Foundations Work Stream

Overall Documentation IW Working Sessions

Oli de Weck
FuSE Foundations Lead

Table of Contents.

- Keynote *“1st Law on System Science and Engineering” at a Glance*
- Takeaways from *“Complexity”* Experiment
- Takeaways from Case Study on *“Technical Complexity”*
- Takeaways from Case Study on *“Organizational Complexity”*

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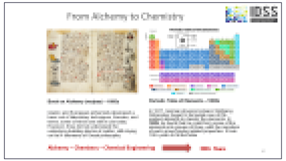
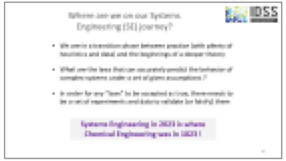
Keynote “Law of Complexity Conservation” at a Glance

The First Law of Systems Science: Conservation of Complexity

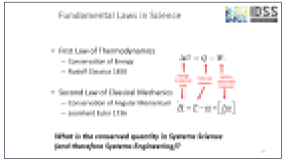
INCOSE International Workshop 2025

Prof. Olivier de Weck
Massachusetts Institute of Technology


From Alchemy to Chemistry

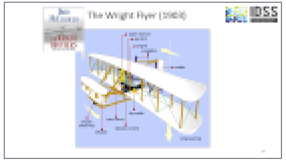

Where are we on our Systems Engineering (SE) journey?

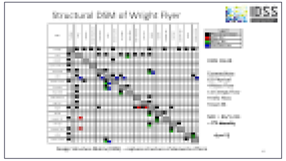
Systems Engineering in 2025 is where Chemical Engineering was in 1825 !

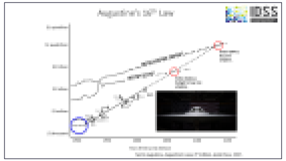

Fundamental Laws in Science

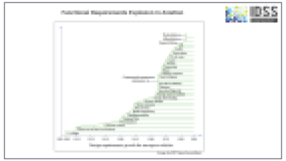
- First Law of Thermodynamics
  - Conservation of Energy
  - Rudolf Clausius 1850
- Second Law of Classical Mechanics
  - Conservation of Angular Momentum
  - Leonhard Euler 1736

What is the conserved quantity in Systems Science (and therefore Systems Engineering)?

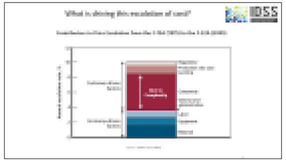

The Wright Flyer (1903)

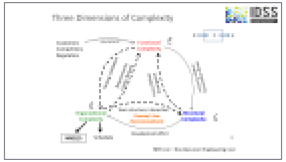

Structural DSM of Wright Flyer

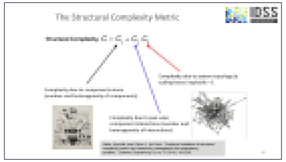

Augustine's 16th Law

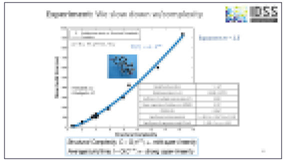

Functional Requirements Explosion in Aviation

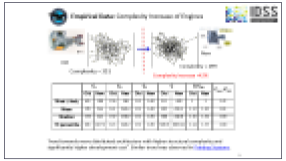
F-35 JSF

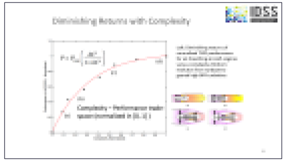

What is driving this escalation of cost?


Three Dimensions of Complexity


The Structural Complexity Metric


Experiments: We slow down w/complexity

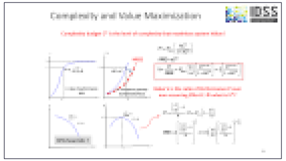

Empirical Data: Complexity Increase of Engines

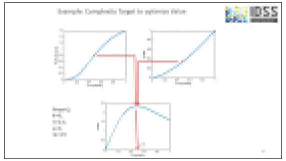

Diminishing Returns with Complexity

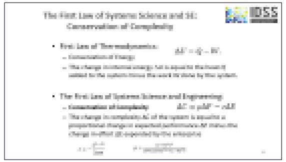
Complexity – Performance trade space (normalized in [0, 1])

