A Dynamic Conceptual Model to Explore Technology-Based Perturbations to a Complex System: The Land Force

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See also ADM001929. Proceedings, Held in Sydney, Australia on July 8-10, 2003., The original document contains color images.
Outline - we will present:

– The problem of trying to enhance a complex system like the Land Force with technology

– A conceptual model of the Land Force and technological change

– A means of gaining semiquantitative insights

– Application examples:
  – Which items are more important for technology insertion?
  – What broad areas of research should we undertake?
  – For a specific technology, what strategy should we adopt?
The Problem

- The Land Force system is complex and comprises:
  - People and organisations
  - Equipment and formations
  - Specialist tasks
  - The environment
- How do we best apply technology to enhance this complex system?

THE PROBLEM → POSSIBILITIES → SOLUTIONS

FOCUS OF THIS WORK
The Conceptual Model: Elements

- **Skills** (the hows) that the Army needs to do the job
- A high level **measure** and how it is achieved for each skill
- An anisotropic **influence diagram** that links variables where position in the diagram has meaning
- A **connectivity** that links higher level goals, contributory measures and technology based factors
- **Critical and high pay-off components**
- **Semiquantitative numerical values**
- **Interactions** between skills that lead to synergisms and antagonisms
Army as a System Descriptors

- Engagement (E)
- Information collection (I)
- Sustainment (S)
- Communication (C)
- Protection (P)
- Movement (M)
- Decision Making (D)

*(self explanatory titles)*

Generic influence diagram

Areas that we have no control over

Number of actions

Number of blue entities

Environment terms

Red terms

Number of actions required

High level goal

Efficiency of process

Technology terms

Links to other skills

Devolve to primary, secondary, tertiary measures etc

Identify areas where we can influence through technology

If we perturb these - what happens?

(+) (+) (+)

(+/-) (+/-) (+/-)

(+/-)

(+) (+/-)

(+) (+/-) (+/-) (+/-) (+/-)

(feedback)
Example for “Engagement”

**Technology Based Variables**

- **Red Weapon Capability**
  - (+) Effectiveness of Red Fire Power
  - (+) Number of Blue Forces Providing Fire
  - (+) Red Freedom of Action

- **Blue Fire Power**
  - (+) Volume of Red Fire Power
  - (+) Blue Loss Rate
  - (+) Number of Red Targets
  - (+) Blue Safety
  - (+) Blue Positioning

- **Blue Combat Sustainability**
  - (+) Blue Targeting Capability
  - (+) Blue Weapon Capability
  - (+) Blue Fire Power
  - (+) Red Vulnerability

- **Primary Positive Feedback Loop**
  - (+) Blue Targeting Capability

- **Secondary Negative Feedback Loop**
  - (-) Red Vulnerability

- **Protection**
  - (+) Red Fire Power

- **Movement**
  - (+) Available Supply
  - (+) Usage Rate

- **Sustainment**
  - (+) Blue Targeting Capability

- **Information Collection**
  - (+) Blue Targeting Capability

- **Decision Making**
  - (+) Blue Targeting Capability
Results for “Engagement” - Technology Based Variables (TBV)

- **High pay-off** - leads to many points in the diagram
  - “blue targetting capability”
- **Critical** - leads directly to a primary or secondary measure
  - *none for “engagement”*
- **Less important**
  - “blue safety”
  - “blue positioning”
  - “usage rate”
  - “blue weapon capability”
What is the current value of our capability?

If we have a 4 point scale for each skill, eg for “engagement”

- $E_4$: very high effectiveness
- $E_3$: high effectiveness but deficiencies in some cases
- $E_2$: moderate effectiveness with deficiencies in several areas
- $E_1$: limited effectiveness

then we have a scale to judge technological capability in the form:

$$E_e I_i S_s C_c P_p M_m D_d$$

Method - we assess the value of each TBV according to this scale, and apply weightings – high and critical pay-off worth twice the others

We can propose a current “capability description” of:

- $E_{1.6} I_{2.3} S_{2.3} C_{2.6} P_{1.5} M_{2.3} D_{1.3} \rightarrow E_2 I_2 S_2 C_3 P_2 M_2 D_1$
- ie we have a measurable (but subjective) baseline
Perturbations to the current value – synergisms and antagonisms

- If we increase the capability of each of these Technology Based Variables, what is the effect on the “System”?  
- NB changes may be good (synergism) or bad (antagonism)  
- Level 1 - within the same skill  
  - high pay-off and critical are factored more than the others  
- Level 2 - between the skills  
- Determined through the requirements and impacts  
  - NB these tend to mirror each other but this is done to ensure that everything is covered
Example - pay-off matrix for engagement (impacts shown)

<table>
<thead>
<tr>
<th></th>
<th>E</th>
<th>I</th>
<th>S</th>
<th>C</th>
<th>P</th>
<th>M</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>blue safety (Ea)</td>
<td>++(B)</td>
<td>-(R)</td>
<td></td>
<td></td>
<td>+(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>blue positioning (Eb)</td>
<td>++(B)</td>
<td>-(R)</td>
<td></td>
<td></td>
<td>-(R)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>usage rate (Ec)</td>
<td>+(B)</td>
<td>-(R)</td>
<td>-(B)</td>
<td></td>
<td>-(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>blue targeting capability (Ed)</td>
<td>++(B)</td>
<td>-(R)</td>
<td>-(R)</td>
<td>+/- (B)</td>
<td>-(R)</td>
<td>-(R)</td>
<td>+(B)</td>
</tr>
<tr>
<td>blue weapon capability (Ee)</td>
<td>+(B)</td>
<td>-(R)</td>
<td>+(B)</td>
<td>-(R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of blue force providing fire (Ef)</td>
<td>++(B)</td>
<td>-(R)</td>
<td>-(B)</td>
<td>-(B)</td>
<td>+(B)</td>
<td>-(B)</td>
<td></td>
</tr>
</tbody>
</table>

++(B) has a large positive effect on the blue force
-(R) has a smaller negative effect on the red force
Diversion

- The Army as a System model is based on perceptions of the effectiveness and feasibility of combinations of core skills.

