Training personnel in multiple tasks/irregular ops</td>
<td>Go to pre-validated design</td>
<td></td>
<td>Use only radar towers for detection</td>
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<tr>
<td><strong>Replacement</strong></td>
<td>Spares</td>
<td>Replace unavailable asset with one at disposal</td>
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<td>Train personnel for prompt vehicle replacement</td>
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<td><strong>Repair</strong></td>
<td>Trained repair crews</td>
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<tr>
<td><strong>Adaptation</strong></td>
<td>Change detection UAV to interception UAV</td>
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<th>DESIGN PRINCIPLES</th>
<th>DISTURBANCES</th>
<th>ASSET UNAVAILABLE</th>
<th>STORM (DECREASED SITUATIONAL AWARENESS)</th>
<th>TSUNAMI (SOSS SERIOUSLY DAMAGED)</th>
<th>INFO ATTACK</th>
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<td>Prevention</td>
<td>Buy spares</td>
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<td>Mobility</td>
<td>Vary speeds</td>
<td>Layer on windshield</td>
<td>Enhanced control system</td>
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<td>UAV flight</td>
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<td>Change</td>
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</tbody>
</table>

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**Hardness**

- Armor

**Decentralization**

- Distribute authority

**Value Survivability**

- Serious Attack

**Design Principles**

- Only use boats for intercept
- Buy spares
- Water repellant layer on windshield
- Bring assets back to base promptly
- Higher altitude
- Enhanced control system
- Move to non-affected region
- Fast planes
- Multi-role asset
- Multi-role asset
- Satellite and direct links
- Geographical distribution
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- Go to pre-validated design
- Use only radar towers for detection
- Training personnel in multiple tasks/irregular ops
- Train personnel for prompt vehicle repair
- Train personnel for prompt vehicle replacement
- Training personnel in multiple tasks/irregular ops
- Spares
- Go to pre-validated design
- Use UAVs that are able to change role (detection/identification, etc.)
- Enhanced control system
- Training personnel in multiple tasks/irregular ops
### Change Option

<table>
<thead>
<tr>
<th>Change Mechanism</th>
<th>Path Enabler</th>
<th>Latent Path Enabler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra Intercept UAV</td>
<td>Contract with Aircraft Supplier</td>
<td>Extra Cameras</td>
</tr>
<tr>
<td>Adding Vehicle</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Change Task Assignment</td>
<td>C5</td>
<td>-</td>
</tr>
<tr>
<td>Change Geographic Segmentation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Change Number of Operators per UAV</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Go back to Pre-Validated Set</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Change Authority distribution</td>
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<td>-</td>
</tr>
<tr>
<td>Add extra features</td>
<td>C21</td>
<td>C22</td>
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### Resistance Option

<table>
<thead>
<tr>
<th>Resistance Mechanism</th>
<th>Path Inhibitor</th>
<th>Latent Path Inhibitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overstaffing</td>
<td>R1</td>
<td>-</td>
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<tr>
<td>Change Trajectory of Flight</td>
<td>-</td>
<td>R2</td>
</tr>
<tr>
<td>Asset resistance to attacks</td>
<td>-</td>
<td>R5</td>
</tr>
<tr>
<td>Disperse around AOI</td>
<td>-</td>
<td>R6</td>
</tr>
<tr>
<td>Multiple Assets perform Same Function</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rapidly Recover against Asset Loss</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Distract Hostile Attacks</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Training Personnel for Multiple Tasks</td>
<td>R16</td>
<td>-</td>
</tr>
</tbody>
</table>

2. Discern among the four entries of the matrix and sort into lists.
3. Match compatible PEs and CMs (and PIs and RMs) appropriately in order to generate a comprehensive list of change (and resistance) options.
2. Discern among the four entries of the matrix and sort into lists

3. Match compatible PEs and CMs (and PIs and RMs) appropriately in order to generate a comprehensive list of change (and resistance) options

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<tr>
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<td>Extra Interception UAV</td>
<td>Contract with Aircraft Supplier</td>
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<tr>
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<td>C1</td>
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<table>
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<th>Path Inhibitor</th>
<th>Latent Path Inhibitor</th>
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<tbody>
<tr>
<td></td>
<td>Workforce Buffer</td>
<td>Armor on UAV</td>
</tr>
<tr>
<td>Overstaffing</td>
<td>R1</td>
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In order to be able to differentiate among them
• Optionability
• Number of Uses
• Cost
• Perturbation Coverage
Evaluate Options: Optionability

