INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

Requirement Connectivity & Uncertainty Propagation

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Who **USES** requirements in their projects?

Who **TRACES** requirements in their projects?

Who **PERFORMS** traceability analyses?

How does it work?

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The customer wants to change a requirement, does it have any major impact?

Mmmm, I see what you mean… Yes or no?

Well, it depends because $E=mc^2$ *and* $f(x)=sqrt(i)$…

Wait a sec, I'll do a traceability analysis and check our margins!

Traditional traceability analysis

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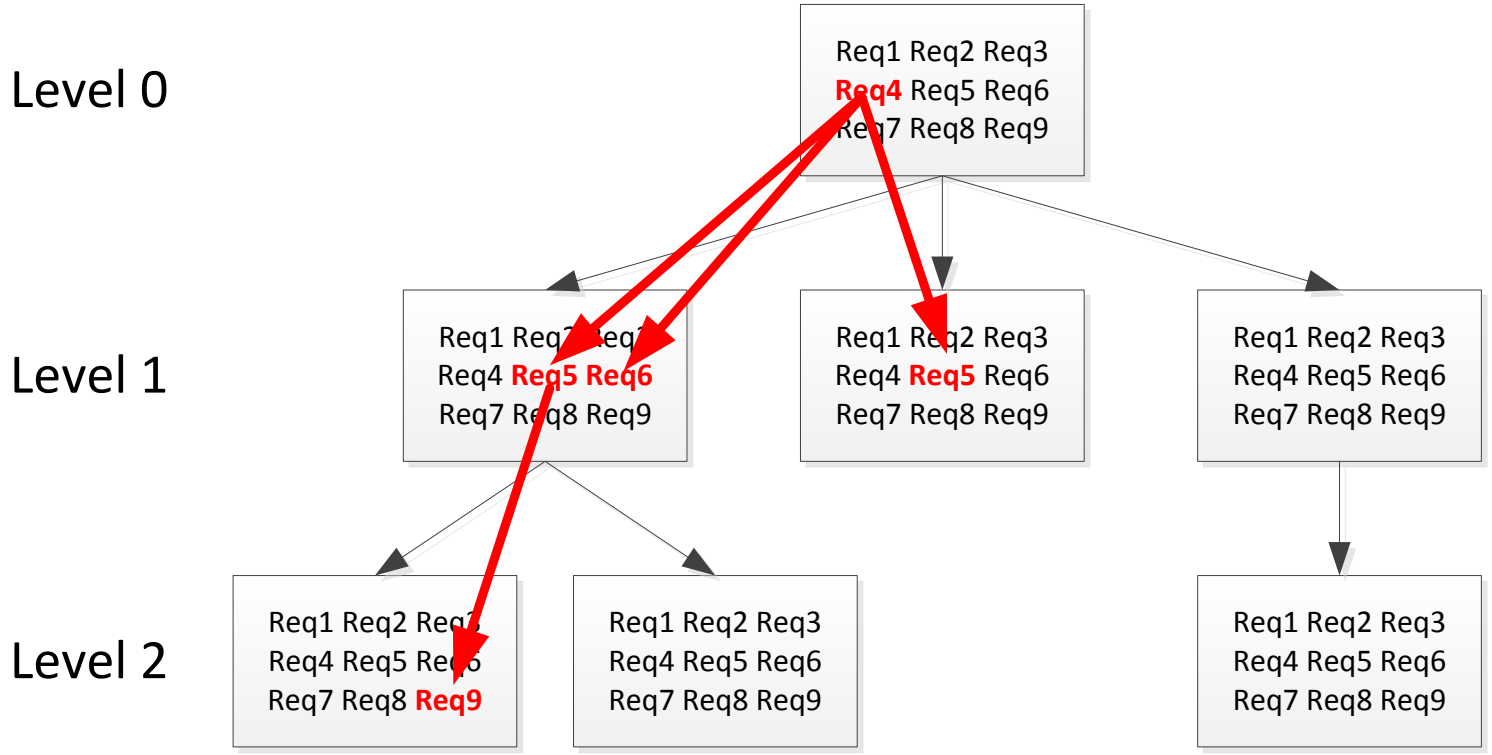

Are we sure this type of analysis is **comprehensive** and **most valuable**?

A bit of theory…

Lemma 9: Given a set of requirements, the set of systems that satisfy all requirements is the intersection of the sets of systems that satisfy each requirement independently.

$$R{\downarrow}i = \{r{\downarrow}i\},\ i = 1, 2, \ldots n$$
$$R{\downarrow}j = \bigcup i=1{\uparrow}n \blacksquare r{\downarrow}i = \{r{\downarrow}1, r{\downarrow}2, \ldots, r{\downarrow}n\}$$
$$CT{\downarrow}R{\downarrow}j = \{x \in UT : c(x, r{\downarrow}1) = true \wedge c(x, r{\downarrow}2) = true \wedge \cdots \wedge c(x, r{\downarrow}i) = true\} = \bigcap i=1{\uparrow}n \blacksquare CT{\downarrow}R{\downarrow}i$$

[Salado, Nilchiani, and Verma 2013]

What does it mean in practice?

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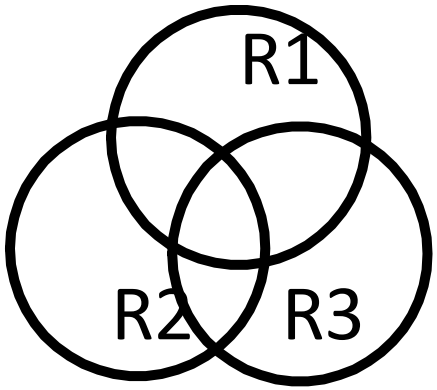

ONE requirement is NOT easy or difficult.

Difficulty lays on fulfilling TWO or MORE requierments SIMULTANEOUSLY

So why do we do **ACROSS** analysis and not **ALONG** analysis?