VISION 2035

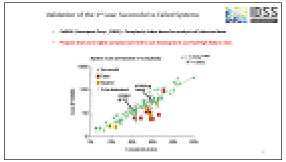
Theoretical Foundations

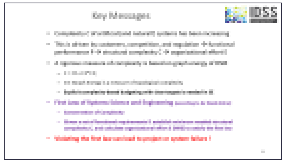

Complexity and Value Maximization


Example: Complexity Target to optimize Value


The First Law of Systems Science and SE: Conservation of Complexity

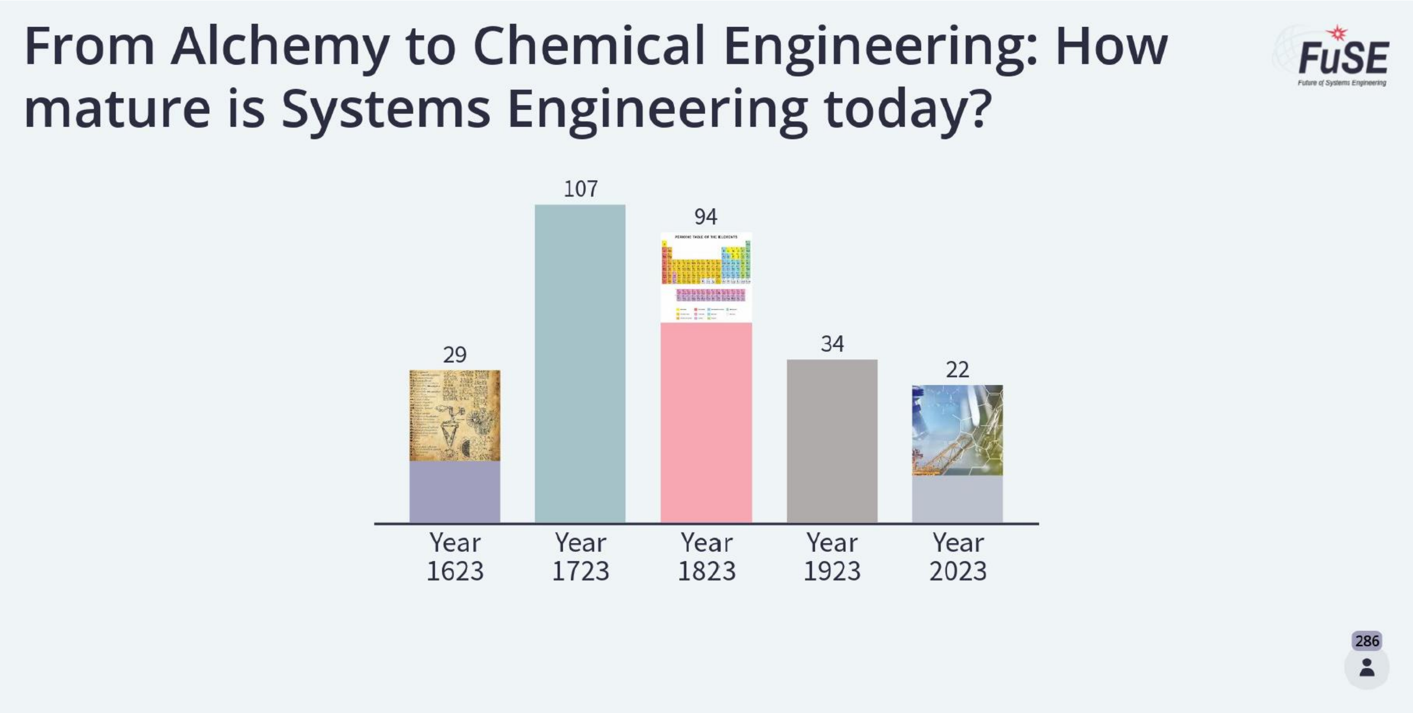
- First Law of Thermodynamics:
  - Conservation of Energy
- The First Law of Systems Science and Engineering
  - Conservation of Complexity


Validation of the 1st Law: Successful vs Failed Systems


Key Messages

- Violating the first law can lead to project or system failure !

Audience survey result “Where are we on our SE journey?”



From Alchemy to Chemical Engineering: How mature is Systems Engineering today?

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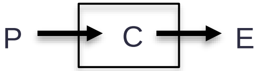
- Takeaways from Case Study on *“Technical Complexity”* on SUN
- Takeaways from Case Study on *“Organizational Complexity”* on MON

Test the (proposed) 1st Law of Systems Science & Engineering

Conservation of Complexity:

The change in complexity C of the system is equal to a proportional change in expected performance P minus the change in effort E expended by the enterprise