**Optionability:** the number of options that are connected to a particular path enabler/inhibitor

(Mikaelian)

A highly “optionable” path enabler/inhibitor is a convenient one to include as it can enable different change/resistance mechanisms, in turn used to mitigate against perturbation.
### Evaluate Options: Uses and Cost

**Number of Uses**: *the number of times a particular option can be employed* (related to its PE/PI).

**Example**:
- C4 (adding vehicle via spares) can be used a number of times (N) and has a high cost
- C17 (going back to pre-validated set using an already established pre-validation process) can be used for the entire existence of the SoS and has no cost

<table>
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<tr>
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**Resistance Option**: *uses [1, N, ∞]*

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**Cost**: *approximate cost of including the option in the system architecture*.

- Qualitative assessment carried out with the aid of domain experts
- Assessment for relative comparison

**Precision of the evaluation can vary widely, subject to**:
- Expertise of people performing the task
- Level of detail they are willing to go into
Evaluate Options: Perturbation Coverage

Assess Probability and Impact of Perturbation

Considerations in this step:
- A serious attack has a very low probability of occurrence, but it could have lethal consequences on the SoS.
- Boat arrival rate is likely to change, and it can have moderate impacts on SoS.

Fineness of the grid depends on level of competency of assessor and whether analytical tools are actually employed.

---

**Perturbation**

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**SHIFT**

- Tech Level: low medium medium high
- Workforce Availability: medium medium low
- Info Sharing Availability: medium low
- Boat Arrival Rate: medium low high
- Pirate Percentage: medium low
- Smuggler Percentage: low medium
- Search & Rescue: medium low
- Jamming: high medium
- Serious Attack: low medium
- Asset Unavailable: medium high
- Storm (decreased situational awareness): medium high
- Tsunami (SoS seriously damaged): medium low
- Information Attack: medium high

**DISTURBANCE**

- High-Medium-Low
- Low-Medium-High

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Evaluate Options: Perturbation Coverage

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Perturbation coverage matrix, in which it is possible to identify (a) most perturbation-mitigating options and (b) most commonly mitigated perturbations
Evaluate Options: Perturbation Coverage

Assess whether or not perturbation is covered by option

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<th>Info Sharing Availability</th>
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Σ 5 9 6 13 22 14 21 9 18 20 12 23 13
Evaluate Options: Perturbation Coverage

Assess whether or not perturbation is covered by option

### Perturbation

<table>
<thead>
<tr>
<th>Perturbation</th>
<th>Tech Level</th>
<th>Workforce Availability</th>
<th>Info Sharing Availability</th>
<th>Boat Arrival Rate</th>
<th>Pirate Permanence</th>
<th>Smuggler Permanence</th>
<th>Search &amp; Rescue</th>
<th>Jamming</th>
<th>Serious Attack</th>
<th>Asset Unavailable</th>
<th>Storm (decreased situational awareness)</th>
<th>Tsunami (SoS seriously damaged)</th>
<th>Informatio Attack</th>
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<table>
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<tr>
<td>R17</td>
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</tr>
</tbody>
</table>

Σ 5 9 6 13 22 14 21 9 18 20 12 23 13

#### C2

Adding Vehicle – Contract with Aircraft Supplier

**most perturbation-addressing change option**

#### Tsunami

**Most commonly addressed perturbation**

(this is because its impact on the system is large and many things can be done to partially mitigate against it)
Evaluate Options: Perturbation Coverage

Perturbation Coverage: proxy for risk (of disrupting value delivery) attenuation.

v1 (simple) →

\[ PeC(option) = n \]  \hspace{2cm} (1)

\( n \) is number of perturbations covered by option

v2 (more complex) →

\[ PeC(option) = \sum_{i=1}^{n} P_i^\gamma I_i \]  \hspace{2cm} (2)

\( n \) is number of perturbations covered by option
\( i \) is the given perturbation considered
\( P_i \) is the assessed probability for perturbation \( i \) to occur
\( I_i \) is the impact on value delivery caused by occurrence of perturbation \( i \)
\( \gamma \) is the risk aversion factor for assessment of perceived probability

*Note*: PeC can be normalized against the sum of \( P_i^\gamma I_i \) across all perturbations

This metric is computed for a given option. Higher scores are considered to be better.
Generate Options → Evaluate Options → Select Options

Downselect list of desired options from initial list
There are other analytical tools that can be used to inform final selection decision.
For evaluation, four different metrics are considered:

- **OPTIONABILITY**: the number of options a path enabler/inhibitor is linked to.
- **NUMBER OF USES**: how many times can a path enabler/inhibitor be used.
- **COST**: the cost of acquiring and using a particular path enabler/inhibitor.
- **PERTURBATION COVERAGE**: metric that takes into account impact and probability of perturbations covered by path enabler/inhibitors when paired with change/resistance mechanism.

