Investigating Relationships and Semantic Sets amongst System Lifecycle Properties (Ilities)

Olivier L. de Weck, Adam Ross, Donna Rhodes
MIT Engineering Systems Division
deweck@mit.edu

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What are the “Illities”?

• Complex Engineering Systems live for decades or centuries
• The *ilities* are desired properties of systems, such as flexibility or maintainability (usually but not always ending in “ility”) that often manifest themselves after a system has been put to initial use. These properties are not the primary functional requirements of a system’s performance, but typically concern wider system impacts with respect to time and stakeholders than embodied in those primary functional requirements
  – Most research has looked at the Illities – one at a time.

• Research Questions:
  – What are the most prevalent or most important (top 20) Illities in the scientific literature and in common use?
  – What are the relationships amongst Illities? Do they form semantic sets?
  – Can we use this information for better system design?

• Approach:
  – Method 1: Prevalence Analysis using Literature/Web Survey
  – Method 2: Human Cognitive Experiments using Hierarchy Exercise
Prevalence Analysis

Journal Articles (thousands) vs. Google Hits (millions)

- Scientific Articles
- Internet

Common usage is leading academic interest is leading

Journal Articles from Compendex/Inspec Databases between 1884 and 2010
Cumulative number of journal articles where an Ility appears in the title or abstract of the paper (1884-2010). Source: Inspec and Compendex, accessed via Engineering Village [http://www.engineeringvillage.com](http://www.engineeringvillage.com)

Fig. 4-2
1: Relationships amongst the Illities

- Made well with high quality in early life
- Performs well over time under uncertainty
- Easy to change system configuration
- Scalability, extensibility, modularity, agility
- Usability, sustainability, resilience, robustness, flexibility

Network structure with classical engineering illities at the core and newer emerging ones at the periphery based on co-occurrence

Line weight reflects strength of relationships

Source: web keyword 2-tupel correlation analysis, August 2010

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2: Human Experiments with Hierarchy

- Humans have deep, but possibly varied, semantic notions of a hierarchy of Ilities
  - Elicit means-ends-hierarchy through direct elicitation and group discussion and interviews
  - Two rounds
    - **Round 1**: 4 groups with 2-4 members each. Find parent-child relationships. Describe means → ends relations
    - Interviews
    - **Round 2**: Revise group findings based on inputs from other groups at the end of round 1
      - Constructed combined means-ends hierarchy

12 experienced system designers and researchers were presented with a list of 15 ilities similar to this one:

<table>
<thead>
<tr>
<th>Ility Name</th>
<th>Definition (“ability of a system…”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>adaptability</td>
<td>to be changed by a system-internal change agent with intent</td>
</tr>
<tr>
<td>agility</td>
<td>to change in a timely fashion</td>
</tr>
<tr>
<td>changeability</td>
<td>to alter its operations or form, and consequently possibly its function, at an acceptable level of resources</td>
</tr>
<tr>
<td>evolvability</td>
<td>design to be inherited and changed across generations (over time)</td>
</tr>
<tr>
<td>extensibility</td>
<td>to accommodate new features after design</td>
</tr>
<tr>
<td>flexibility</td>
<td>to be changed by a system-external change agent with intent</td>
</tr>
<tr>
<td>interoperability</td>
<td>to effectively interact with other systems</td>
</tr>
<tr>
<td>modifiability</td>
<td>to change the current set of specified system parameters</td>
</tr>
<tr>
<td>modularity</td>
<td>degree to which a system is composed of modules (not an ability-type ility)</td>
</tr>
<tr>
<td>reconfigurability</td>
<td>to maintain its component arrangement and links reversibly</td>
</tr>
<tr>
<td>robustness</td>
<td>to change its level and/or set of specified parameters in the context of changing system external and internal forces</td>
</tr>
<tr>
<td>scalability</td>
<td>to maintain the current level of a specified system parameter</td>
</tr>
<tr>
<td>survivability</td>
<td>to minimize the impact of a finite duration disturbance on value delivery</td>
</tr>
<tr>
<td>value robustness</td>
<td>to maintain value delivery in spite of changes in needs or context</td>
</tr>
<tr>
<td>versatility</td>
<td>to satisfy diverse needs for the system without having to change form (measure of latent value)</td>
</tr>
</tbody>
</table>

What is their relationship? Do they form a hierarchy?
Combined Means to Ends Hierarchy

**Value Robustness**

- Robustness
- Changeability
- Agility
- Versatility

**Median Level Ordering**

- Survivability
- Evolvability
- Adaptability
- Flexibility
- Scalability
- Extensibility
- Reconfigurability
- Interoperability
- Modifiability
- Modularity

Means to ends 3-4 out of 4
2 out of 4
Summary

- Lifecycle properties (Ilities) are critical for long term value
- Despite differences, the two methods led to similar high-level conclusions regarding the relationships amongst Ilities:
  - Some ilities are closely related to each other and form semantic sets that are tied together by both synonymy and polysemy relationships.
  - System value is heavily driven by the ability of a system to be robust (despite internal and exogenous disturbances), flexible or changeable and resilient or survivable over time.
  - A hierarchy of ilities with two or three levels appears to exist whereby some ilities, such as modularity and interoperability appear at lower levels and serve as enablers of higher level ilities.
- Future work will apply both methods to larger sets of ilities, with larger groups of test subjects and will use consistent sets of ilities.