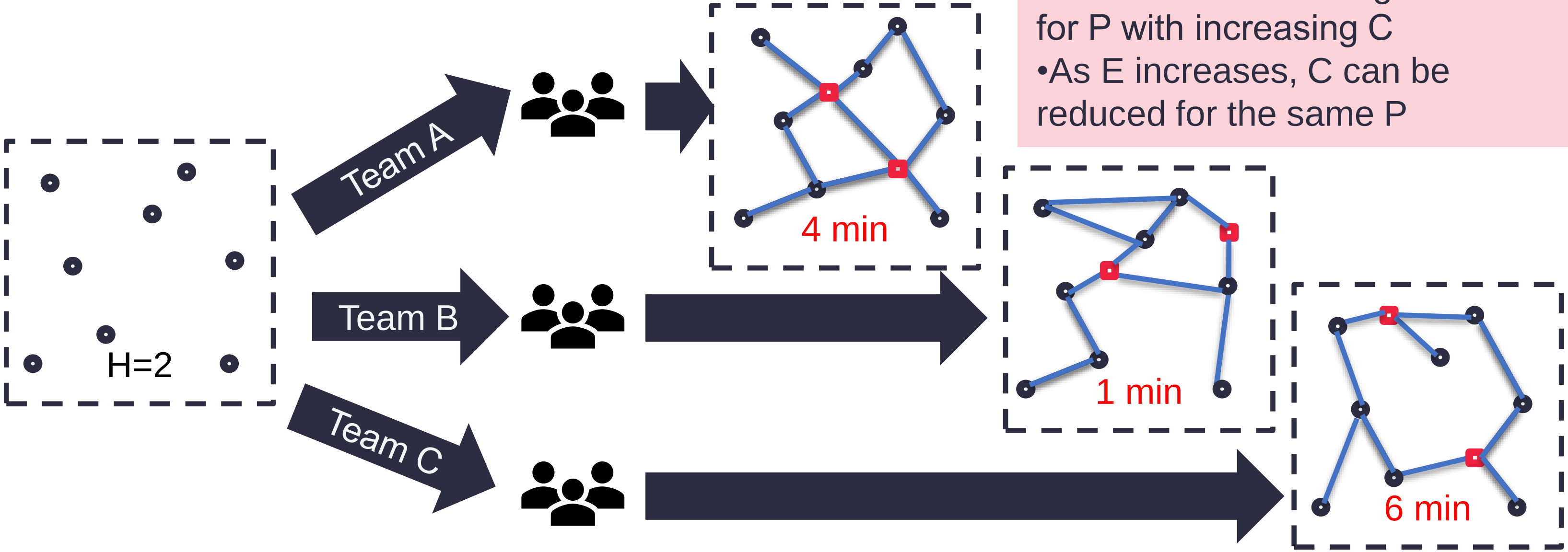


$$\Delta C = \mu \Delta P - \varepsilon \Delta E$$

Hypotheses tested:

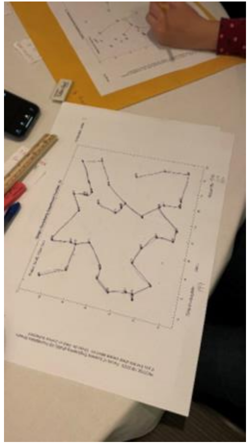
- Effort E (time) increases super-linearly with Complexity (C)
- The more effort a team spends the better the solution will be (P)
- There are diminishing returns for P with increasing C
- As E increases, C can be reduced for the same P

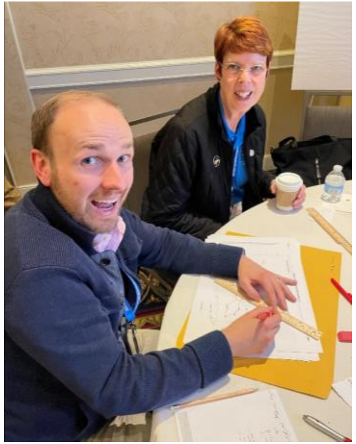
Designing a new transport system for a city.

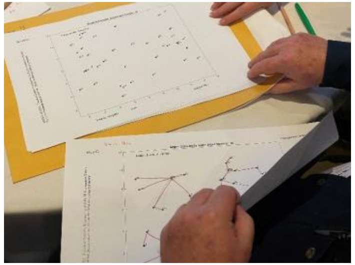


Impressions on “Complexity Experiment”

60 participants. Session A: 40 Participants. Session B: 20 Participants.



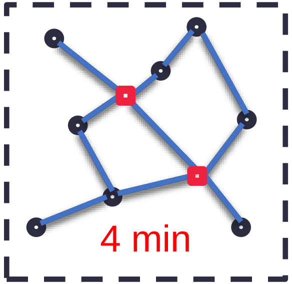




Details from “Complexity” Experiment

- **Observations** from the experiment:
  - Teams used **different approaches** which used more/less Effort E (time)
  - Teams produced **different designs** for each node network using more/less Effort
  - Teams developed **different heuristics** on their initial designs that they used in later sheets

- **Post Processing** to be done at MIT:



1								1	
	1					1			1
		1							1
			1			1		1	
				1			1		
					1		1	1	
	1		1			1			
				1	1		1		1
1			1		1			1	1
	1	1					1	1	1