For selection criteria, two tools will be developed:

- **VISUALIZATION TOOLS**: look at different metrics at once.
- **ANALYTICAL TOOLS**: PC vs. cost tradespace exploration.

Final list of options to consider for:

1. Direct inclusion into system (if time is a concern)
1. Model and simulation for more detailed analysis and better informed decision
DISCUSSION & NEXT STEPS
Final Remarks and Important Assumptions to Address

- The approach is a first order attempt to tackle a problem that is very broad!

- The assessment of certain metrics, such as perturbations’ probability and impact, as well as cost, strongly depends on the level of knowledge and expertise of the people involved in the evaluation task.

- The perturbation coverage quantification problem is not a simple one.
  - First, options do not usually mitigate the full impact of a perturbation. They often mitigate a portion of the total damage a perturbation causes.
  - Considerations related to the lifetime of a perturbation and option utilization timing ought to be made in order to incorporate partial damage coverage in the analysis.

- It is important that one be able to consider the approximate number of occurrences of a perturbation through time as well. This way, a dynamic analysis of perturbation coverage could be performed.
  - Throughout the approach presented, this issue was tackled only by the number of uses (NU) metric.
Next Steps

- Exploration of the **dynamics** of the PeC vs. Cost tradespace using Number of Uses metric, as options are executed over time

- Delineation of risk attenuation metric for a portfolio of options

- General portfolio analysis, inspired by financial portfolio theory (Markowitz), could be performed to identify **PORTFOLIOS** of options that, through diversification:
  - Maximize PeC, given a desired Cost.
  - Minimize Cost, given a desired PeC.

- Inclusion of all types of costs associated with an option: i.e., acquisition cost, carrying cost, execution cost, disposal cost, as well as switching costs for portfolios of options

- Consideration of the **upside** of uncertainty (i.e., *opportunity*)

Overall, the approach:
- Enables the **identification of options** that can improve system’s performance, as well as lifecycle properties (e.g., flexibility, robustness).
- Is **scalable** with regard to effort required, time invested, and data availability needs (when using mostly qualitative assessments).
- Contributes to Systems Engineering **risk-benefit** techniques, and provides **structure** to dealing with uncertainty in modern-day systems.
QUESTIONS?

**GENERATION**
- Identify perturbation sources using a structured approach.
- Prioritize options based on risk.
- Generate a comprehensive list of candidate options.

**EVALUATION**
- Preliminary metrics:
  - **OPTIONABILITY**: The number of options a path enabler or path inhibitor is based on.
  - **NUMBER OF USES** $> (n + r)$: How many times can a path enabler or path inhibitor be used.
  - **COST**: The cost of acquiring and using a particular path enabler.
  - **PERTURBATION COVERAGE**: The number of perturbations covered by path enablers/inhibitors when paired with change resistance mechanisms.

- Formula: $P_c = \sum P/I$

**SELECTION**
- Using visualization aids and tools, evaluate and select options to consider for the system.
- Consider trade-offs and align with system requirements.

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1. **PERTURBATIONS**: “Unintended state change in a system’s design, context, or stakeholder needs that could jeopardize value delivery”

- **Shift**: “Long-lasting changes in design (i.e., form and operations), context, or needs [that could affect value delivery]” (Ross, Rhodes, and Hastings 2008)

- **Disturbance**: “Finite-(short) duration changes of a system’s design, context, or needs [that could affect value delivery]” (Richards 2009; Mekdeci 2012)

1. **DESIGN PRINCIPLES**: “Guiding thoughts [for design] based on empirical deduction of observed behaviour or practices that prove to be true under most conditions over time” (Wasson 2006)

- They serve to help intentionally create desirable properties in a system.
Inputs to Approach

- Value Sustainment
  - Changeability
    - Flexibility
    - Susceptibility
  - Survivability
    - Vulnerability
    - Resilience
  - Robustness
    - Robustness
    - Changeability

- Design Principles
  - Targeted Modularity
  - Integrability
  - Scalability
  - Decentralization
  - Redundancy
  - Architecture changeability
  - Reconfigurability
  - Margin
  - Slack
  - Proper Documentation
  - Leverage Ancestors
  - Mimicry
  - Disruptive Architectural Overhaul
  - Resourceful Exaptation

Note: DPs in red are common to all three
Generating Change/Resistance Options from DPs

Using design principles to generate path variables and change mechanisms is an exercise in creative design, leveraging domain expertise and historical examples.