This paper is about…

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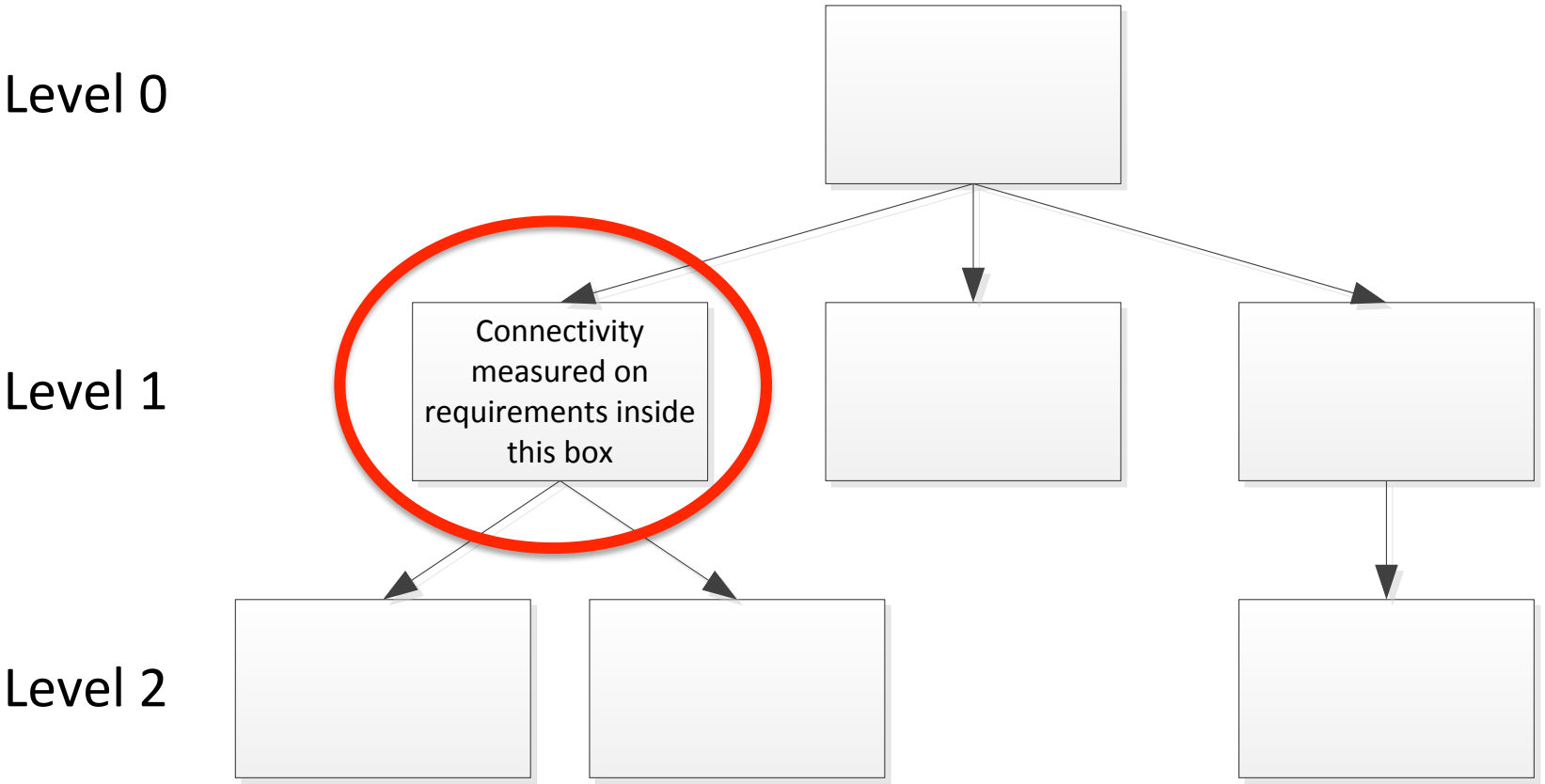

Types of requirement dependency

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[Robinson, Pawloaski, and Volkov 1999)]
Positive correlation
Negative correlation
Unspecified correlation
No correlation
Structure
Resource
Task
Causality
Temporal

[Pohl 1996]
Condition
Content
Documents
Evolutionary
Abstraction

[Carlshamere et al. 2001]
AND
REQUIRES
TEMPORAL
CVALUE
ICOST
OR

[Kulshreshtha, Boardman, and Verma 2012]
Requires
Requires (loop)
Implementation sequence
Value/cost
Derive
Structure
Conflict

Types of representations

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Design Structure Matrix (DSM)

Change Risk Plot

Propagation Networks

Propagation Tree

In this paper…

Tailor [Robinson, Pawloaski, and Volkov 1999)]

Positive correlation

Negative correlation

No correlation

Resource

Causality

What is uncertainty propagation?

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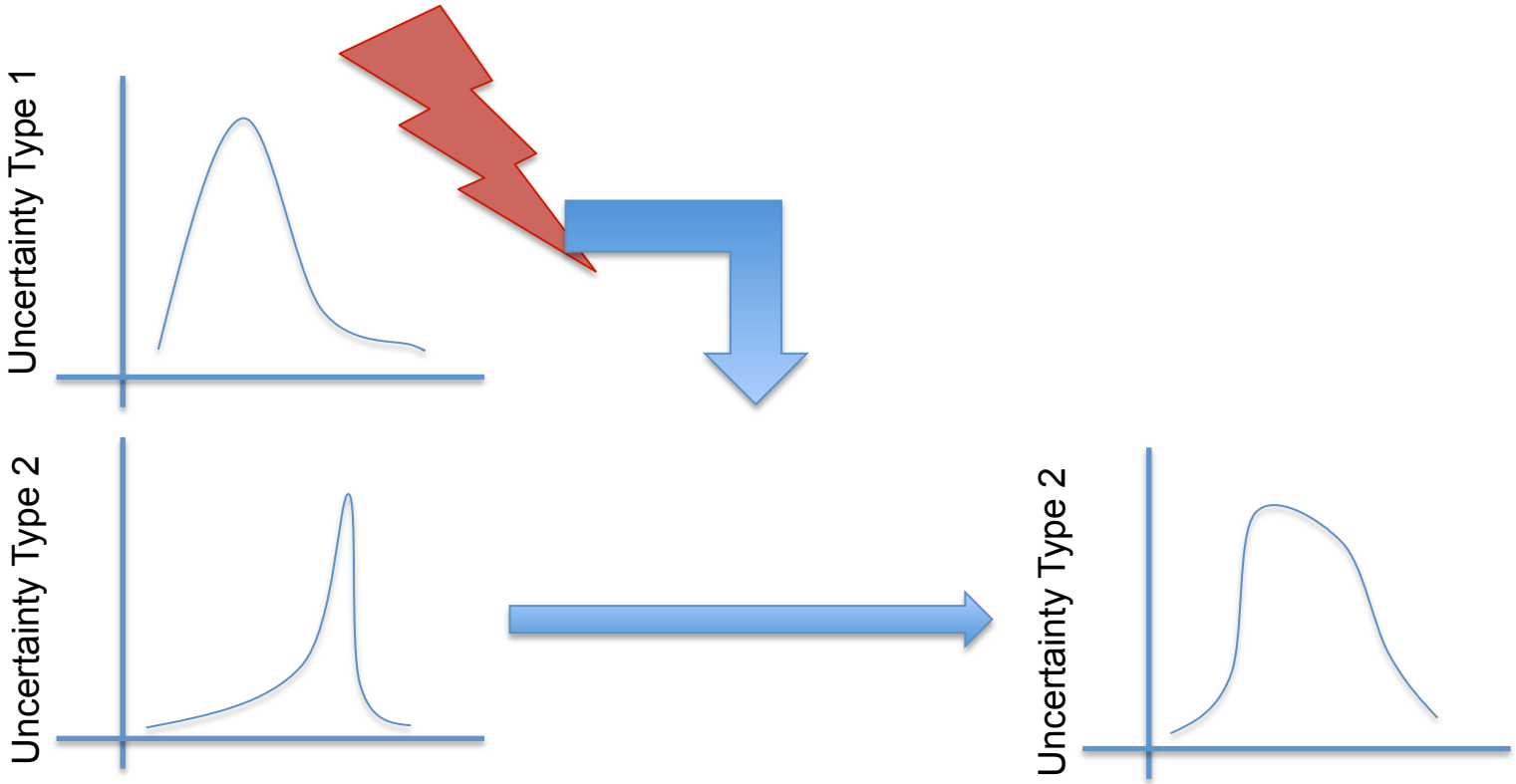