Performance P

- minimum average path length

Complexity C

- normalized graph energy of network

Effort

- Time spent designing the system

Details from “Complexity” Experiment

Feedback and Suggested Improvements

- Making the experiment more realistic to real SE tasks:
  - Make the task **more complex**
  - More **constraints**: e.g Time limits
  - **Add uncertainty** by mid task: Introduce/Eliminate new nodes, Change team members, Change requirements, Pass partial solution to new team.
  - **Team adjustments**: Larger team sizes, Peer review, Assigned roles in teams.
  - **Focused** on **defined SE tasks** e.g. Requirements Analysis.
  - Introduce **legacy**: Existing network to modify
  - **Learning**: Get a score after each submission
  - **Tools**: Provide/Don't Provide support tools and compare benefits

Details from “Complexity” Experiment

Feedback and Suggested Improvements

- Some **difficulty understanding** the **task**. Especially what a success looks like. Improve instructions (perhaps printed and distributed to the team):
  - Show examples of optimal solution (minimum spanning tree) and worst solution (fully connected)
  - Walk through an example to start with
- Don't provide all the sheets at start. Once a sheet is complete, submit and collect a new one.
- Record abilities of participants before starting the task

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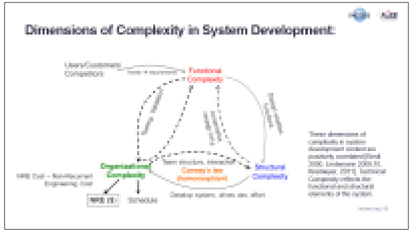
Takeaways from Case Study on “Technical Complexity”

- Approx. 60 participants in 6 groups
- Shared case study on Aviation Engines and evolution of their technical complexity
- Discussed proposed definition of “technical complexity”, **key aspects being confirmed** (e.g. #nodes, #interactions), and **additional aspects** (e.g. predicatibility, context, characteristics of nodes) **to consider** within definition **being proposed**
- Identified **areas for case studies** to generate **additional data** on the evolution of technical complexity **to verify or falsify** the definition of technical complexity

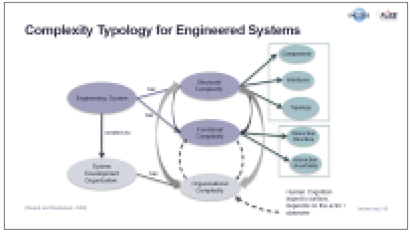
Key note 1 on “Technical Complexity” at a Glance



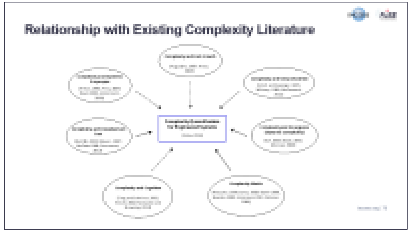
Dimensions of Complexity in System Development:

Users/Customers
Competitors
Functional Complexity
Organizational Complexity
Structural Complexity
Team structure, interaction
Conway's law (homomorphism)
Develop system, drives dev. effort
NRE Cost = Non-Recurring Engineering Cost
NRE ($)
Schedule

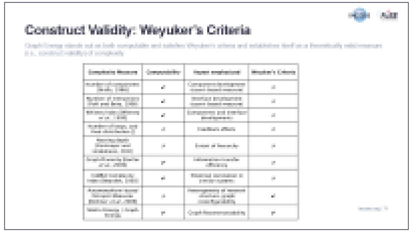
Three dimensions of complexity in system development which are positively correlated [illegible]. Technical Complexity reflects the functional and structural elements of the system.



Complexity Typology for Engineered Systems

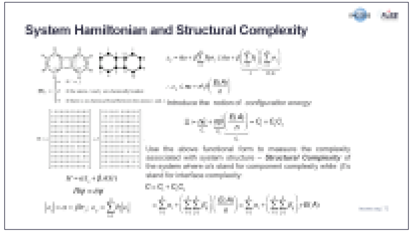


Relationship with Existing Complexity Literature



Construct Validity: Weyuker's Criteria

Complexity Measure	Computability	Aspect emphasized	Weyuker's Criteria
[illegible]	✓	[illegible]	[illegible]
[illegible]	✓	[illegible]	[illegible]
[illegible]	✓	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	✓	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	✓
[illegible]	[illegible]	[illegible]	[illegible]

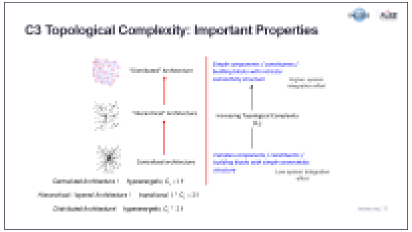


System Hamiltonian and Structural Complexity

Introduce the notion of configuration energy

Use the above functional form to measure the complexity associated with system structure – Structural Complexity of the system where αs stand for component complexity while βs stand for interface complexity

