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Ilities Semantic Basis: Research Progress and Future Directions

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Success can be determined by factors outside of our control…

AKOFS

156.9 meters long "AKOFS Seafarer" is in Karmsundet at the entrance to Haugesund. Photo: Tommy Ellingsen

Newbuild costs (2010): 1B NOK
Final actual: 4.3B

At order: Multi-purpose
Now: "Multi-useless"

Business Oil service

Super ship that became a nightmare

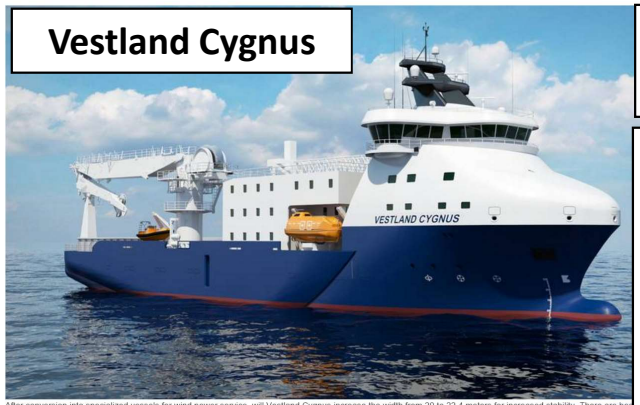
This ship has cost Kjell Inge Røkke and the state 4.3 billion. Now it has been without a contract for one year.

Espen Linderud Asgaut Næss
Published: 14/06/2015 - 8:52 p.m. Updated: 06/15/2015 - 8:22

Source: http://www.dn.no/nyheter/naringsliv/2015/06/14/2052/Oljeservice/superskipet-som-ble-et-mareritt

Outcome: Offered in the spot market, **no contracts for more than a year**. Failure?

Vestland Cygnus



After conversion into specialized vessels for wind power service, will Vestland Cygnus increase the width from 20 to 22.4 meters for increased stability. There are be
The ship is 77 meters long. Photo: Wärtsilä Ship Dsign

Original cost: 320 mNOK
Retrofit cost: 150 mNOK

"The ship must now increase stability. Sponsors of 1.2 meters must be built on each side and covered reinforced where 100-tonne crane to be placed."

VESTLAND CYGNUS

Offshore vessel was delivered in April. Already built it into wind power service

The supply ship was given a brief career in the petroleum industry. Now "Vestland Cygnus" serve renewable market.

By Tore Stenvold (stensvold)

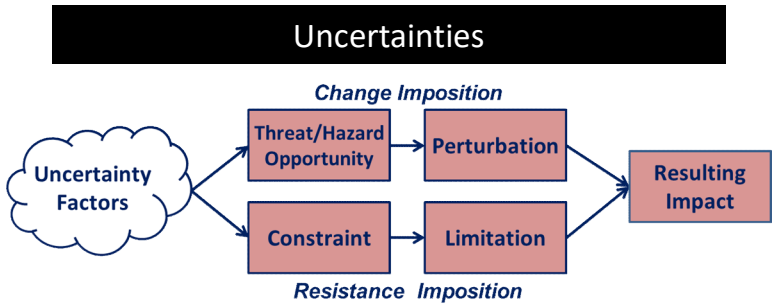
Published 23. October 2015 kl. 12:41

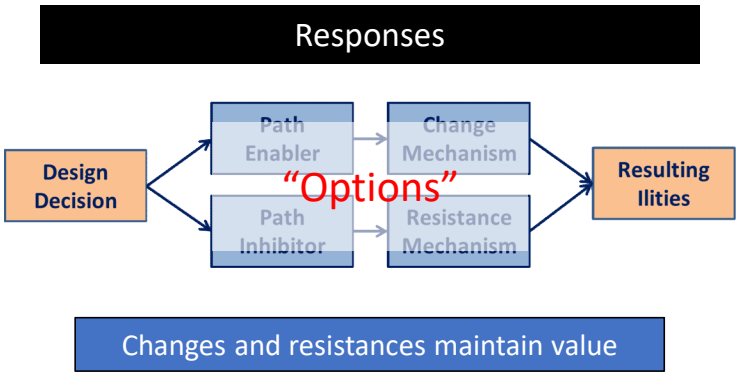
Outcome: successful second life serving new wind service mission

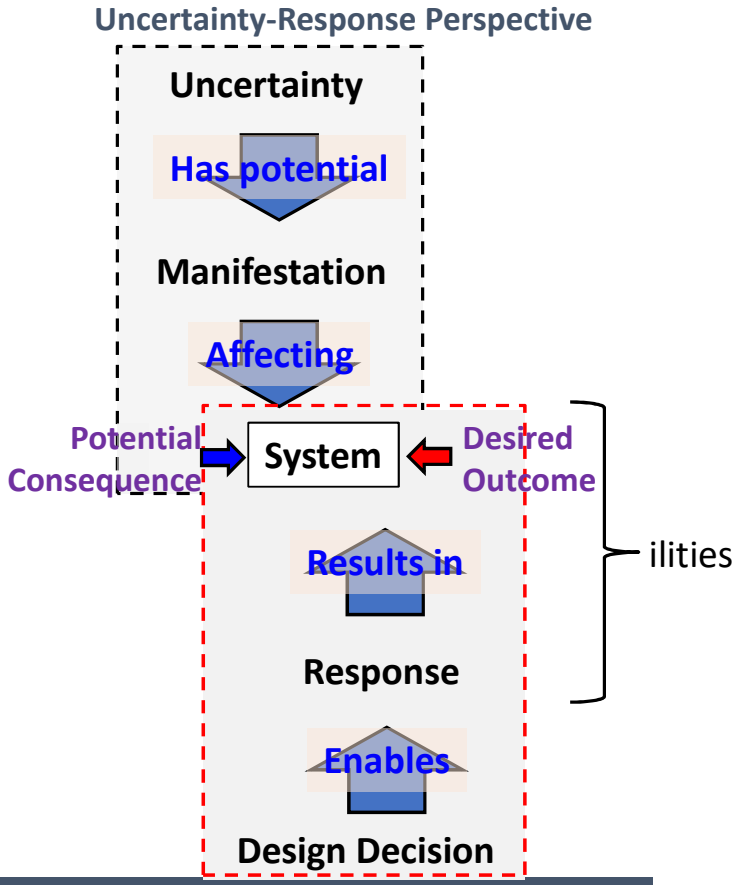
Source: http://www.tu.no/industri/2015/10/23/offshoreskipet-ble-levert-i-april.-allerede-na-bygges-det-om-til-vindkraftservice