How do you structure uncertainties?

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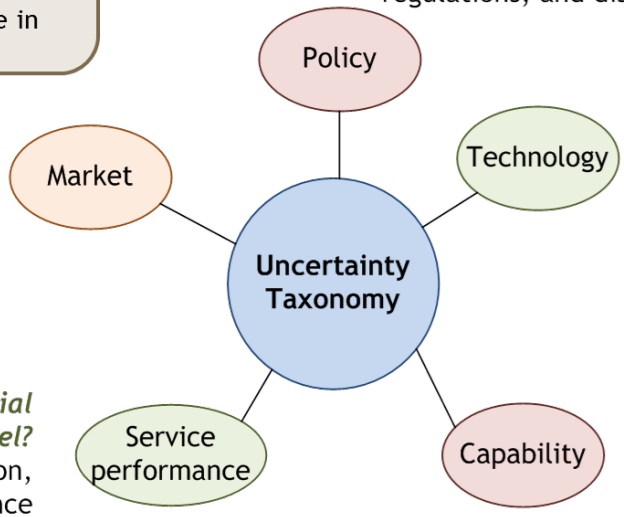
[Salado, Nilchiani, and Efatmaneshnikh, 2012]

Process to aim at completeness

Top-down: in addition to evaluating the uncertainties inherent to the system, stakeholders for space systems are consulted.

Bottom-up: review of uncertainty collections available in existing literature



Is it allowed to build and use the system?
Export, Frequency allocation, Mission-specific regulations, and disposal

Is it feasible to build and use the system?
Obsolescence, Technology readiness, and system readiness

Is the system successful?
Market size, Discount rate, Competitor, Market caputre, and Schedule

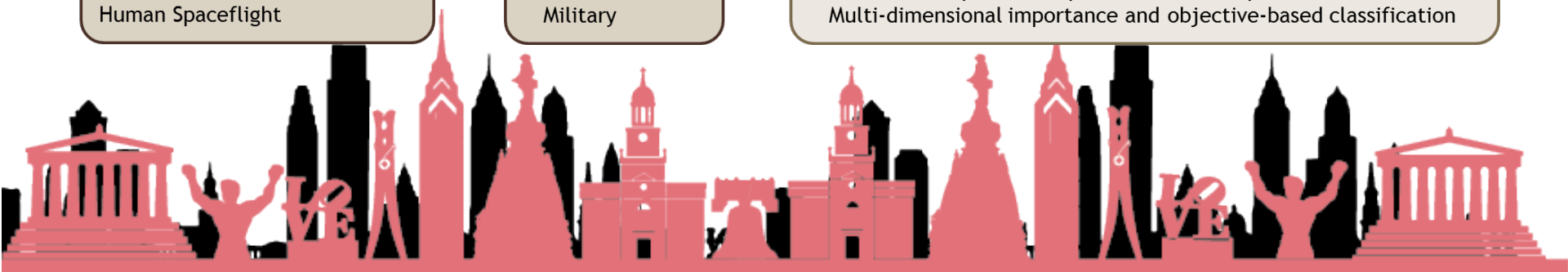
Does the system operate within the initial specified performance level?
Reliability, Availability, Debris, Radiation, Weather hazard, Lifetime, and Performance

Can we build and operate the system?
Supply chain, Cost, Technical capability, Key people, V&V, Design, Requirements, and Customer involvement

Missions
Communications - Navigation - Earth Observation - Science - Human Spaceflight

Customers
Commercial
Government
Military

Application to the design of adaptable and flexible systems
System level structure and completeness
Behavioral impact description and inter-dependencies
Multi-dimensional importance and objective-based classification



