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Original title on 712 A/B: Effects Assessments

Revised title: Probability of Effects for Systems

Presented in (input and Bold one): (WG_X, CG__, Special Session ____, Poster, Demo, or Tutorial):

This presentation is believed to be:
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<table>
<thead>
<tr>
<th>Title and Subtitle</th>
<th>Probability of Effects for Systems</th>
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</thead>
<tbody>
<tr>
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<td>Science Applications International Corporation 6825 Pine St. MS B-100 Omaha, NE 68106</td>
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</table>
\[ P_{\text{Facility}}^n = 1 - \prod_{k=1}^{\infty} (1 - P_{\text{E}, n+1}^k) \]
Problem

- Problem:
  - How do you calculate the probability of getting the effect you want against a system?
  - What else is important when you impose an effect?

- Why do we care?
  - We ultimately seek to compare Courses of Action (COAs)
Key Definitions

- **Actions** are applied to **objects**
- Actions **modify** the object’s **functions**, thereby producing an **effect**
- The extent of the effect depends on the **vulnerability** of the object to the action
- The overall effect depends upon the physical and functional **relationship** of the objects, sub-objects, and their functions
Top Level Methodology

1. What do you want to accomplish?
2. Which objects are pertinent, and what do they do?
3. How are they put together?
4. How are they vulnerable to what you want to do, and to which actions?
5. What’s the math?
6. What else is important besides effectiveness?
7. What are the uncertainties?
1. Specifying Desired Effects

• Essentially, the commander’s intent
  – Defined by his value structure¹

• Can specify a desired effect at any level in the system

• Specify effect, not action²
  – The desired functional capability or behavior to impact
  – Extent (facilities or individuals) over which effect is desired
  – Extent of effect
  – Start time
  – Minimum duration

• What constraints or other evaluation metrics are important?

¹ “Value Focused Thinking For Organizing Effects-Based Planning” Phipps and Gallagher 27 Aug 04.
² “Precisely Defining Effects for Effects-Based Operations (EBO)” Gallagher and True, 19 Aug 04.
2. ID Pertinent Objects & What They Do

Object (Physical) View

Function View
Breakdown to Targetable Object

• In general, objects are comprised of subobjects
• The object at the level of an appropriate action is the “targetable object”
  – Breakdown below this level is not necessary
• Examples of different targetable objects:
  – HEMP attack on entire power net (level n)
  – Nuclear attack on C3 node (level n+1)
  – GBU 28 attack on a generator (level n+3)
  – CNA attack on a single computer file (level n+6)
• In general, more “nuanced” actions require more breakdown

We seek the functional and physical relationships between targetable objects
Functional Analysis Mini-Example: UGC$^2$

1.0 Provide Message Content
- People
- Computers
- S/W

2.0 Provide Communications
- Radios
- Telephone
- Bicycle
- People

3.0 Provide Connectivity
- Antennas
- Satellites
- Landline
- Roads

Allocate to:
- People
- Computers
- S/W
- Radios
- Telephone
- Bicycle
- People
- Antennas
- Satellites
- Landline
- Roads

Derived Requirements:
- People: Protection, HVAC, food, water, sewer
- Computers: Protection, power
- Radios: Protection, power
- HVAC: Protection, power, water

But functional descriptions are abstract
Example UGC² Functional Diagram

1.1 Make Decision
   - 1.2 Compose Message
   - 1.3 Format Message

or

2.1 Provide Landline Comms
   - 2.2 Provide Emergency Comms
   - 2.3 Provide HF Comm
   - 2.4 Provide SHF Comm

3.1 Provide Landline Connectivity
   - 3.2 Provide Roads
   - 3.3 Provide HF Connectivity
   - 3.4 Provide SHF Connectivity

4.1 Provide Peacetime Power
   - 4.2 Provide Backup Power
   - 4.3 Provide Emergency Power

or

4.4 Distribute Power
   - 4.5 Provide HVAC
3. How are Objects Put Together?

Desired Effect + Functions + Object Allocations ⇒ Critical Hybrid Diagram

E.g., For a desired effect of interruption:
## 4. ID Object Vulnerabilities to Actions