<table>
<thead>
<tr>
<th>Ility</th>
<th>Design Principle</th>
<th>Change/Resistance Mechanism</th>
<th>Path Enabler/Inhibitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survivability</td>
<td>Concealment</td>
<td>Operating UAVs at higher altitudes</td>
<td>Long range communication</td>
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<tr>
<td>Survivability</td>
<td>Hardness</td>
<td>Ability to absorb a hit</td>
<td>Armor</td>
</tr>
<tr>
<td>Evolvability</td>
<td>Targeted Modularity</td>
<td>Easily upgrading and adding new sensors/sensor technology</td>
<td>Modularized sensor set</td>
</tr>
<tr>
<td>Evolvability</td>
<td>Decentralization</td>
<td>Updating constituent without disturbing other SoS constituents</td>
<td>Dispersed communication network</td>
</tr>
<tr>
<td>Survivability</td>
<td>Heterogeneity</td>
<td>Using multiple means for detection/interception</td>
<td>Selection of multiple different UAVs that can perform similar functions</td>
</tr>
</tbody>
</table>

Example flow (notional, not implemented in this analysis)

Using design principles to generate path variables and change mechanisms is an exercise in creative design, leveraging domain expertise and historical examples.
Generate “Resistance Mechanism” and Path Inhibitor Set

2. Discern among the four entries of the matrix and sort into lists

<table>
<thead>
<tr>
<th>Change Mechanism</th>
<th>Resistance Mechanism</th>
<th>Path Enabler</th>
<th>Path Inhibitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Add vehicle</td>
<td>• Overstaffing</td>
<td>• Multi-role asset</td>
<td>• Extra personnel</td>
</tr>
<tr>
<td>• Change the function of an Asset</td>
<td>• Vary velocity of flight</td>
<td>• Extra UAV capable of performing interception</td>
<td>• Armor on UAVs</td>
</tr>
<tr>
<td>• Disperse around AOI</td>
<td>• Increase armor</td>
<td>• Central authority</td>
<td>• Strong software architecture</td>
</tr>
<tr>
<td>• Change velocity and position of a specific asset</td>
<td>• Have multiple constituent systems perform the same task</td>
<td>• Port authority boats</td>
<td>• High-altitude UAV</td>
</tr>
<tr>
<td>• Add extra feature to asset</td>
<td>• Training personnel for multiple tasks</td>
<td>• Satellite</td>
<td>• Decoys</td>
</tr>
<tr>
<td>• Go back to pre-validated set</td>
<td>• Have multiple constituent systems perform the same task</td>
<td>• Acquiring faster UAV</td>
<td>• Extra feature for Constituent systems</td>
</tr>
<tr>
<td>• Change task assignment</td>
<td>• Training maintenance crew</td>
<td>• Contracts with aircraft suppliers</td>
<td>• Extra constituent systems</td>
</tr>
<tr>
<td>• Change authority distribution</td>
<td>• Oversizing SoS</td>
<td>• Sea planes</td>
<td>• Spares</td>
</tr>
<tr>
<td>• Change geographic segmentation</td>
<td>• Distract hostile attacks</td>
<td>• Spares</td>
<td>• Versatile Constituent System</td>
</tr>
<tr>
<td>• Change # of operators per UAV</td>
<td>• Rapid recovery against asset/component loss</td>
<td>• Pre-validation process</td>
<td>• Better control system</td>
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<td>• …</td>
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### Change Options