Uncertainty inter-dependencies

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Columns are triggered by rows		Techn.			Service performance							Market					Capability								Legal			
		Obsolescence	Technology readiness	System readiness	Reliability	Availability	Debris	Radiation	Weather hazard	Lifetime	Performance	Market size	Discount rate	Competitor	Market capture	Schedule	Supply chain	Cost	Technical capability	Key people	V&V	Design	Requirements	Customer involvement	Export	Frequency allocation	Mission-specific regulations	Disposal
Technology	Obsolescence		11	12		21				41							100	110							79			
	Technology readiness	1		13												72	101	111							80			
	System readiness	2														73	102	112							81			
Service performance	Reliability					22				42																		
	Availability													63	68			113										
	Debris					23				43																		99
	Radiation					24				44																		
	Weather hazard					25				45																		
	Lifetime	3			18	26	31	34	38			?		?	?													
	Performance									?		60		64	69													
Market	Market size					27				46	52			65									135		82	92		
	Discount rate																											
	Competitor											61			70		103			123			136		83	93		
	Market capture					28				47	53			66											84	94		
	Schedule	4	6	14			32	35				62		67	71		104	114		124			137	146	85			
Capability	Supply chain															74		115	150		127			147				
	Cost																						139	148				
	Technical capability		7	15							54					75					128	132	140	149				
	Key people																		119									
	V&V				19	29				48	56																	
	Design				20	30				49	57										129							
	Requirements		9	17			36	37	39	?	58					77		116	120		130	133				96		
	Customer involvement															78	105	117	121	125	131	134	141					
Policy	Export	5	10						40			55				107	106	118	122	126			142					
	Frequency allocation														?	108							143					
	Mission-specific regulations	?	?	?	?	?	?		?	?	?	?		?	?	?	?	?		?			144	?	88			
	Disposal						33			?											?	?	145					

[Salado, Nilchiani, and Efatmaneshnikh, 2012]

Case study: an EO space instrument

Image the Earth in 4 spectral channels **simultaneously**.
Image the Earth **without obscuration** between consecutive images.
Provide image data at a maximum **rate** of 20 Mbps.
Self-command and control.
Performance (MTF, resolution or similar) better than 5 units.
SSD lower than 2 nm.
Power consumption lower than 200 W.
Operate at 650 km **altitude** and 70° inclination.
Mass lower than 950 kg.
Fit inside an **envelope** of 1 m^3.

Who deals with who?

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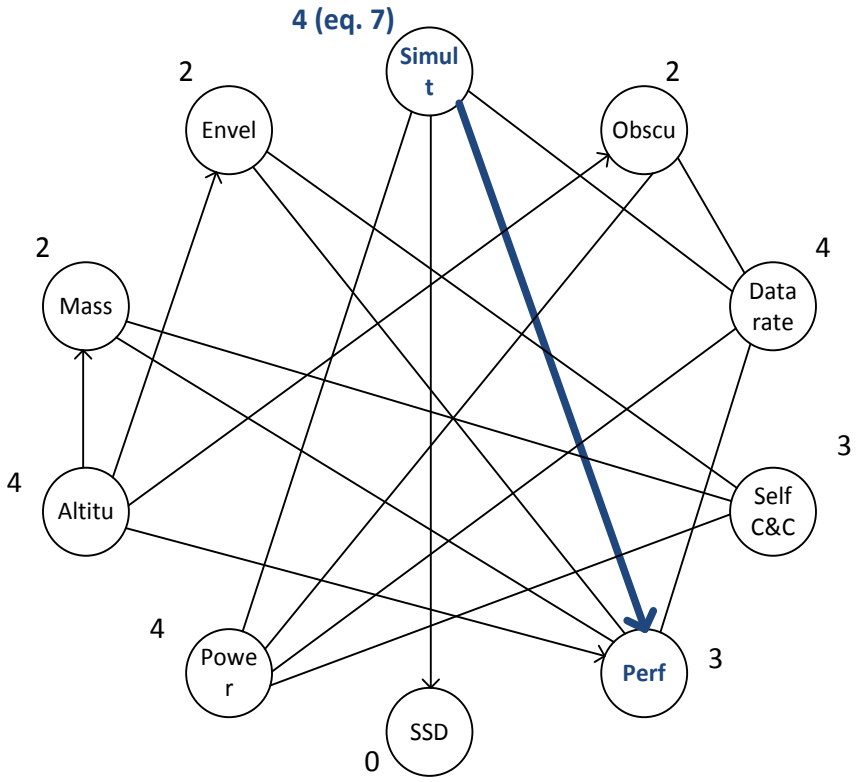

(n) The **amount of channels** to be imaged influences the amount of data generated and therefore the **data rate** required to transfer all data.

(r) The **function** requires **power** to operate.

(n) **Obscuration** drives the amount of images to be taken per second, which influences the amount of data generated and therefore the **data rate** required to transfer all data.

(p) (n) The satellite **orbit** speed depends on its altitude. Varying orbit speed results in different sizes of image taking, influencing therefore **obscuration**. For higher orbits effect is positive whereas for lower orbits effect is negative.

(n) Higher **resolution** requires higher **data rates**.

We evaluate these ones

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Uncertainty	Rationale or Example
Market size	New estimations on market size may result in **adaptation of requirements**.
Competitor	Introduction of competitors in the market may result in **adaptation of requirements** to be more competitive.
Schedule	The longer it takes to develop a system, the more probable stakeholders may **change requirements**.
Cost	Variation in cost may lead to modify (**upgrade or waive**) requirements.
Technical capability	Technical capability of the manufacturer may lead to modify (**upgrade or waive**) requirements.
Customer involvement	The more the customer is involved the more probable requirements will **evolve**.
Export	Export regulations may result in **updating requirements**.

Note on color code

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Requirements marked in **red** are the ones **changing**.

Requirements marked in **yellow** are the ones being **affected**.

Red lines and arrows represent probable **negative impacts** (more stringent requirement). **Green lines and arrows** represent **additional margin** to fulfill a requirement.