"ilities" can be valuable, but how can we ensure their presence in design?
The first step is to rigorously characterize what these ilities are, and explicitly trade them with other factors

Framing the Need for Change-Type Ilities



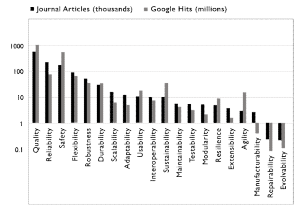


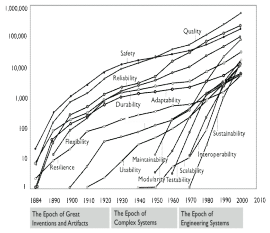


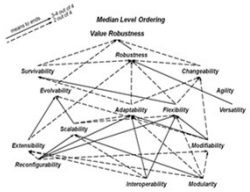
One does not need to know the "ility" term label to specify a desired response

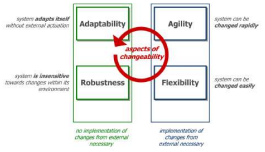
Approach

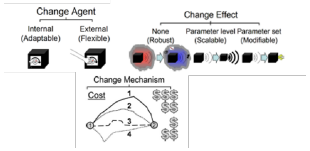
- Extracted concepts from wide review of literature and theoretical frameworks
- Avoiding imposed definitions; focused on potential degrees of freedom implied within an array of “change-type” ility definitions
- Results in a “mix and match” set of *bases* from which to propose “definitions” that can be labelled with ility terms
- Iterated/peer reviewed via conferences and research collaborations











10D Basis — Prescriptive Semantic Basis for Change-type Ilities

In response to “cause” in “context”, desire “agent” to make some “change” in “system” that is “valuable”

Cause	Context	Phase	Agent	Change	System	Valuable

In response to “perturbation” in “context”, desire “agent” to make some “effect” to the “parameter” in the “aspect” of the “abstraction” during “phase” with “destination(s)” that are valuable with respect to thresholds in “reaction”, “span”, “cost” and “benefits”

Perturbation	Context	Phase	Agent	Effect	Parameter (Ty…	…nation	Aspect	Abstraction	Reaction	Span	Cost	Benefit
					“paran…	…ite”			“threshold”	“threshold”	“threshold”	“threshold”
1	2	3	4	5			8	9	10			

14D Basis — Prescriptive Semantic Ba… for Change-type Ilities

In response to “cause” in “context”, desire “agent” to make some “change” in “system” that is “valuable”

Cause	Context	Phase	Agent	Impetus Change	System	Outcome Change	System	Valuable

In response to “perturbation” in “context” during “phase” desire “agent” to make some “nature” impetus to the design “parameter” with “destination(s)” in the “aspect” to have an “effect” to the outcome “parameter” with “destination(s)” in the “aspect” of the “abstraction” that are valuable with respect to thresholds in “reaction”, “span”, “cost” and “benefits”

Perturbation	Context	Phase	Agent	Impetus				Outcome				Abstraction	Reaction	Span	Cost	Benefit
				Nature	Parameter	Destination	Aspect	Effect	Parameter	Destination	Aspect					
					“parameter”	“state”			…meter”	“state”			“threshold”	“threshold”	“threshold”	“threshold”
1	2	3	4	5	6	7	8			11	12	13	14			

20D Basis — Prescriptive Semantic Basis for Change-type Ilities

In response to “perturbation” in “context”, desire “agent” to make some “change” in “system” that is “valuable”

Perturbation	Context	Phase	Agent	Impetus Change					Mech	Outcome Change					System	Valuable* (this category is not complete)

In response to “perturbation” in “context” during “phase” desire “agent” to make some “nature” impetus to the system “parameter” from “origin(s)” to “destination(s)” in the “aspect” using “mechanism” in order to have an “effect” to the outcome “parameter” from “origin(s)” to “destination(s)” in the “aspect” of the “abstraction” that are valuable with respect to thresholds in “reaction”, “span”, “cost” and “benefits”

Perturbation	Context	Phase	Agent	Impetus* (optional)					Mech	Outcome					Abstraction	Reaction	Span	Cost	Benefit
				Nature	Parameter	Origin	Destination	Aspect	Mechanism	Effect	Parameter	Origin	Destination	Aspect					
optional	circumstantial: required; general: optional	null	optional	null	required	optional	optional	null* (this is implied by “parameter”)	Optional	null	required	optional	optional	null*	optional	required	required	required	required
“name”	“name(s)”		“name(s)”		“parameter”	“state(s)”	“state(s)”		“name”		“parameter”	“state(s)”	“state(s)”		“name”	“threshold w/units”	“threshold w/units”	“threshold w/units”	“threshold w/units”
none	circumstantial	pre-ops	none	decrease	level	one	one	form		decrease	level	one	one	form	architecture	sooner	shorter	less	more
disturbance	general	ops	internal	same	set	few	few	function		same	set	few	few	function	design	later	longer	same	same
shift	<empty>	inter-LC	external	increase	<empty>	many	many	operations		increase	<empty>	many	many	operations	system	always	same	more	less
<empty>		<empty>	either	not-same		<empty>	<empty>	<empty>		not-same		<empty>	<empty>	<empty>	<empty>	<empty>	<empty>	<empty>	<empty>
			<empty>	<empty>						<empty>									

Having such a semantic model would show relationships between ilities:

- Can you have a flexible AND robust system?
- Can you have a single adaptably, scalable, extensible, affordable change?
- What metrics can be used to evaluate and valuate along ilities?