**AKA: Action-Object-Effect Linkage Analysis**

<table>
<thead>
<tr>
<th>Targetable Object</th>
<th>Level</th>
<th>Function</th>
<th>Desired Effect</th>
<th>Vulnerability</th>
<th>Action and Mechanism</th>
<th>P_e</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGC3 Facility</td>
<td>N</td>
<td>Provide command decisions</td>
<td>Halt decisions for &gt;72 Hrs</td>
<td>Crush facility</td>
<td>Nuclear overpressure</td>
<td>P_e,1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Destroy contents</td>
<td>Conventional penetrator fragmentation</td>
<td>P_e,2</td>
</tr>
<tr>
<td>1.0 People</td>
<td>N+1</td>
<td>Provide decisions</td>
<td>Halt decisions for &gt;72 Hrs</td>
<td>Crush</td>
<td>Nuclear overpressure</td>
<td>P_e,3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Perforate</td>
<td>Conventional penetrator fragmentation</td>
<td>P_e,4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intimidate</td>
<td>Nearby nuclear blast</td>
<td>P_e,5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Persuade</td>
<td>Leaflets</td>
<td>P_e,6</td>
</tr>
<tr>
<td>2.0 Comm System</td>
<td>N+1</td>
<td>Provide communications</td>
<td></td>
<td>Not targetable at this level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 SHF Radio</td>
<td>N+2</td>
<td>Provide high bandwidth real time communications</td>
<td>Halt output for &gt;72 hours</td>
<td>Turn off</td>
<td>CNA virus attack</td>
<td>P_e,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nuclear EMP burnout</td>
<td>Nuclear EMP burnout</td>
<td>P_e,8</td>
</tr>
<tr>
<td>1.2 Bicycle</td>
<td>N+2</td>
<td>Provide comms when all electronic means gone</td>
<td>Halt use for &gt;72 hours</td>
<td>Area denial</td>
<td>Nuclear ground burst radiation</td>
<td>P_e,9</td>
</tr>
</tbody>
</table>
What is $P_e$ at the Targetable Element Level?

- Ideally, $P_e$ derived from a math model that includes the effect desired, vulnerability, and action mechanism
  - E.g., $P_d$ from PDCALC or JMEM
- $P_e$ for many action-object-effect mechanisms must be developed
- $P_e$ must be consistent
  - $P_e$ of an lower level effect must be consistent with the overall effect desired
  - E.g., can’t include “halt for >72 hours” with “alter message content for >72 hours”
5. Determine the Math

Probability of Effect Expectancy Defined

**Action** → **Object** → **Effect**

\[
\text{Probability of Arrival (PA}_n) \times \text{Probability of Effect (P}_{e,n}) = \text{Probability of Effect Expectancy (PE}_n)
\]
Math Example: Interrupting a UGC$^2$ Facility

Stopping any of these n+1 level functions stops the n level facility function. Thus the Effect Expectancy at the n$^{th}$ level is:

$$PE_{n+1} = 1 - \prod_{k=1}^{z} (1 - PE_{n+1}^k)$$

where k refers to the attacked critical path objects

However, some functions are redundant systems that are not directly targetable at the n+1 level; e.g.:

- Power
- Comms
- Connectivity

The math is generalizable to other desired effects, but the hybrid diagram will probably be different
Targeting Redundant Systems

All these n+2 level objects must be addressed to affect the n+1 level function. So….

\[ \text{PE}_{n+1}^{\text{level}} = \prod_{k=1}^{z} \text{PE}_{n+2}^{k} \]

\[ \text{PE}_{\text{Power}}^{n+1} = \text{PE}_{\text{Batteries}}^{n+2} \cdot \text{PE}_{\text{Commercial}}^{n+2} \cdot \text{PE}_{\text{Backup Gen}}^{n+2} \]

\[ \text{PE}_{\text{Connectivity}}^{n+1} = \text{PE}_{\text{HF}}^{n+2} \cdot \text{PE}_{\text{Road}}^{n+2} \cdot \text{PE}_{\text{T-1}}^{n+2} \cdot (1 - [(1 - \text{PE}_{\text{SHF}}^{n+2}) \cdot (1 - \text{PE}_{\text{Satellite}}^{n+2})]) \]

Series component in a parallel subsystem
Including Intelligence Uncertainties

<table>
<thead>
<tr>
<th>Power Source</th>
<th>Prob Used</th>
<th>Prob We Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>$P_{\text{comm, used}}$</td>
<td>$P_{\text{comm, know}}$</td>
</tr>
<tr>
<td>Backup gen</td>
<td>$P_{\text{gen, used}}$</td>
<td>$P_{\text{gen, know}}$</td>
</tr>
<tr>
<td>Batteries</td>
<td>$P_{\text{batt, used}}$</td>
<td>$P_{\text{batt, know}}$</td>
</tr>
</tbody>
</table>