Market size

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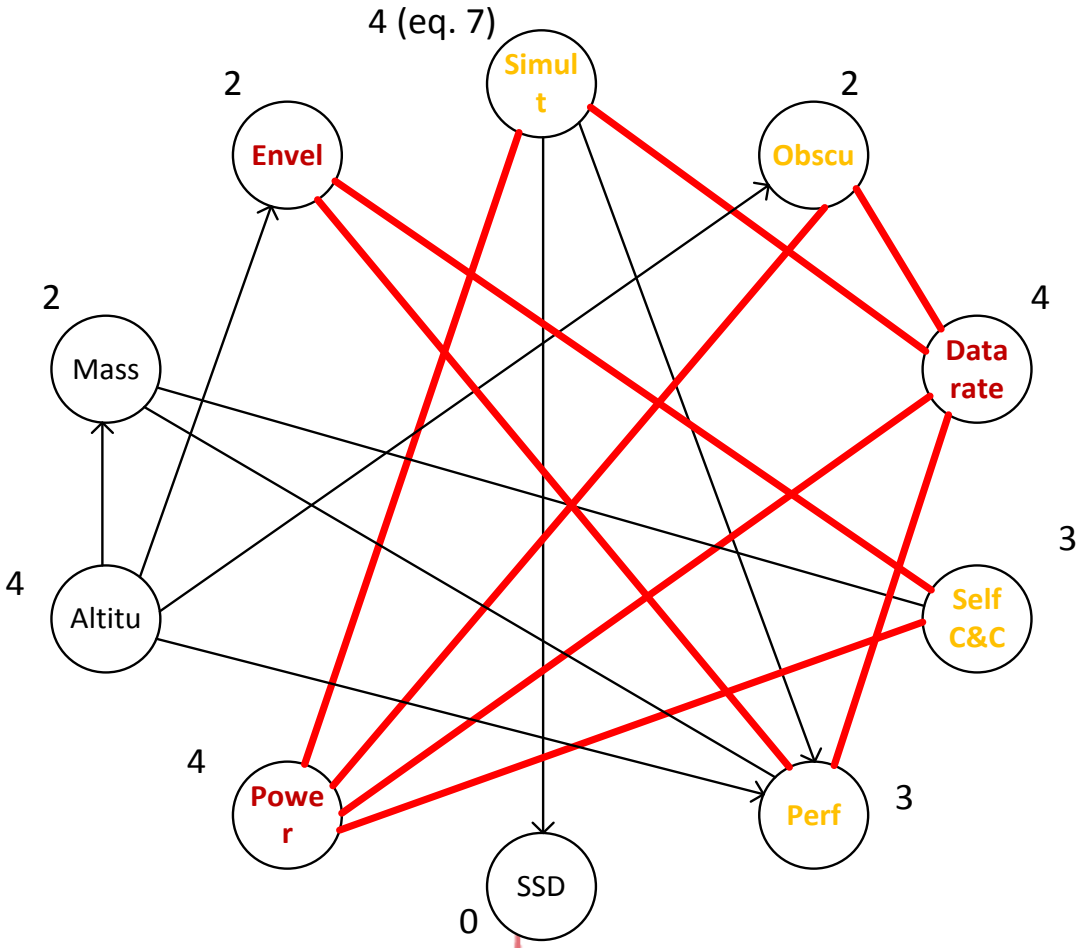

Less optimistic **prediction** than initially planned.

Change satellite platform to reduce upfront investment.

It results in **lower resources** for the instrument.

Resources → Functionality and performance.

Competitor

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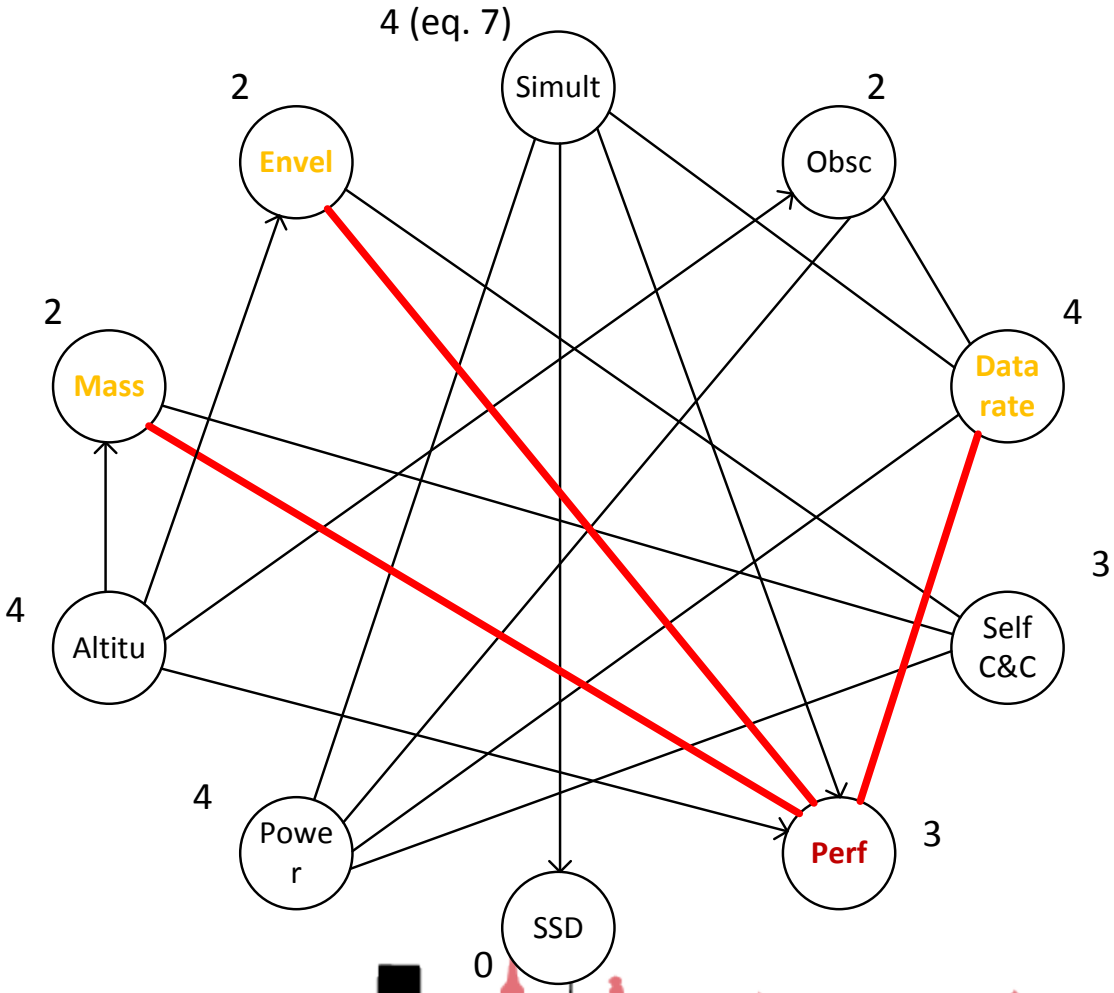

Competitor **same performance.**

Investors decide to **upgrade.**

Increase **performance**.