Verbose Full Change Statement

In response to "perturbation" in "context" during "phase" desire "agent" to make some "nature" impetus to the system "parameter" from "origin(s)" to "destination(s)" in the "aspect" using "mechanism" in order to have an "effect" to the outcome "parameter" from "origin(s)" to "destination(s)" in the "aspect" of the "abstraction" that are valuable with respect to thresholds in "reaction", "span", "cost" and "benefits"

The semantic model would be used differently in different use cases

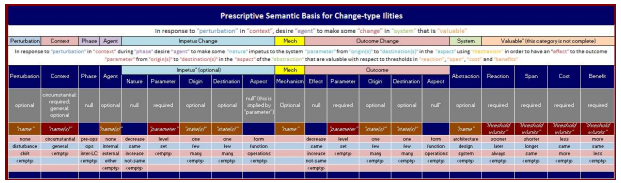
Full model:

- When trying to write a very specific requirement statement (should not occur until AFTER analysis to determine what should be done)

Subset of model:

- Early in the design phase, leave out the "valuable" categories (these are subjective, depend on outside factors)
- If one is trying to avoid fixating on a solution-centric approach, leave out change mechanism (allow engineers to propose own alternatives)

Full model: 20 columns



For more info, please see:

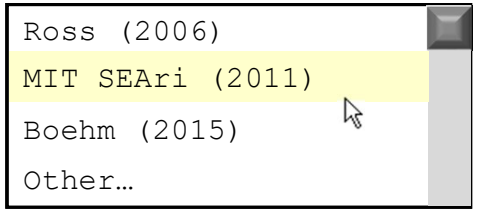
Ross, A.M., and Rhodes, D.H., "Towards a Prescriptive Semantic Basis for Change-type Ilities," *13th Conference on Systems Engineering Research*, Hoboken, NJ, Mar. 2015.

Dou, K., Wang, X., Tang, C., Ross, A.M., and Sullivan, K., "An Evolutionary Theory-Systems Approach to a Science of the Ilities," *13th Conference on Systems Engineering Research*, Hoboken, NJ, Mar. 2015.

Proof of Concept Translation Layer

Welcome to the Ilities Semantic Translation Layer Assistant

Please pick an ilities dictionary to use in this tool
(you can change this later under *Settings*)



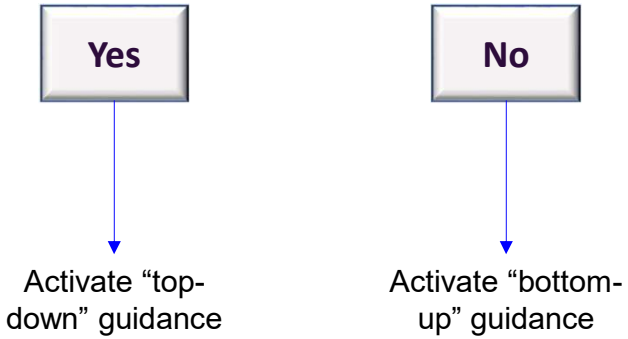
Great, you have picked the **MIT SEAri (2011)** dictionary.

The dictionary will determine how particular ilities are defined and provide you context-aware guidance in formulating ilities statements and requirements.

Reset
(pick new dictionary)

Proceed
(begin ilities guidance)

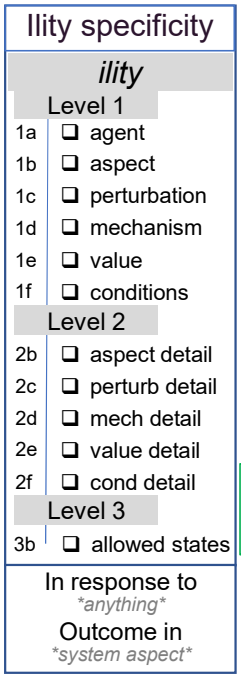
Do you know what ility you want?



Ilities Advisor Sidebar

Did you know there are many ility terms that mean the same thing to some people?
(e.g. flexibility and changeability)

If you don’t know what ility term applies to your need, we can guide you to it with a series of questions.



Do you know what ility you want?

Yes → Activate "top-down" guidance

No → Activate "bottom-up" guidance

Ilities Advisor Sidebar

Did you know there are many ility terms that mean the same thing to some people?
(e.g. flexibility and changeability)

If you don't know what ility term applies to your need, we can guide you to it with a series of questions.

Ility specificity	
flexibility	
Level 1	
1a	❑ agent
1b	❑ aspect
1c	❑ perturbation
1d	❑ mechanism
1e	❑ value
1f	❑ conditions
Level 2	
2b	❑ aspect detail
2c	❑ perturb detail
2d	❑ mech detail
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	❑ allowed states

In response to **anything**
Outcome in **system aspect**

Do you know what ility you want?

Yes

Flexibility
Adaptability
Scalability
Survivability
Resilience

Great, you care about **flexibility**.

This implies that **you want to have your system able to be changed.**

Back
(alter answer)

Next
(begin specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Did you know there are many ility terms that mean the same thing to some people?
(e.g. flexibility and changeability)

*Typically **flexibility** means "the ability for a system to be changed by a system-external agent"*

Ility specificity	
flexibility	
Level 1	
1a	❑ agent
1b	❑ aspect
1c	❑ perturbation
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Level 3	
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In response to
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Outcome in
system aspect

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Yes

Flexibility
Adaptability
Scalability
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Great, you care about **flexibility**.