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Path Enabler</th>
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<tr>
<td>1 Adding vehicle</td>
<td>Extra interception UAV</td>
</tr>
<tr>
<td>2 Adding vehicle</td>
<td>Contract with aircraft supplier</td>
</tr>
<tr>
<td>3 Adding vehicle</td>
<td>Workforce buffer</td>
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<tr>
<td>4 Adding vehicle</td>
<td>Spares</td>
</tr>
<tr>
<td>5 Change task assignment</td>
<td>Extra interception UAV</td>
</tr>
<tr>
<td>6 Change task assignment</td>
<td>Extra cameras</td>
</tr>
<tr>
<td>7 Change task assignment</td>
<td>Sea planes</td>
</tr>
<tr>
<td>8 Change task assignment</td>
<td>Dispersed Com network</td>
</tr>
<tr>
<td>9 Change task assignment</td>
<td>Multi-role asset</td>
</tr>
<tr>
<td>10 Change geographic segmentation</td>
<td>Sea planes</td>
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<td>11 Change geographic segmentation</td>
<td>Long Range UAV</td>
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<tr>
<td>12 Change geographic segmentation</td>
<td>Dispersed Com network</td>
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<tr>
<td>13 Change geographic segmentation</td>
<td>Satellite Relay</td>
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<td>14 Change number of operators per UAV</td>
<td>Pre-validation process</td>
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<td>15 Change number of operators per UAV</td>
<td>Workforce buffer</td>
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<td>16 Change number of operators per UAV</td>
<td>Spares</td>
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<tr>
<td>17 Go back to pre-validated set</td>
<td>Pre-validation process</td>
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<tr>
<td>18 Go back to pre-validated set</td>
<td>Multi-role asset</td>
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<tr>
<td>19 Change authority distribution</td>
<td>Central authority</td>
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<td>21 Add extra features to assets</td>
<td>Contract with aircraft supplier</td>
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<tr>
<td>22 Add extra features to assets</td>
<td>Extra cameras</td>
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### Resistance Options

<table>
<thead>
<tr>
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<th>Path Inhibitor</th>
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<tbody>
<tr>
<td>1 Overstaffing</td>
<td>Workforce buffer</td>
</tr>
<tr>
<td>2 Change trajectory of flight</td>
<td>Better UAV control system</td>
</tr>
<tr>
<td>3 Change trajectory of flight</td>
<td>Long range signal transmitter</td>
</tr>
<tr>
<td>4 Change trajectory of flight</td>
<td>High altitude UAV</td>
</tr>
<tr>
<td>5 Asset resistance to attacks</td>
<td>Armor on UAV</td>
</tr>
<tr>
<td>6 Disperse around AOI</td>
<td>Better UAV control system</td>
</tr>
<tr>
<td>7 Disperse around AOI</td>
<td>Long range signal transmitter</td>
</tr>
<tr>
<td>8 Disperse around AOI</td>
<td>UAV swarm</td>
</tr>
<tr>
<td>9 Multiple assets perform same function</td>
<td>Spares</td>
</tr>
<tr>
<td>10 Multiple assets perform same function</td>
<td>Multi-role asset</td>
</tr>
<tr>
<td>11 Multiple assets perform same function</td>
<td>UAV swarm</td>
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<tr>
<td>12 Rapidly recover against asset loss</td>
<td>Spares</td>
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<tr>
<td>13 Rapidly recover against asset loss</td>
<td>Pre-validation process</td>
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<tr>
<td>14 Rapidly recover against asset loss</td>
<td>Multi-role asset</td>
</tr>
<tr>
<td>15 Distract hostile attacks</td>
<td>Decoy</td>
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<tr>
<td>16 Training personnel for multiple tasks</td>
<td>Workforce buffer</td>
</tr>
<tr>
<td>17 Training personnel for multiple tasks</td>
<td>Pre-validation process</td>
</tr>
</tbody>
</table>

3. Match compatible PEs and CMs (and PIs and RMss) appropriately in order to generate a comprehensive list of change (and resistance) options.
Select Options: Analytical Tools

**Perturbation Coverage vs. Cost tradespace**

Can be thought as trading **risk** *(inverse of PeC)* versus **benefit** *(inverse of Cost)*

Exploration of the **dynamics** of the Perturbation Coverage vs. Cost tradespace using Number of Uses metric

- Must have knowledge of approximate number of occurrences of a perturbation
Select Options: Visualization Tools

Legend
- = COVERED
- = NOT COVERED

- ASSET UNAVAILABLE
- BOAT ARRIVAL RATE
- SMUGGLER %

- INFO SHARING
- WORKFORCE AVAILABILITY
- INFO ATTACK
- PIRATE %
- JAMMING

- STORM
- TECH LEVEL
- TSUNAMI
- SERIOUS ATTACK
- S&R