$C = C_1 + C_2C_3$



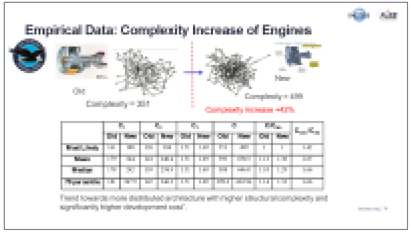
C3 Topological Complexity: Important Properties

"Distributed" Architecture
"Hierarchical" Architecture
Centralized Architecture
Simple components / constituents / building blocks with intricate connectivity structure
Higher system integration effort
Increasing Topological Complexity (C_3)
Complex components / constituents / building blocks with simple connectivity structure
Low system integration effort

Centralized Architecture : hypoenergetic $C_3 < 1$

Hierarchical / layered Architecture : transitional $1 \le C_3 < 2$

Distributed Architecture : hyperenergetic $C_3 \ge 2$



Empirical Data: Complexity Increase of Engines

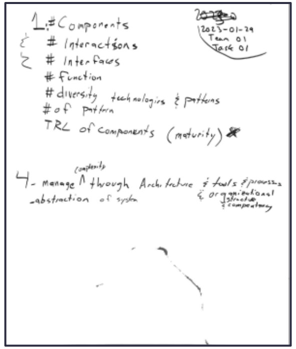
Trend towards more distributed architecture with higher structural complexity and significantly higher development cost.

Discussion: Technical Complexity

1. How would you define technical complexity?
2. How do you currently quantify technical complexity? How should it be done?
3. Has technical complexity increased in your domain over time? How much? Why?
4. How would you actively manage technical complexity?

Results on “Technical Complexity” - Group breakout 1

T1

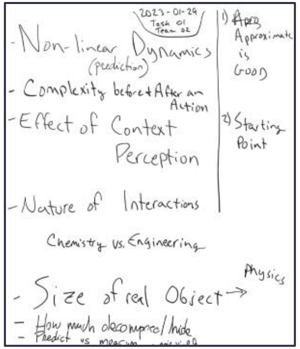


2023-01-29
Team 01
Task 01

1. # Components
   # Interactions
   # Interfaces
   # Function
   # diversity technologies & patterns
   # of pattern
   TRL of components (maturity)

4 - manage complexity through Architecture & tools & processes & organizational structure & competency
- abstraction of system

T2



2023-01-29
Task 01
Team 02

- Non-linear Dynamics (prediction)
- Complexity before + After an Action
- Effect of Context Perception
- Nature of Interactions

Chemistry vs. Engineering

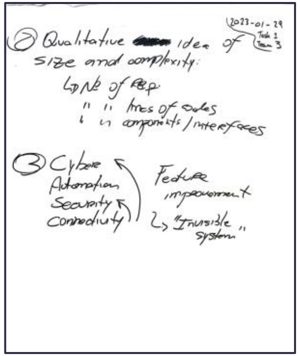
Physics

- Size of real Object →
- How much decompose / hide
- Predict vs measur

1) ~~Appr~~ Approximate is Good

2) Starting Point

T3



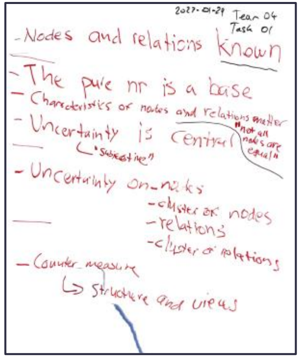
2023-01-29
Task 1
Team 3

② Qualitative [redacted] idea of size and complexity:
↳ Nº of Req.
" " lines of codes
" " components / interfaces

③ Cyber
Automation
Security
Connectivity

Feature improvement
↳ "Invisible system"

T4



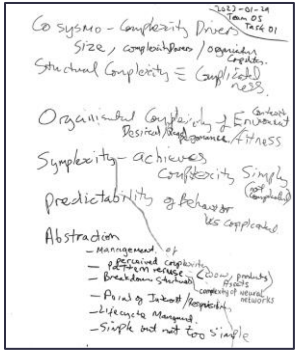
2023-01-29 Team 04
Task 01

- Nodes and relations known
- The pure nr is a base
- Characteristics of nodes and relations matter
- Uncertainty is central
  ↳ "subjective"

"not all nodes are equal"

- Uncertainty on nodes
  - cluster of nodes
  - relations
  - cluster of relations
- Counter measure
  ↳ Structure and views

T5



2023-01-29
Team 05
Task 01

Co sysmo - Complexity Drivers
Size, complexity drivers / organization capabilities.
Structural Complexity ≡ Complicatedness.