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Back
(alter answer)

Next
(begin specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Did you know there are many ility terms that mean the same thing to some people?
(e.g. flexibility and changeability)

*Typically **flexibility** means "the ability for a system to be changed by a system-external agent"*

Ility specificity	
flexibility	
Level 1	
1a	❑ agent
1b	❑ aspect
1c	❑ perturbation
1d	❑ mechanism
1e	❑ value
1f	❑ conditions
Level 2	
2b	❑ aspect detail
2c	❑ perturb detail
2d	❑ mech detail
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	❑ allowed states

In response to
anything
Outcome in
system aspect

Do you want to change the system **yourself**?

- Yourself
- On its own
- Doesn't matter
- Other…

You want a flexible change that can be executed by **yourself**.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Desired changes to a system are typically set in motion by an "agent."

An agent can be outside of the system or inside of the system.

An agent must be able to execute the change, as well as know when to do so.

Often an external agent is associated with the concept of flexibility.

Ility specificity

flexibility

Level 1
- 1a ✓ agent
- 1b ❑ aspect
- 1c ❑ perturbation
- 1d ❑ mechanism
- 1e ❑ value
- 1f ❑ conditions

Level 2
- 2b ❑ aspect detail
- 2c ❑ perturb detail
- 2d ❑ mech detail
- 2e ❑ value detail
- 2f ❑ cond detail

Level 3
- 3b ❑ allowed states

In response to **anything**
Outcome in ***number of satellites***

Do you know **what** you want to change?

- Form
- Function
- Operations
- Other…

Optional: what is the name of this aspect of the system?

`number of satellites`

You want a flexible change that alters its **form (i.e. number of satellites)**.

Back (alter answer)

Next (continue specifying)

Done (show ility statement)

Ilities Advisor Sidebar

There are several possible "aspects" to a system that could change, including form, function, operations, among others.

The "form" describes the particular set of elements that make up the system.

The "function" describes the particular set of things that the system does.

The "operations" describes how the system behaves in order to apply its functions to create effects.

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	❑ perturbation
1d	❑ mechanism
1e	❑ value
1f	❑ conditions
Level 2	
2b	❑ aspect detail
2c	❑ perturb detail
2d	❑ mech detail
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	❑ allowed states

In response to
anything
Outcome in
number of satellites

What specifically about the **number of satellites** do you want to change?

Level
Set

Other…

You want a flexible change that can change the **level** of **number of satellites**.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Desiring change to the level of a system parameter is often considered "scalability" while changes to a set is considered "modifiability."

Change to a level of a system parameter is considered scalability.

Scalability can be up or down (or both).

Whether scalability is attractive depends on the value of the change.

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	❑ perturbation
1d	❑ mechanism
1e	❑ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	❑ perturb detail
2d	❑ mech detail
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	❑ allowed states

In response to
anything
Outcome in
number of satellites

Do you want to specify **allowable or desired end states** for **number of satellites**?

Yes
No

You want a flexible change that can change the **level** of **number of satellites** from X to Y.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Specifying allowable end states helps to constrain the specific type of change desired, helping with verification and design implementation. But desirability of particular end state may be difficult to determine a priori.

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	❑ perturbation
1d	❑ mechanism
1e	❑ value
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Level 2	
2b	✓ aspect detail
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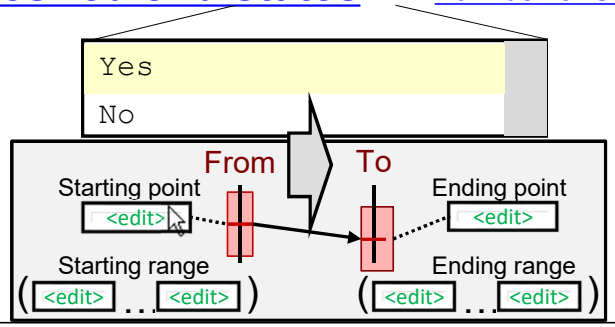
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	❑ allowed states

In response to
anything
Outcome in
number of satellites

Do you want to specify **allowable or desired end states** for **number of satellites**?

Yes
No



You want a flexible change that can change the **level** of **number of satellites** from X to Y.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Specifying allowable end states helps to constrain the specific type of change desired, helping with verification and design implementation. But desirability of particular end state may be difficult to determine a priori.

Starting states can be specified as points or ranges.

Ending states can be specified as points or ranges.

More detailed contingent graphs could be created showing what particular starting and ending states should be allowed.

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	❑ perturbation
1d	❑ mechanism
1e	❑ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
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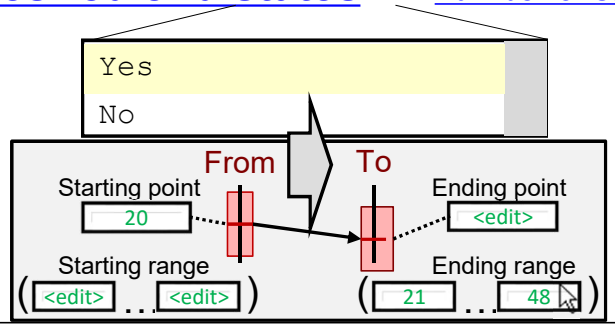
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	❑ allowed states

In response to
anything
Outcome in
number of satellites

Do you want to specify **allowable or desired end states** for **number of satellites**?

Yes
No



You want a flexible change that can change the **level** of **number of satellites** from **20** to **21 up to 48**.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Specifying allowable end states helps to constrain the specific type of change desired, helping with verification and design implementation. But desirability of particular end state may be difficult to determine a priori.

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Ility specificity	
flexibility	
Level 1	
1a	✓ agent
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1f	❑ conditions
Level 2	
2b	✓ aspect detail
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2d	❑ mech detail
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2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
something*
Outcome in
number of satellites

Do you want the change to be in response **to something**?

Yes
No

You want a flexible change that occurs in response to **something**.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Oftentimes a change is desired in response to a "perturbation," which provides the reason for a change.

