A New "ility": Controlling Change Within Complex Systems Through **Pliability**

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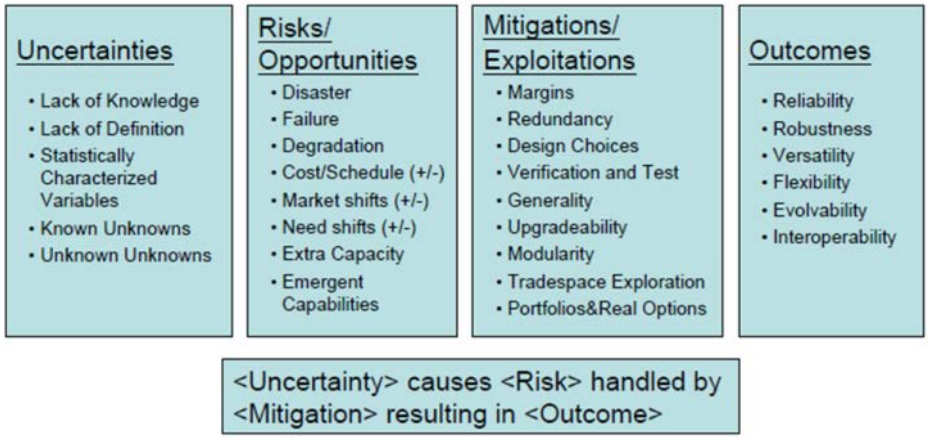
System Properties: Ilities

Framework for Handling Uncertainty (McManus and Hastings 2006)



How does one choose the best concepts?

Decision makers may improve their capacity to discriminate between system concepts and design choices by measuring a system's "ilities" such as changeability, scalability, and survivability

- Non-traditional system properties that are increasingly recognized as qualities that lead to successful systems (McManus et al. 2007)
- Derived by considering system properties

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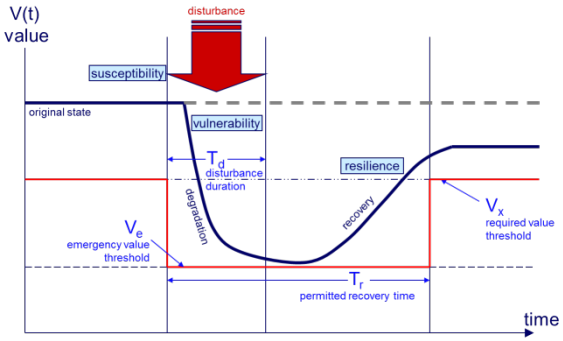
Lots of Named "ilities": e.g. Changeability and Survivability



value robustness	ability of a system to maintain value delivery in spite of changes in needs or context
changeability	ability of a system to be intentionally altered in form or operations, and consequently possibly in function, at an acceptable level of "cost"
flexibility	ability of a system to be altered by a system-external change agent
adaptability	ability of a system to be altered by a system-internal change agent
survivability	ability of a system to minimize the impact of finite-duration disturbances on value delivery
susceptibility	reduction of the likelihood or magnitude of a disturbance
vulnerability	satisfaction of minimally acceptable value level during and after disturbance
resilience	timely recovery to an acceptable value level after a disturbance

A ***valuably changeable*** system is one that can be intentionally altered, typically in response to a perturbation (such as a change in context), in order to improve its value

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Change Is Inevitable

Compared with traditional systems, systems of systems (SoSs) tend to:

- have longer life cycles
- be larger in size
- operate in multiple contexts
- have diverse stakeholders
- be never quite fully formed (evolutionary development)
- depend on human decision making
- include voluntary participation of components

The more a system is like a SoS, the more likely *something* will change

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Changeability is Desirable

- Often, changes in context will result in value delivery loss for engineered systems unless they change in response.
- There has been considerable amount of research on "-ilities" and the desire to build systems that can change (i.e. c*hangeable*) in response to shifts in context (McManus & Hastings, 2006). Examples include:
  - Latent capabilities that grant the ability to change at a later date (e.g., de Neufville and Scholtes, 2011)
  - The ability to change during operational phases (e.g., Gupta and Goyal, 1989)
  - The ability to change easily / rapidly (e.g., McGaughey, 1999)
  - The ability to change in size only (e.g., Elkins et al., 2004)