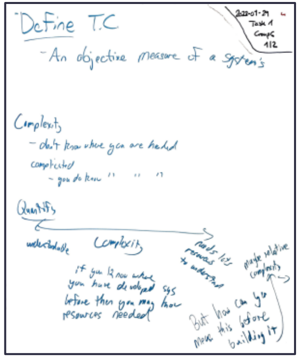
Organisational Complexity & Environment Context
Desired / Req. performance / fitness

Symplexity - achieves Complexity Simply (not complicated)

Predictability of behavior
less complicated

Abstraction
- Management of perceived complexity
- Pattern reuse
- Breakdown Structure (SOW, products, Assets)
  complexity of neural networks
- Point of Interest / Responsibility
- Lifecycle Management.
- Simple but not too simple

T6



2023-01-29
Task 1
Group 6
1/2

Define T.C
- An objective measure of a system's

Complexity
- don't know where you are headed
complicated
- you do know " " "

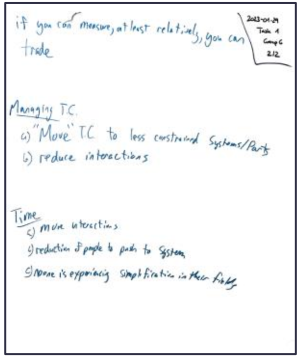
Quantify

understandable ← Complexity → needs lots resources to understand

if you know what you have developed sys before then you may know resources needed

maybe relative complexity

But how can you know this before building it



2023-01-29
Task 1
Group 6
2/2

if you can measure, at least relatively, you can trade

Managing T.C.
a) "Move" T.C to less constrained Systems/Parts
b) reduce interactions

Time
a) more interactions
b) reduction of people to push to System
c) None is experiencing simplification in their fields

Some details on “Technical Complexity” - Group breakout 1

Group feedback **confirming** key aspects of proposed definition of technical complexity…

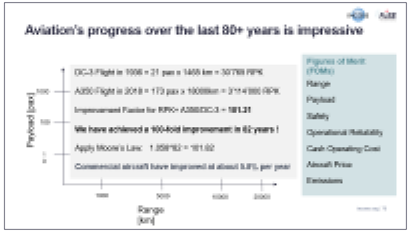
- # of components, interactions, and functions
- # of diversity of patterns
- # of nodes and relations known as a base

Term "simplexity“ discussed, defined as “achievement of complexity but simple”

Group feedback **indicating aspects to be considered** within definition of technical complexity

- predictability and non-linearity
- effect of context and perception
  - person looking at system
  - context the system is put into
- size of system
- characteristics of nodes and relationships (e.g. uncertainty on nodes, nature of interactions)
- maturity level of system, system elements

Key note 2 on “Technical Complexity” at a Glance



Aviation's progress over the last 80+ years is impressive

DC-3 Flight in 1936 = 21 pax x 1465 km = 30765 RPK

A350 Flight in 2018 = 173 pax x 18000km = 3'114'000 RPK

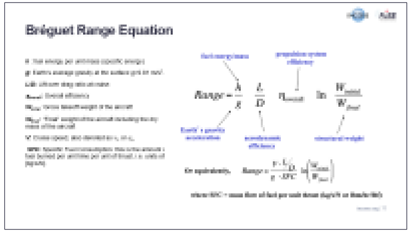
Improvement Factor for RPK= A350/DC-3 = 101.21

We have achieved a 100-fold improvement in 82 years !

Apply Moore's Law: 1.058^82 = 101.02

Commercial aircraft have improved at about 5.8% per year

Figures of Merit (FOMs)
Range
Payload
Safety
Operational Reliability
Cash Operating Cost
Aircraft Price
Emissions

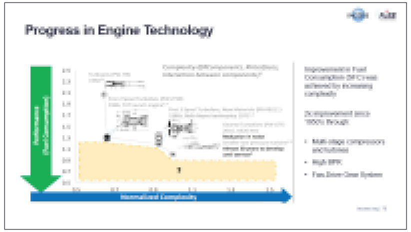


Bréguet Range Equation

$$Range = \frac{h}{g}\,\frac{L}{D}\,\eta_{overall}\,\ln\frac{W_{initial}}{W_{final}}$$

Or equivalently,
$$Range = \frac{V \cdot \frac{L}{D}}{g \cdot SFC}\,\ln\left(\frac{W_{initial}}{W_{final}}\right)$$

where SFC = mass flow of fuel per unit thrust (kg/s/N or lb/s/lbf)

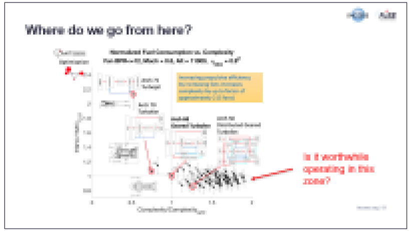


Progress in Engine Technology

Improvements in Fuel Consumption (SFC) were achieved by increasing complexity

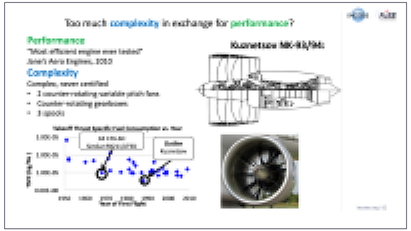
Improvement since 1930's through:

- Multi-stage compressors and turbines
- High BPR
- Fan Drive Gear System



Where do we go from here?