Perturbations come in several types:

A "disturbance" is a finite, short duration imposed change on the system, its context, or needs.
A change in context is a longer duration, unlikely to revert, imposed change in the environment or needs for a system.
System state is the particular system form, function, and operations configuration

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	❑ mechanism
1e	❑ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	❑ perturb detail
2d	❑ mech detail
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand*
Outcome in
number of satellites

What specifically do you want the change to be **in response to**?

- Disturbance
- Change in context
- System state
- Other…

Optional: what is the name of this perturbation?

Increased demand

You want a flexible change that occurs in response to **increased demand**.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Oftentimes a change is desired in response to a "perturbation," which provides the reason for a change.

Perturbations come in several types:

A "disturbance" is a finite, short duration imposed change on the system, its context, or needs.
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2d	❑ mech detail
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand
Outcome in
number of satellites

Does it matter **how** it achieves the change?

Yes
No

You care about how the flexible change is accomplished.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

A "mechanism" is the way by which a change occurs. For example "turning a knob" or "adding fuel". Typically it relates to an action verb.

There are many possibly mechanism that may result in the same system change.

Specifying one or more mechanisms constrains expectations on HOW a change can occur.

Not specifying a mechanism frees up designers to propose and evaluate multiple different mechanisms.

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	✓ mechanism
1e	❑ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	✓ perturb detail
2d	❑ mech detail
2e	❑ value detail
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand*
Outcome in
number of satellites

Do you care about the **value** of the change?

Yes
No

You care about the value of the flexible change.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

The "value" of the change is typically a function of the starting state, ending state, context, and various costs of carrying and executing the change.

Typically the value of a change can be decomposed into four elements:

How quickly the change happens
How much the change costs
How long after the reason the change occurs
How useful the change end state will be

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	✓ mechanism
1e	✓ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	✓ perturb detail
2d	❑ mech detail
2e	❑ value detail(1)
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand*
Outcome in
number of satellites

Do you care about **how quickly** the change happens?

Yes
No

Optional: do you have an acceptability threshold on this?

6 mos or less

You want a flexible change that can be changed **quickly** (i.e. in **6 mos or less**).

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Changes made to a system typically take finite time to accomplish (from start to completion of the change).

Typically if you care about how quickly a change is accomplished, this means you care about the concept of "agility."

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	✓ mechanism
1e	✓ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	✓ perturb detail
2d	❑ mech detail
2e	■ value detail(2)
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand
Outcome in
number of satellites

Do you care about **how much** the change **costs**?

Yes
No

Optional: do you have an acceptability threshold on this?

$2M or less per unit

You want a flexible change that has **appropriate costs** (i.e. **$2M or less per unit**).

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Changes made to a system typically take finite resources to accomplish (i.e. dollar cost for executing the change).

Typically if you care about how much a change costs, this means you care about the concept of "affordability."

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	✓ mechanism
1e	✓ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	✓ perturb detail
2d	❑ mech detail
2e	■ value detail(3)
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand*
Outcome in
number of satellites

Do you care about **how long after the reason** the change occurs?

Yes
No

Optional: do you have an acceptability threshold on this?

within 3 mos

You want a flexible change that can be executed **soon after the reason** for it (i.e. **within 3 mos**).

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Changes made to a system typically do not take place immediately after the reason for making the change (i.e. there is some "response time" for executing the change).

Typically if you care about how long after the reason the change occurs, this means you care about the concept of "reactivity."

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	✓ mechanism
1e	✓ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	✓ perturb detail
2d	❑ mech detail
2e	■ value detail(4)
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand
Outcome in
number of satellites

Do you care about **how useful** the change end state will be?

Yes
No

Optional: do you have an acceptability threshold on this?

You do not care about the specific benefit of the end state.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Changes made to a system typically result in a new system state that has different usefulness than its original state.

The usefulness of a system state is context dependent.

Assessment of the usefulness of a system often requires a more nuanced valuation activity that is often context dependent.

One can loosely specify "improved" usefulness, but this often requires specifying particular functions or capabilities desired.

One can put off the "valuation" statement to a later point in time.

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	✓ mechanism
1e	✓ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	✓ perturb detail
2d	❑ mech detail
2e	■ value detail(4)
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand
Outcome in
number of satellites

Do you care about **how useful** the change end state will be?

Yes
No

Optional: do you have an acceptability threshold on this?

You do not care about the specific benefit of the end state.

Back
(alter answer)

Next
(continue specifying)

Done
(show ility statement)

Ilities Advisor Sidebar

Changes made to a system typically result in a new system state that has different usefulness than its original state.

The usefulness of a system state is context dependent.

Assessment of the usefulness of a system often requires a more nuanced valuation activity that is often context dependent.

One can loosely specify "improved" usefulness, but this often requires specifying particular functions or capabilities desired.

One can put off the "valuation" statement to a later point in time.

Ility specificity	
flexibility	
Level 1	
1a	✓ agent
1b	✓ aspect*
1c	✓ perturbation**
1d	✓ mechanism
1e	✓ value
1f	❑ conditions
Level 2	
2b	✓ aspect detail
2c	✓ perturb detail
2d	❑ mech detail
2e	■ value detail
2f	❑ cond detail
Level 3	
3b	✓ allowed states

In response to
increased demand*
Outcome in
number of satellites

This is the ilities statement you have generated using the tool

In response to a shift in context (increased demand), you desire a **flexible** (external change initiator) change that results in a change in form (number of satellites) from 20 to 21 to 48, that begins to change within 3 mos, takes 6 mos or less to change, and costs $2M or less per unit.

Extracted implied ility term labels include:
flexibility, scalability, agility, affordability, reactivity
Design principles of interest: *design principles page*

Back
(alter answer)

Save
(keep ility statement)

Restart
(reset to first page)

Ilities Advisor Sidebar

The ility statement generated by this tool has many dimensions to it.