Performance → Resources

Schedule

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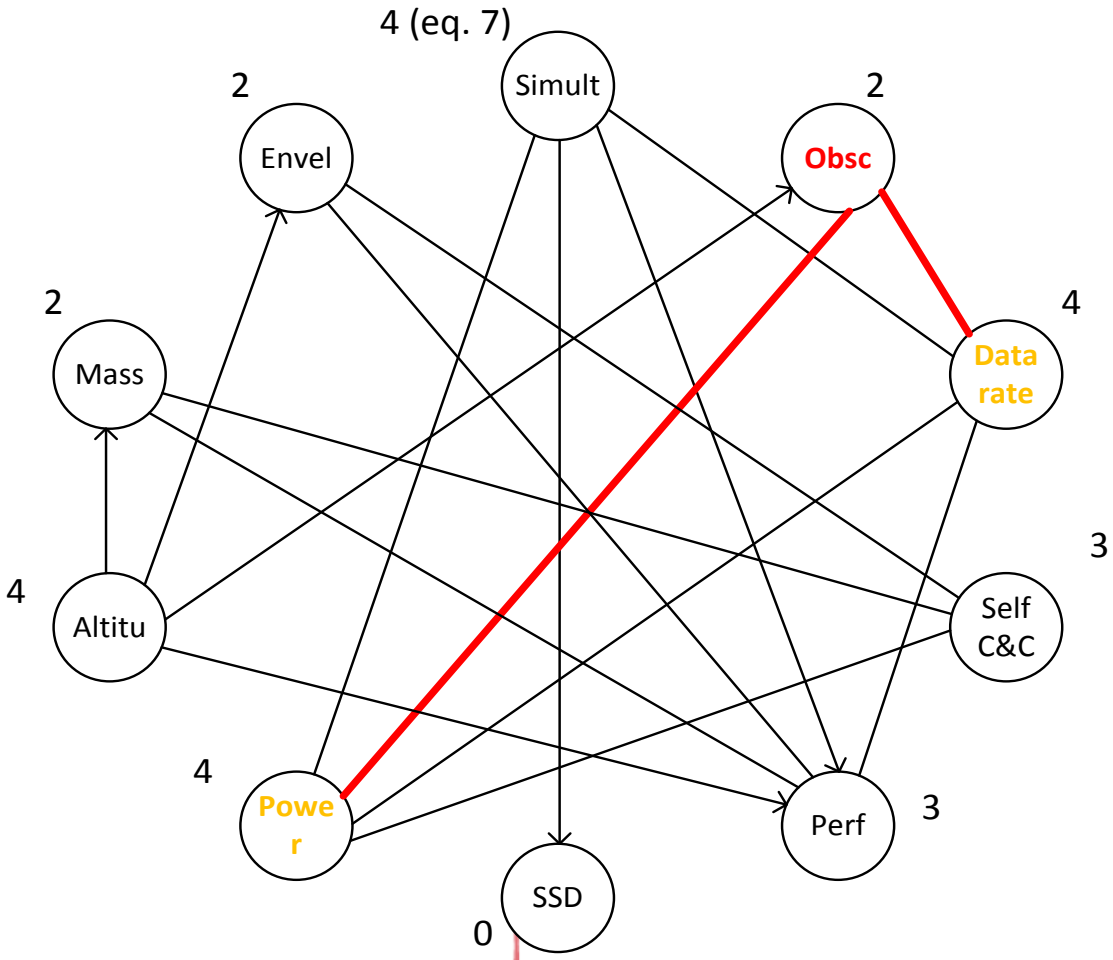

New **processing algorithm.**

Need **overlapping images.**

Decrease **obscuration level**.

Functionality → Perfomance and resources

Cost

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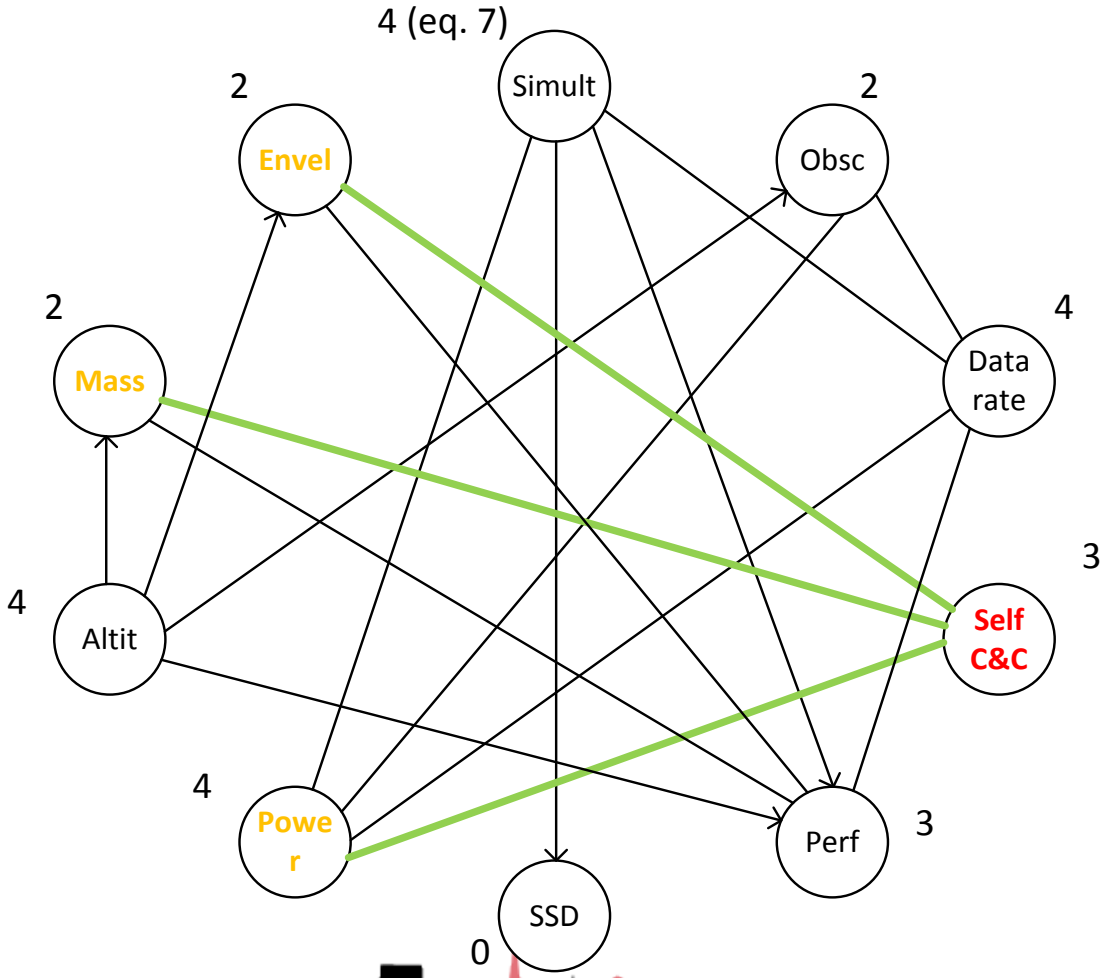

Severe **cost overrun.**

Move capability to platform.