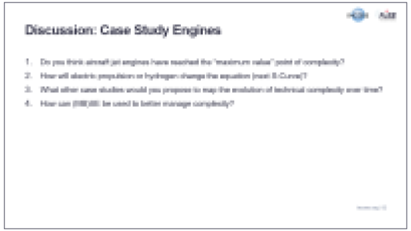
Is it worthwhile operating in this zone?



Too much complexity in exchange for performance?

Performance
"Most efficient engine ever tested"
Jane's Aero Engines, 2002

Complexity
Complex, never certified
- 2 counter-rotating variable pitch fans
- Counter-rotating gearboxes
- 3 spools

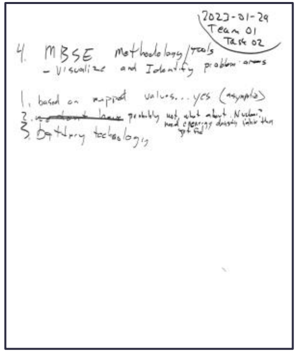


Discussion: Case Study Engines

1. Do you think aircraft jet engines have reached the "maximum value" point of complexity?
2. How will electric propulsion or hydrogen change the equation (next S-Curve)?
3. What other case studies would you propose to map the evolution of technical complexity over time?
4. How can (MB)SE be used to better manage complexity?

Results on “Technical Complexity” - Group breakout 2

T1

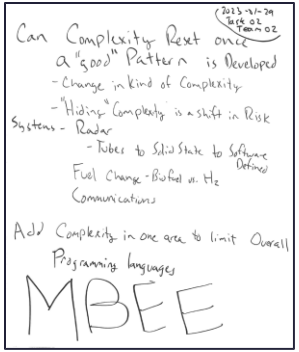


2023-01-29
Team 01
Task 02

4. MBSE methodology/tools
- visualize and Identify problem areas

1. based on mapped values... yes (asymptote)
2. ~~we don't have~~ probably not, what about Nuclear? need energy density better than got fuel
3. Battery technology

T2



2023-01-29
Task 02
Team 02

Can Complexity Reset once a "good" Pattern is Developed
- Change in Kind of Complexity
- "Hiding" Complexity is a shift in Risk

Systems - Radar
- Tubes to Solid State to Software Defined

Fuel Change - Biofuel vs. H_2

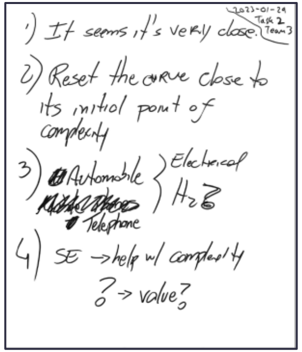
Communications

Add Complexity in one area to limit Overall

Programming languages

MBEE

T3



2023-01-29
Task 2
Team 3

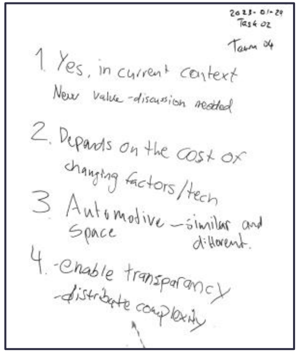
1) It seems it's veRy close.

2) Reset the cuRve close to its initial point of complexity

3) Automobile } Electrical
Telephone } H_2?

4) SE → help w/ complexity
? → value?

T4



2023-01-29
Task 02
Team 04

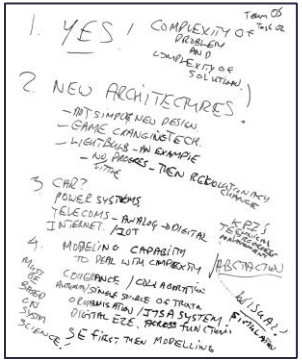
1. Yes, in current context
New value-discussion needed

2. Depends on the cost of changing factors/tech

3. Automotive – similar and different.
Space

4. -enable transparency
-distribute complexity

T5



Team 05
Task 02

1. YES! (COMPLEXITY OF PROBLEM AND COMPLEXITY OF SOLUTION.)

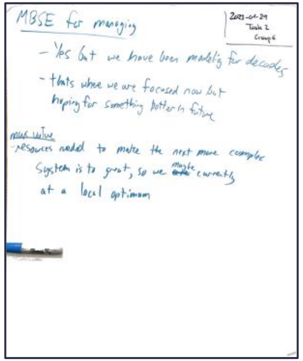
2. NEW ARCHITECTURES.
- NOT SIMPLE NEW DESIGN
- GAME CHANGING TECH.
- LIGHTBULB - AN EXAMPLE
- NO/LITTLE PROGRESS - THEN REVOLUTIONARY CHANGE