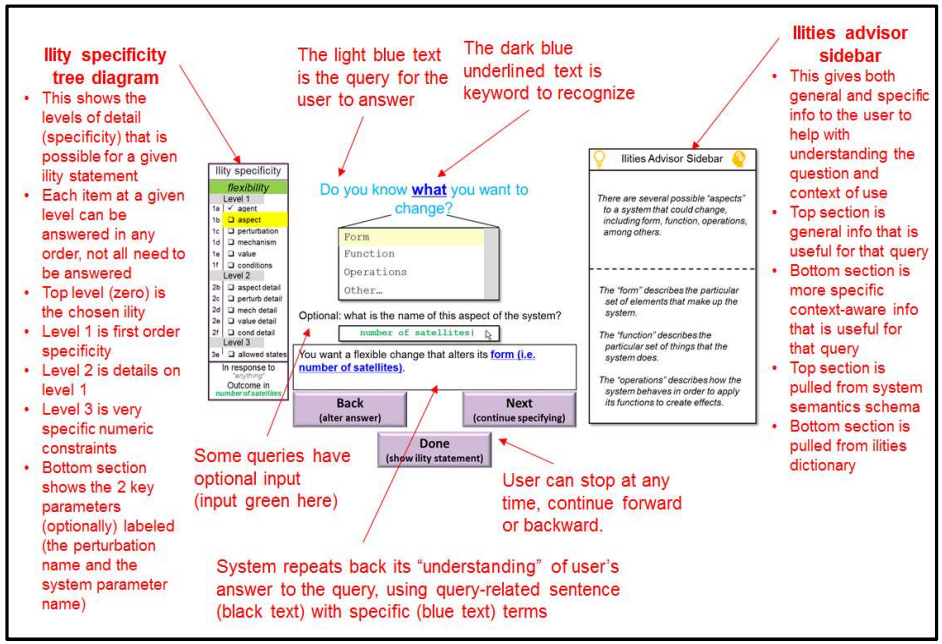
Not all dimensions are required and specificity can vary.

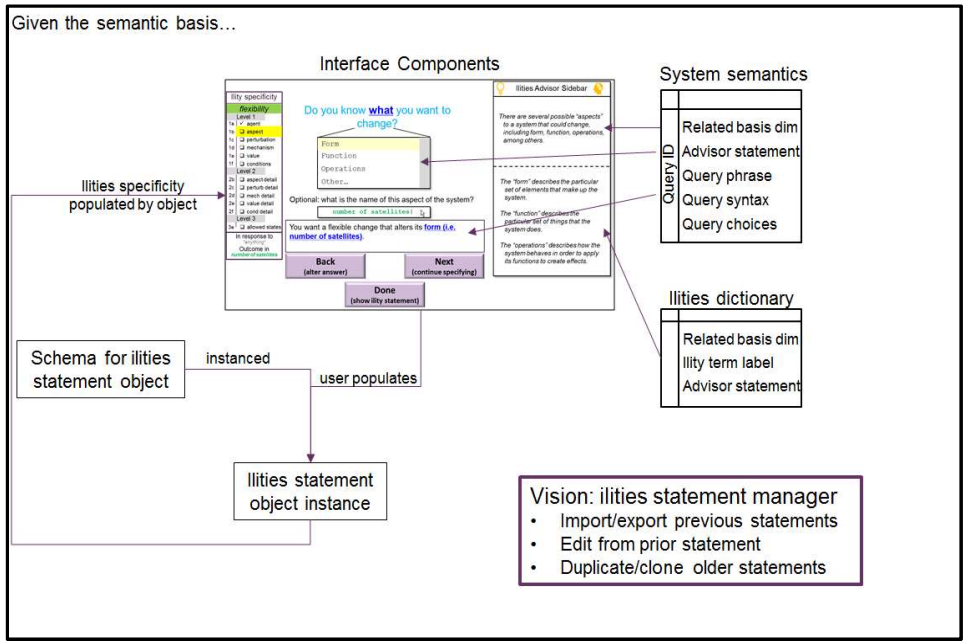
The ility statement generated by this tool has many dimensions to it.

Not all dimensions are required and specificity can vary.

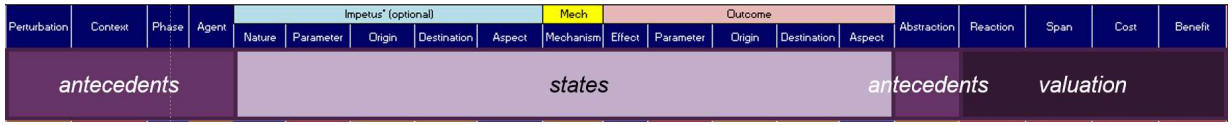
Toggle highlighted specificity items to show simplified versions of statement