The research seems to suggest that changeability is always a good thing

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Change Can Be Bad

Involuntary Changes

- Changes that the system is “forced” to go through
- Two types:
  - Without any intervention from decision makers
  - With intervention from decision makers
- Reliability, survivability and robustness strive to prevent, mitigate and recover from involuntary changes

Voluntary Changes

- Ones that decision makers choose to make
- ***Should**** increase, or at least maintain value delivery (otherwise, why do it?)
  - However it may decrease overall value delivery if
    - there are diverse stakeholder preferences
    - **the system is too complex**

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London Ambulance Service

(Case Study by Ian Somerville, 2004)

- SoS consisting of
  - Central dispatch, communication systems, hundreds of independent ambulances, personnel
- Challenging environment
  - Large geographical area
  - Thousands of addresses, many different routes
  - Dynamic
    - Traffic
    - Weather
    - Major events

- New computer-assisted dispatch introduced on Oct 26, 1992.
  - Reverted back to old system 2 days later
  - Somewhere between 20 and 30 people died as a result of the chaos

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London Ambulance Service

(Case Study by Ian Somerville, 2004)

What went wrong?

- New dispatch system assumed perfect information, but information wasn't perfect
  1. Personnel provided bad information, or failed to provide information
     - Due to poor training, communication, lack of trust, poor interfaces, apathy, etc.
  2. System started losing track of vehicles
     - Poor allocation of resources leading to delays in response
- Numerous changes to call center operation reduced resilience
  - Changes made it difficult for staff to intervene when problems were discovered

Changes to complex systems are not to be taken lightly

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London Ambulance Service

(Case Study by Ian Somerville, 2004)

- Done with a low budget, aggressive timetable
  - < £ I Million, 1 year
- Change to new dispatch was not minor
  - Significant change to both form and operations
  - Humans in organizations are notorious for resisting change
- There was never a complete, end-to-end design of the London Ambulance Service that used the new dispatch
  - Who said that this change would work?
- Formal, independent QA did not exist at any stage throughout the new dispatch system development.
  - A lot of assumptions were made and these assumptions were never tested properly

Problem #1:
When does a “change” result in a new system that needs to be re-validated?

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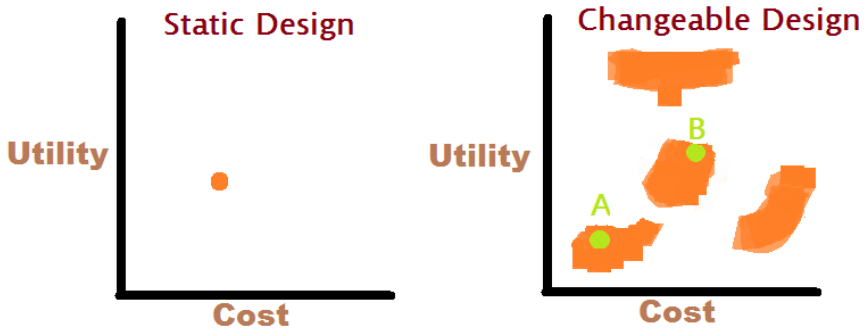
Change in Tradespace Studies

- Tradespace studies are often necessary to compare competing designs for complex systems.
- Certain systems can change in certain ways, both in form and operations.
  - Instead of just a “point” design, a particular system may be able to move within a “cloud” of possible utility / cost points within a particular context by enacting certain change mechanism.



Problem #2:
How can systems that change in form and operations be enumerated and represented in tradespace studies so that their benefits and limitations can fully recognized by decision makers?

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System Architecture

- Components
  - The actual “things” that make up the system
  - **Operational elements** actually do something (i.e. systems or subsystems themselves)
  - Includes their capabilities (what they can / can’t do)
- CONOPs (Concept of Operations)
  - A description of how the operational elements function and interact with each other to produce value
  - I.e.
    - Which OEs perform which tasks
    - What order are the tasks done?
    - What intensity are the tasks performed at?
    - What conditions start, stop or change the task?
    - Etc.