  We might question the ability of two sides that have equivalent equipment to both attain \( E_4 \) and \( P_4 \)

  - Unstopppable weapons and totally protected targets?

  We also know what has “worked” in the past

- An accompanying paper at this conference (Boswell, Curtis, Dortmans and Tri) will discuss a related piece of work that employs Field Anomaly Relaxation and historical analysis to identify reasonable combinations of skills, and the use of Agent Based Distillations to play these out
Applications

- *Example 1: (requirements pull):*
  - Where do we most need technology?

- *Example 2: (technology push):*
  - Which technology should we research to give best pay-off?

- *Example 3: (comparative analysis)*
  - Which option do we choose?
Example 1 - if we globally enhanced all TBVs in each skill what would be the system effect?

<table>
<thead>
<tr>
<th></th>
<th>new blue state</th>
<th>new red state</th>
<th>sum of raw score differences from initial state</th>
<th>sum of raw score differences between blue and red</th>
</tr>
</thead>
<tbody>
<tr>
<td>no change</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>E</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>E₁I₂S₂C₂P₁M₂D₁</td>
<td>1.0</td>
<td>2.2</td>
</tr>
<tr>
<td>I</td>
<td>E₂I₃S₂C₂P₂M₂D₂</td>
<td>E₁I₂S₂C₂P₂M₂D₁</td>
<td>1.9</td>
<td>2.5</td>
</tr>
<tr>
<td>S</td>
<td>E₂I₂S₃C₂P₃M₂D₁</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>C</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>P</td>
<td>E₂I₂S₃C₃P₂M₂D₁</td>
<td>E₁I₂S₂C₂P₂M₂D₁</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td>M</td>
<td>E₂I₂S₃C₂P₂M₂D₁</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>D</td>
<td>E₂I₂S₂C₂P₂M₂D₂</td>
<td>E₂I₂S₂C₂P₂M₂D₁</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>all</td>
<td>E₄I₃S₄C₃P₃M₄D₃</td>
<td>E₁I₂S₂C₂P₁M₂D₁</td>
<td>11.2</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Protection technologies followed by information collection and sustainment technologies seem to offer the best pay-off
Example 2 - which of the future technologies identified in the NATO 2020 study are more promising?

<table>
<thead>
<tr>
<th>Technology</th>
<th>New Blue State</th>
<th>New Red State</th>
<th>Sum of raw score</th>
<th>Differences from initial state</th>
<th>Differences between blue and red</th>
</tr>
</thead>
<tbody>
<tr>
<td>no change</td>
<td>E₂₁₂S₂₂C₃P₂M₂D₁</td>
<td>E₂₁₂S₂₂C₃P₂M₂D₁</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>precision attack</td>
<td>E₂₁₂S₃₂C₂P₂M₂D₂</td>
<td>E₁₁₂S₂₂C₃P₁M₂D₁</td>
<td>1.5</td>
<td>2.1</td>
<td>0.6</td>
</tr>
<tr>
<td>sensing, information fusion &amp; digitisation</td>
<td>E₂₁₃S₃₂C₂P₂M₃D₃</td>
<td>E₁₁₂S₂₂C₃P₁M₂D₁</td>
<td>5.3</td>
<td>6.3</td>
<td>1.0</td>
</tr>
<tr>
<td>non-lethal weapons</td>
<td>E₂₁₂S₂₂C₃P₂M₂D₁</td>
<td>E₂₁₂S₂₂C₃P₂M₂D₁</td>
<td>not amenable to analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>robotics</td>
<td>E₃₁₃S₃₂C₂P₂M₃D₁</td>
<td>E₁₁₂S₂₂C₃P₁M₂D₁</td>
<td>3.8</td>
<td>4.7</td>
<td>0.9</td>
</tr>
<tr>
<td>simulation</td>
<td>E₂₁₂S₂₂C₃P₂M₂D₂</td>
<td>E₂₁₂S₂₂C₃P₂M₂D₁</td>
<td>0.8</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>modular systems</td>
<td>E₂₁₂S₃₂C₂P₂M₃D₁</td>
<td>E₂₁₂S₂₂C₃P₂M₂D₁</td>
<td>0.8</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>all</td>
<td>E₃₁₃S₄₂C₃P₃M₄D₃</td>
<td>E₁₁₂S₂₂C₃P₁M₂D₁</td>
<td>8.4</td>
<td>8.9</td>
<td></td>
</tr>
</tbody>
</table>

Sensing etc and robotics are best singles and overall it is a balanced program. Simulation comes out poorly as training issues are not in the original model.
Example 3 - which is the best way to exploit hybrid engines?

- Two options:
  1. Reduce the weight and increase range
  2. Increase firepower and protection
- Results:
  - Option 1: new Blue $E_2I_2S_3C_3P_2M_3D_1$
    
    new Red $E_1I_2S_2C_3P_2M_2D_1$
    
    enhancement to blue = 2.8
    differential blue-red = 2.9
  - Option 2: new Blue $E_3I_2S_3C_3P_2M_3D_1$
    
    new Red $E_1I_2S_2C_3P_2M_2D_1$
    
    enhancement to blue = 3.6
    differential blue-red = 4.5
Summary

- This is a semiquantitative method to gain *insights* into possible directions of technology insertion.
- Although we have used this for Land Force capability development it could be used in many areas.
- Importantly the technique is “solution” free as it concentrates on the generic “what is needed” not “how we do it now”.