Translation Layer

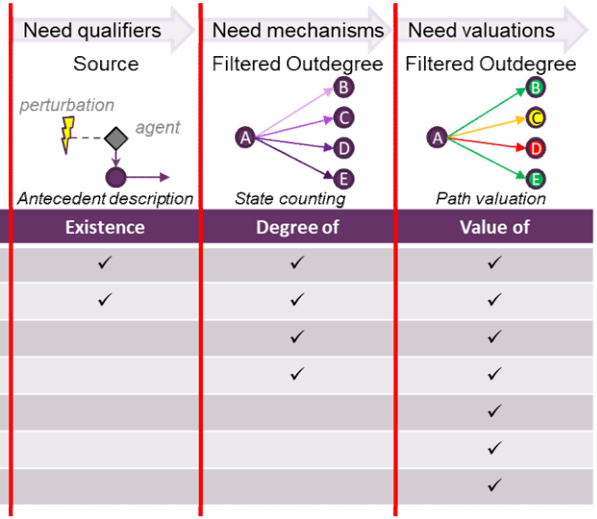




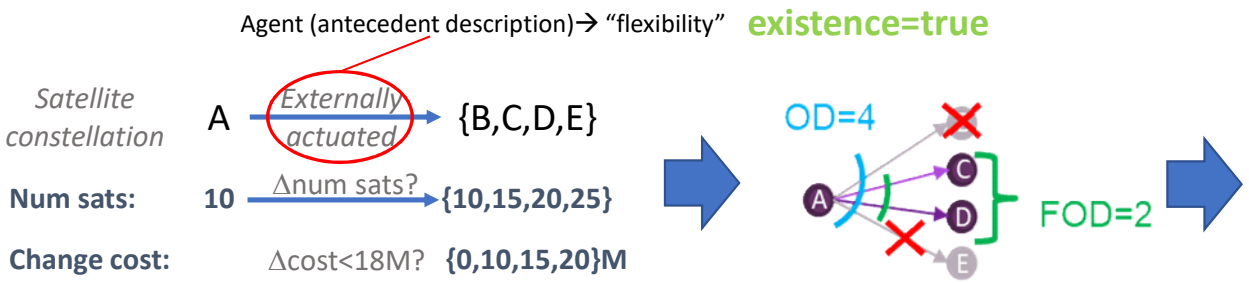
Ilities Metrics and the Basis



- The basis categories can be partitioned into three sets related to the **antecedent description**, the state counting, and the **path valuation**
- These then can map to three types of quantification for an ility: existence (binary), degree (state counting), and value (path valuation)
- Ility term labels that require particular basis categories within the three sets can indicate the types of metrics that can be used



Ility Label	Existence	Degree of	Value of
Flexibility	✓	✓	✓
Adaptability	✓	✓	✓
Scalability		✓	✓
Modifiability		✓	✓
Agility			✓
Affordability			✓
Reactivity			✓



a flexible constellation whose degree is 4, but whose flexibly scalable degree is 3 and whose affordably flexible scalable degree is 2.

Application: Using Semantic Basis for Educating Students and Practitioners

- Given lack of accepted common definitions of ilities, or system qualities, students learn definition as written text, used by the educating organization/instructor
- Semantic basis could provide enhanced learning experience
  - Teach students a more precise understanding and appreciation of what is required for a complete ilities statement
  - Use of various versions (e.g., 10-dimension basis, 14-dimension basis) show how simple statements can be elaborated as more information is gained
  - Use of a translation layer assistant enables step-by-step guidance
  - Class exercise to construct a formal ilities statement (e.g., extract from text in a document)

Hypothesis: use of the semantic basis in educating students will enable more critical thinking than simply teaching students simple definitions of ilities.

Advanced Application: Automated Technical Document Comprehension of Ilities

- Desired abilities include:
  - Automatically extract technical content from text documents, yielding rich, non-ambiguous ilities statements that convey precisely what is mean
  - Automatically synthesize change-type ilities and architecture-type ilities semantic field information from multiple documents to generate new design concepts (e.g., concepts for achieving a specific aspect of system flexibility through modularity)
- Research opens possibilities for automatic extraction and methods to structure and analyse a comprehensible ilities statement, e.g.,
  - Natural Language Processing (NLP) for extraction
  - Lightweight Formal Methods (LFM) for structuring and analysing

While ilities sometimes emerge unexpectedly in operational systems, the **ability to design ilities properties into systems in advance will be the true game-changer**.

Current State of the Semantic Model

The nature of modern systems necessitates being able to translate ilities information across an increasing number of domains and disciplines (e.g., computer science, politic science, cognitive science), driving the need for a 'Rosetta Stone."

This work was intended to provoke dialogue and motivate a community of research and development toward a more integrated, rigorous, and quantitative use of change-type ilities

Perturbation	Agent	Impetus		Outcome	
		Nature	Aspect	Effect	Aspect
disturbance	internal	incease	form	same	form
defect	external	decrease	scope	not-same	scope
opportunity	<empty>	re-host	<empty>	reduced	<empty>
<empty>		<empty>		increased	
				<empty>	

						USC Ility Label	USC-MIT Differences	MIT Ility Label					
				not-same		Changeability	Match	Changeability		either	not-same		not-same	
disturbnce	internal			same		Robustness	Shift vs. Disturbance	Robustness	shift				same	
disturb, opp'y	internal			not-same		Adaptability	Match	Adaptability		internal	not-same		not-same	
disturb, opp'y	external			not-same		Modifiability	Just External (Internal = Adaptability)	Modifiability			not-same		not-same	
			form	not-same	form	Reconfigurability	Similar	Form Reconfigurability			same	form	not-same	form
disturb, opp'y		increase	scope	not-same	scope	Extensibility	Same - Also Scalability-Up	Extensibility		either	not-same		increase	
disturb, opp'y		decrease	scope	not-same	scope	Contractability	Not included - Also Scalability-Down	Scalability			not-same		not-same	
disturb, opp'y			scope	same	scope	Versatility	Similar	Functional Versatility			same	form/ops	not-same	function
						Survivability	Robustness + Adaptability?	Survivability	disturbance				same	
						Evolvability	Same as Changeability?	Evolvability	shift		not-same		not-same	
						Flexibility	External Adaptability?	Flexibility		external	not-same		not-same	
						Agility	Focus on fix speed	Agility			not-same		not-same	
						Reactivity	Focus on duration of fix needs	Reactivity			not-same		not-same	
disturbance		incease		same, increased		Resilience	Not specified	Operational Reconfigurability			same	operations	not-same	operations
defect	internal			same		Fault-Tolerance	Not specified	Operational Versatility			same	form/fnct	not-same	operations
defect	internal			not-same		Self-repairability	Not specified	Substitutability			same	fnct/ops	not-same	form
defect	external					Repairability	Not specified	Value Robustness	shift				same	
	external					Maintainability	Not specified	Value Survivability	disturbance				same	
	internal					Graceful Degredation	Not specified	Active Robustness	shift		not-same		same	
disturb, opp'y		re-host	form	same	form	Portability	Not specified	Passive Robustness	shift		same		same	
						Exchangeability	Like Modifiability?	Classical Passive Robustness	shift	none	same		same	form