Remove **self C&C**.

Functionality → Resources

Technical capability

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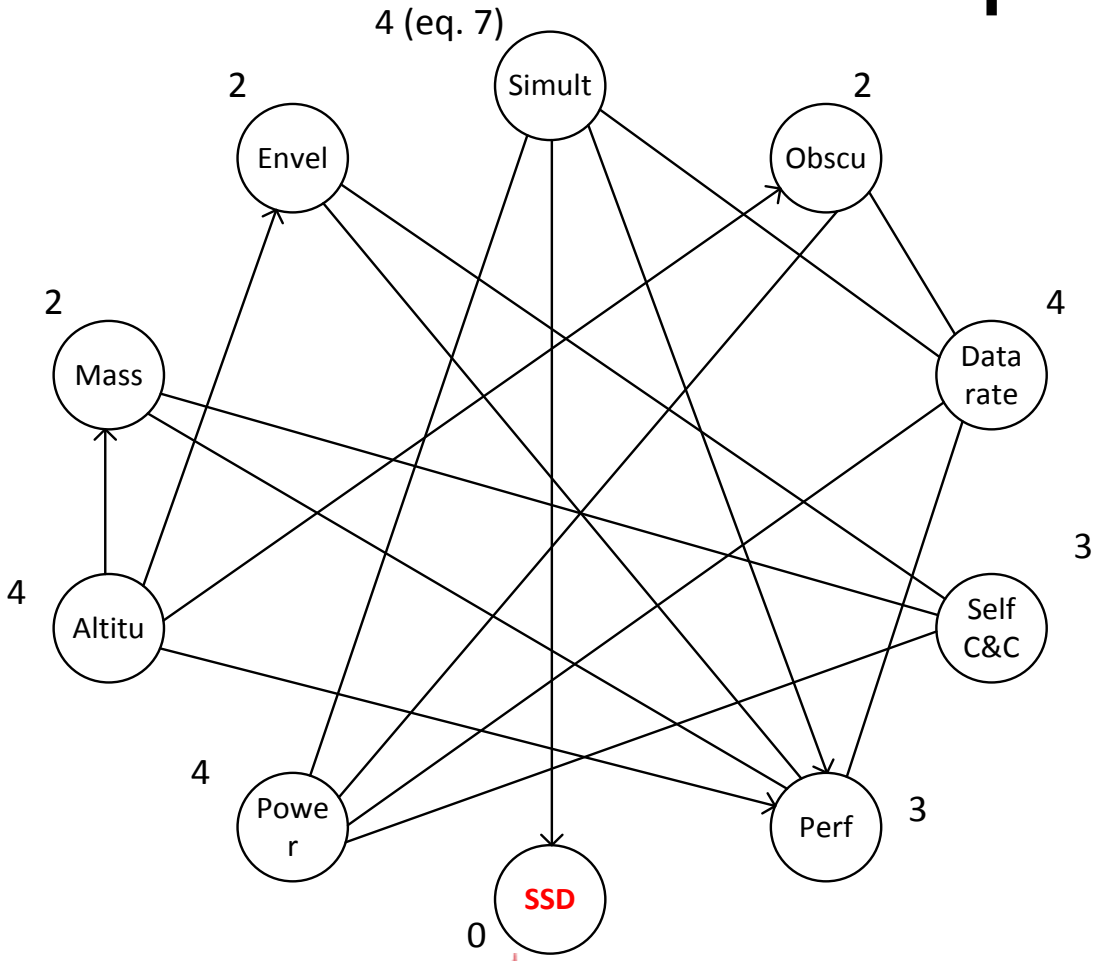

Cannot achieve **SSD.**

Issue an RFD**.**

Relax **SSD** requirement.

No impacts

Customer involvement

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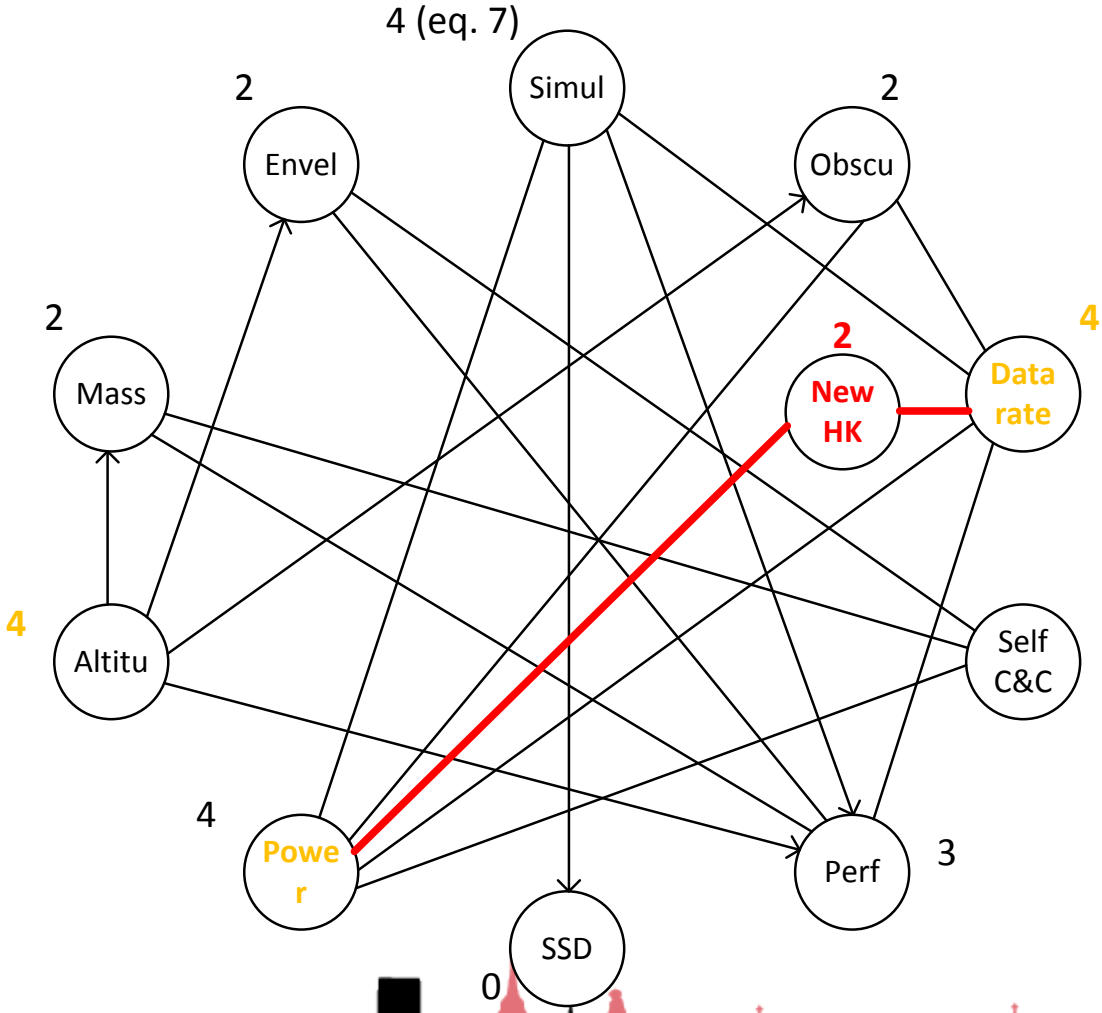