**Key Intelligence Collection Drivers**

\[
PE_{\text{Power}}^{n+1} = (1 - P_{\text{comm, use}} (1 - P_{\text{comm, know}} \cdot PE_{n+2}^{\text{commercial}})) \cdot (1 - P_{\text{gen, use}} (1 - P_{\text{gen, know}} \cdot PE_{n+2}^{\text{gen}})) \cdot (1 - P_{\text{batt, use}} (1 - P_{\text{batt, know}} \cdot PE_{n+2}^{\text{batteries}}))
\]
Limitations

• Actions and their effects assumed to be independent
  – Synergy between actions not included
    ✓ Similar to current approach when allocating multiple weapons to a target – you don’t take credit for prior damage
    ✓ Conservative assumption

• Non-parametric treatment of effectiveness
  – Does not return a function of effect vs. action
  – Must specify a different effect and recalculate $P_e$
    ✓ Similar to $P_d$ (severe damage) and $P_d$ (moderate damage)

• Approach non-dynamic (so far)
Where Does It End…?  

….at a level consistent with the targetable objects that will give the effect desired.
6. What Else is Important?

- Imposing one’s will has consequences:
  - Collateral effects
  - Unintended effects
  - Costs
- These consequences are part of the COA evaluation and comparison process; they are part of the “effect”
- Which consequences are important are tied to the Commander’s value structure
The Effects Array

• Introduce the Effects Array at the $n^{th}$ level:

$$EA_n = \{P_{e,n}, PA_n, PE_n, \text{collateral effects, costs, other value-related issues, .....}\}$$

• Represents the probability the desired effect at the $n^{th}$ level is obtained, and the associated consequences and/or resultant effects
# Deriving the Effects Array

<table>
<thead>
<tr>
<th>Targetable Element (Object)</th>
<th>Level</th>
<th>Function</th>
<th>Desired Effect</th>
<th>Vulnerability</th>
<th>Action and Mechanism</th>
<th>Pe</th>
<th>PA</th>
<th>Collateral Casualties</th>
<th>Air Crew Losses</th>
<th>Cost to Rebuild</th>
<th>BDA</th>
<th>Other??</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 People</td>
<td>n+1</td>
<td>Provide decisions</td>
<td>Halt decisions for &gt;72 hrs</td>
<td>Crush</td>
<td>Nuclear overpressure</td>
<td>0.99</td>
<td>0.9</td>
<td>$10^3$</td>
<td>4</td>
<td>$10^7$</td>
<td>9</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Perforate</td>
<td>Conventional penetrator fragmentation</td>
<td>0.7</td>
<td>0.83</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>4</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intimidate</td>
<td>Nearby nuclear blast</td>
<td>0.3</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Persuade</td>
<td>Leaflets</td>
<td>0.1</td>
<td>1.0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>?</td>
</tr>
</tbody>
</table>

**Effects Vector Components**

- **Pe**
- **PA**
- **Collateral Casualties**
- **Air Crew Losses**
- **Cost to Rebuild**
- **BDA**

- **Other??**

- Estimates derived from modeling, SMEs, WAGNERs, astrological tables, and chicken bones

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**Key points:**

- The effects array is meaningful only in the context of what the desired effect is
- You can only compare arrays that result in the same effect
- Arrays can represent multiple (i.e., aggregated) COAs, but their components ($PE_n$ and consequence terms) must represent that fact
7. Estimating Uncertainties

- Most measurable parameters are uncertain
- Uncertainty is closely associated with risk assessment – a key “commander’s value”
- Key uncertainties:
  - Statistical uncertainty inherent in probabilistic estimates
  - Intelligence
  - Weapon system performance
  - BDA
  - Modeling errors, assumptions, limitations
- The effects vector should include an uncertainty estimate with every term; e.g.:
  \[ \mathbf{E} \text{A}_n = \{0.9 \pm 0.1, \ 4 \pm 2, \ 10^3 \pm 10\%, \ 10^7 \pm 50\%, \ \text{etc.}\} \]
  \( (\mathbf{P} \text{E}_n) \) (air crews) (collateral) (costs)
Summary

- Use VFT techniques to determine desired effects at the various levels of objects and functions, and to define other important constraints and metrics
- Use functional analyses techniques from systems engineering to analyze target systems
- Use vulnerability analysis to link effects, objects, and actions, and to derive $P_e$
- Use a hybrid of functional and object relationship representations to derive the “mathematical effect chain” for the effect desired
- Include all relevant effects and uncertainties into an “Effects Vector” for COA comparison