Perturbation	Agent	Impetus		Outcome	
		Nature	Aspect	Effect	Aspect
none	none	decrease	form	decrease	form
disturbance	internal	same	function	same	function
shift	external	increase	operations	increase	operations
<empty>	either	not-same	<empty>	not-same	<empty>
	<empty>	<empty>		<empty>	

Example approach to how one might use the semantic model

- Brainstorm *uncertainties*
- Identify how these uncertainties might *manifest*
- Identify how the manifestation of uncertainty might *impact* the system
- Brainstorm design/operations decisions ("*options*") that could be used as *responses* to mitigate the impact
- Use the semantic model to *describe the options*, *apply ility term labels* (e.g. flexibility), and *identify potential metrics* that could be used to verify a system has the desired properties

Thank you! Any questions?

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Potential Use Cases for the Semantic Model

- For eliciting and codifying ilities-related needs
  - Writing unambiguous requirements (systems engineers)
  - Query whether particular ility is specified/required
  - Determine what ilities are implied by particular change statement
  - Finding information gaps within specified change statement
  - Reverse engineering ility-contained statements
- As a tool for using ilities consistently
  - Tool for researchers to see how ilities are related
  - Tool for comparing ility term label definitions (dictionary map)
  - Tool for teaching how to write complete ilities-related requirements
- For improving use of ilities throughout the lifecycle
  - Deriving test plan / evidence/ metrics for verifying reqts
  - Helping to think through potential change statement needs
  - Challenges in use may reveal need for additional information or trade study

These apply to change statements generated to be consistent with the semantic model

References

1. Ross, A.M. Rhodes, D.H., and Hastings, D.E. (2008). “Defining Changeability: Reconciling Flexibility. Adaptability, Scalability, Modifiability, and Robustness for Maintaining Lifecycle Value,” Systems Engineering. Vol. 11. No. 3. 246-262.
2. Ross, A.M., Beesemyer, J.C. and Rhodes, D.H. (2011). "A Prescriptive Semantic Basis for System Lifecycle Properties", SEAri Working Paper WP-2011-2-1. MIT. Cambridge, MA. http://seari.mit.edu/papers.php.
3. de Weck, O.L., Ross, A.M., and Rhodes, D.H. (2012). Investigating Relationships and Semantic Sets amongst System Lifecycle Properties (Ilities). 3rd International Engineering Systems Symposium. CESUN 2012. TU Delft. 18-20.
4. Ross, A.M. and Rhodes, D.H. (2015). "Towards a Prescriptive Semantic Basis for Change-type Ilities." 13th Conference on Systems Engineering Research. Hoboken, NJ.
5. Lee, J. Y. and Collins, G. J. (2017). On using ilities of non-functional properties for subsystems and components. Systems, 5(3), 47.
6. Daclin, N., Moradi, B. and Chapurlat, V. (2018). Analyzing Interoperability in a Non-functional Requirements Ecosystem to Support Crisis Management Response. Enterprise Interoperability: Smart Services and Business Impact of Enterprise Interoperability, 429-434.
7. Lowe, Donald. (2018). Exploring system ilities and their relationship. In: Systems Evaluation Test and Evaluation Conference 2018: Unlocking the Future Through Systems Engineering: SETE 2018. Melbourne: Engineers Australia, 2018: 352-365.
8. Lockett, J., Swan, M. and Unai, K. (2017). The Agile Systems Framework: Enterprise Content Management Case. 15th Annual Conference on Systems Engineering Research. Redondo Beach, CA.
9. Boehm, B. (2017). System Qualities Ontology, Tradespace and Affordability (SQOTA) Project Phase 5, SERC Technical Report SERC-2017-TR-105.
10. Fitzgerald, M.E. and Ross, A.M. (2012). "Sustaining Lifecycle Value: Valuable Changeability Analysis with Era Simulation," 6th Annual IEEE Systems Conference, Vancouver, Canada.
11. Hirschberg, J. and Manning, C. D. (2015). Advances in natural language processing. Science, 349(6245), 261-266.
12. Jackson D. (2001). Lightweight Formal Methods. In: Oliveira J.N., Zave P. (eds) FME 2001: Formal Methods for Increasing Software Productivity. FME 2001. Lecture Notes in Computer Science, vol 2021. Springer, Berlin, Heidelberg.
13. Boehm, B. and Kukreja, N. (2017). An Initial Ontology for System Qualities. INSIGHT, 20(3), 18-28.
14. Moulton, A., Rhodes, D., Madnick, S., Enos, J. and Matty, D. (2015). Applying Semantic Technology to Early Stage Defense Capability Planning Analysis Based on JCIDS Artifacts. NDIA SE Conference. Springfield, VA.
15. Dou, K., Wang, X., Tang, C.,and Sullivan, K. (2015). An evolutionary theory-systems approach to a science of the ilities. Procedia Computer Science, 44, 433-442.
16. Colombo, E. F., Cascini, G. and de Weck, O. L. (2016). “Classification of Change-Related Ilities Based on a Literature Review of Engineering Changes,” Journal of Integrated Design and Process Science, pp. 1–21.
17. Sinha, K. and de Weck, O.L. (2016). Empirical Validation of Structural Complexity Metric and Complexity Management for Engineering Systems, Systems Engineering, Vol 19, No. 3. 193 – 201.
18. Turner A.J., Monahan W. and Cotter M. (2018). Quantifying the Ilities: A Literature Review of Robustness, Interoperability, and Agility. In: Madni A., Boehm B., Ghanem R., Erwin D., Wheaton M. (eds) Disciplinary Convergence in Systems Engineering Research. Springer.