Customer **veto** at all levels.

Decide to have **more observability**.

Add a **new HK requirement**.

Functionality → Resources and performance

Export regulations

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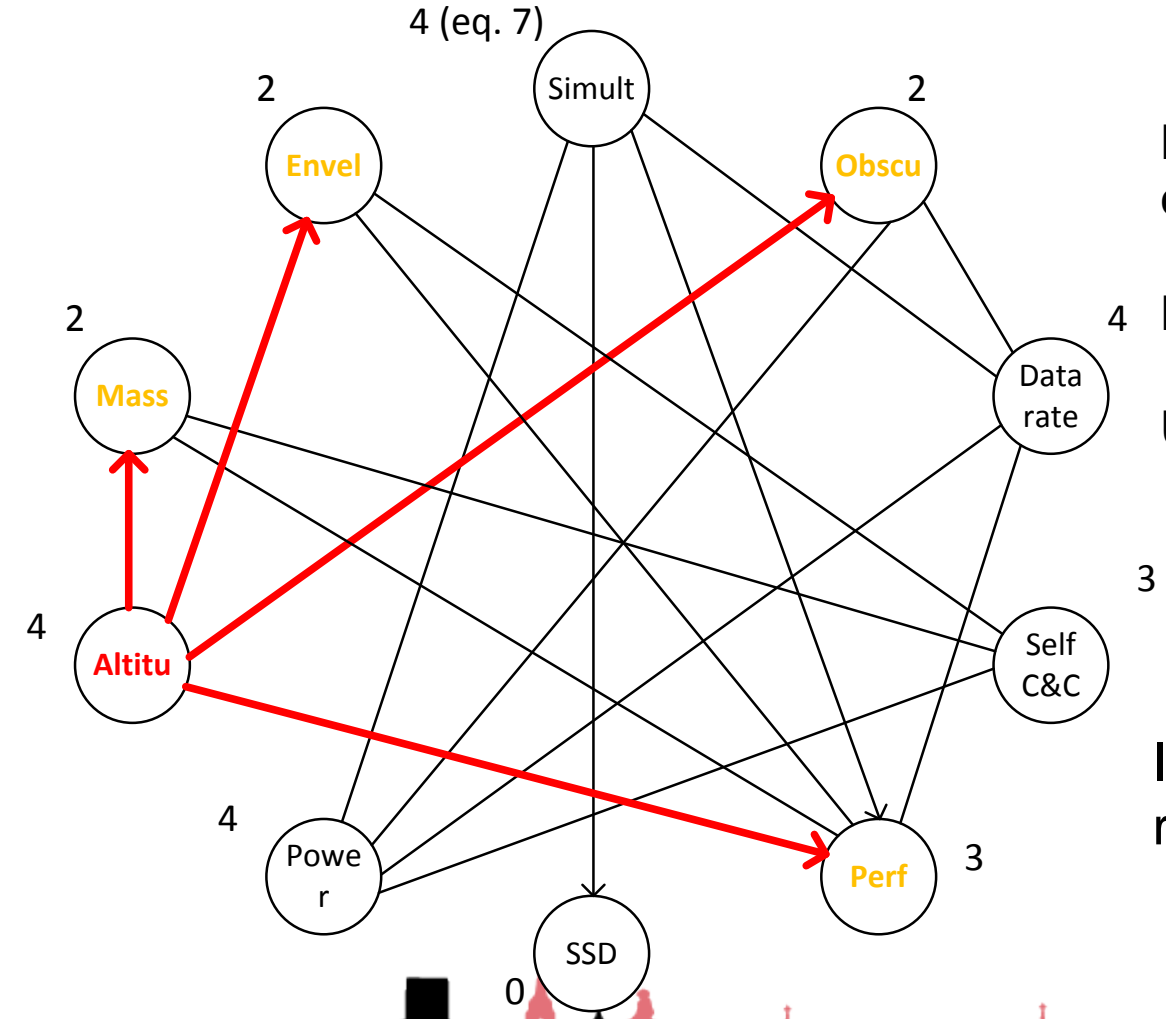

Export **control regulations change.**

Have to go with **different rocket**.

Use **different orbit**.

Interaction → Functionality, resources and performance

No derived laws, yet…

Case	Causal requirement type	Dependency impacts			Affected requirement type			
		C	R	Ch	F	P	R	I
1	Resource	9	5	9	X	X		
2	Performance	3	3	3			X	
3	Function	2	2	2		X	X	
4	Function	3	3	3			X	
5	Performance	0	0	0				
6	Function	2	2	2		X	X	
7	Interaction	4	4	4	X	X	X	

But some useful uses…

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Strategic **compliance** assessment

Strategic **verification** approach

Strategic **deliverable** definition

What's next?

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Search for **patterns**

Computational **algorithms**

Formalize constructs

Open for questions

Please, hold the tough ones…

Survey

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