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Example: Maritime Security SoS

- Components
  - Vehicles
    - UAVs, manned patrol aircraft, helicopters, patrol boats
  - Radar towers
  - Command center, ground control stations
  - Airfield, docks,
- CONOPs
  - One zone vs multi-zone
  - Central vs distributed authority
  - Specialization vs role-sharing

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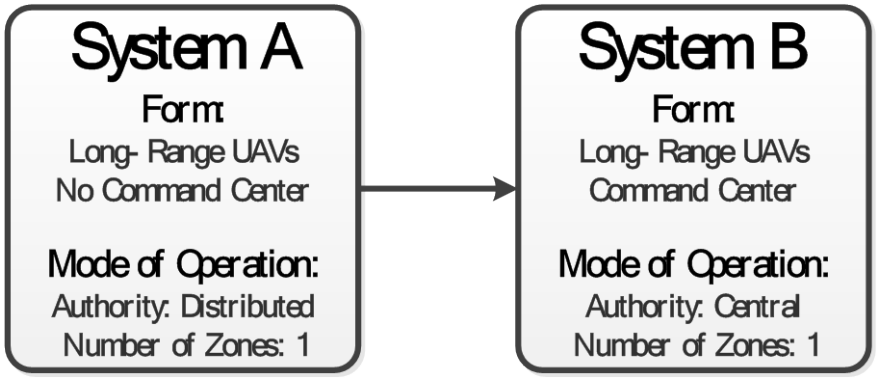
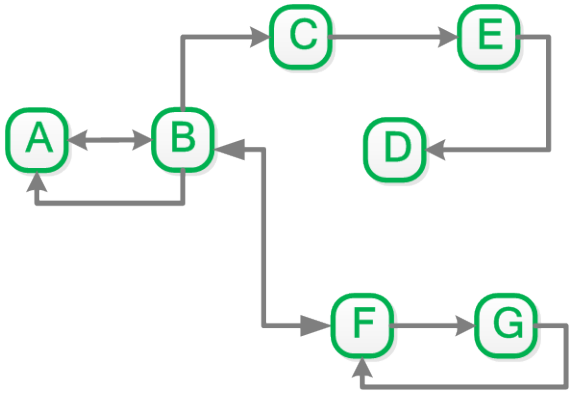
A New ility: Pliability

- Pliability
  - The ability of a system to change in either form and/or operations, to a pair of form & operations that is allowable, as defined by the pliable set of it's system architecture (Brian Mekdeci PhD Dissertation, Expected Aug 2012)
- Pliable set
  - The set of form & operation pairs that a system can transition to that have been validated to provide value in a particular context
- Changes that go beyond pliable set need to be-revalidated
  - They may or may not work
  - Involuntary changes often will be outside pliable set





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Example of Pliability

Aircraft carrier

- Designed for fixed and rotary aircraft.
  - Pliable set may be {20-60 planes, 10-30 helicopters}
    - Anything less than the minimum, means that the aircraft carrier may not be able to meet its mission objectives
    - Carrier cannot accommodate more than the maximum

- Suppose we want to replace the planes with UAVs
  - Possible to do (space for it, budget, etc.)
    - Aircraft carrier is changeable (flexible / adaptable)
  - Not included in pliable set
    - Things may go wrong
      - Radar interference from ground control stations,
      - Noise, motion from aircraft carrier may disrupt UAV operators
      - Etc.

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Benefits of Pliability

- Defines restrictions on how a system can change
  - Distinguishes between when a system change results in a new system that needs to be re-validated, or whether the change is just another allowable instance that is part of the same system architecture
- Improves survivability and robustness
  - Enables validated changes to be made quicker, with less “red tape”
    - Particularly important for SoS with diverse stakeholders
  - The larger the pliable set, the more likely an involuntary change will actually result in a transition to another validated design
- Allows architects the ability to compare holistic system architectures that include possible system transitions, instead of single static systems in tradespace studies

Pliability helps system architects control change by defining limits and requiring validation so that the changes won’t have unintended consequences

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Is this necessary?

- Is a new “ility” necessary to describe the allowed behavior of a system of systems under context changes?
  - Do Systems of Systems need a new and different set of “ilities”?
- Can this be accommodated with the “ility” concepts (flexibility, robustness etc) derived for systems?

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