3. CAR?
POWER SYSTEMS
TELECOMS - ANALOG → DIGITAL
INTERNET /IOT

KPIS TECHNICAL MANAGEMENT

4. MODELING CAPABILITY TO DEAL WITH COMPLEXITY
ABSTRACTION
COHERENCE / COLLABORATION
AUTOMATION/SINGLE SOURCE OF TRUTH
ORGANISATION / JTSA SYSTEM
DIGITAL EZE. ACROSS FUNCTIONS.
VISUAL! SIMULATION
MUST BE BASED ON SYSTEM SCIENCE. - SE FIRST THEN MODELLING

T6



MBSE for managing

2023-01-29
Task 2
Group 6

- Yes but we have been modeling for decades
- thats where we are focused now but hoping for something better in future

max value
- resources needed to make the next more complex system is to great, so we ~~are~~ maybe currently at a local optimum

Some details on “Technical Complexity” - Group breakout 2

Potential areas to look at for **additional case studies** to generate data on evolution of technical complexity being useful to **verify or falsify** the proposed definition of technical complexity

- Radar
- Radio
- Programming languages
- Mobile Phones
- Automotive
- Space
- Telecom
- Power Systems
- Internet
- …

Impressions on “Technical Complexity”

Table of Contents.

- Keynote *“1st Law on System Science and Engineering”* at a Glance
- Takeaways from *“Complexity”* Experiment
- Takeaways from Case Study on *“Technical Complexity”*
- **Takeaways from Case Study on “Organizational Complexity”**

Takeaways from Case Study on “Org Complexity”

- Approx. 50 participants in 6 groups
- Shared **update of Systems Science WG** on current state of their work
- Shared case study on **SLS vs. Space X Falcon 9** regarding their org complexity
- Generated **potential drivers** of “org complexity” during group breakout discussion, key aspects being e.g. #people, #roles, #channels of interaction, etc. …
- … but also admitting **challenges** in measuring org complexity due to its fuzziness, people being in multiple roles, and individual agendas
- Discussed drives for **increased org complexity** and potential **levers to manage**
- Identified **virtues** and **demerits** of strong vertical org integration

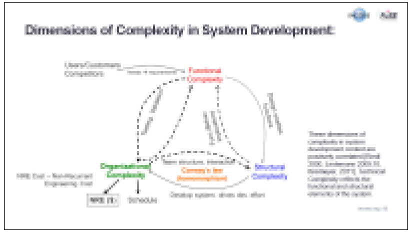
Key note 1 on “Organizational Complexity” at a Glance

Example: Organizational Complexity

- Large offshore oil and gas project (BP) Angola (Greater Plutonio – Block 18)
- Organizational Network revealed through formal relationships in the Management of Change (MOC) process
- Over 500+ individuals involved. Some multi-disciplinary engineers hold the network together

Change owners owning more than 2 disciplines in the Greater Plutonio change owner network act as "hubs" in the MOC system

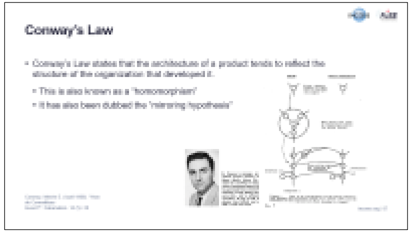
[illegible]



Dimensions of Complexity in System Development:

Users/Customers
Competitors
Functional Complexity
Organizational Complexity
Structural Complexity
Team structure, interaction
Conway's law (homomorphism)
NRE Cost – Non-Recurrent Engineering Cost
NRE ($)
Schedule
Develop system, drives dev. effort

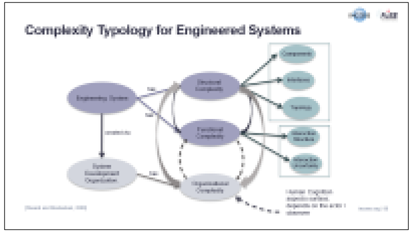
These dimensions of complexity in system development evolve are positively correlated [illegible]. Technical Complexity reflects the functional and structural elements of the system.



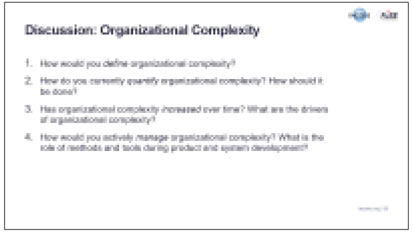
Conway's Law

- Conway's Law states that the architecture of a product tends to reflect the structure of the organization that developed it.
  - This is also known as a "homomorphism"
  - It has also been dubbed the "mirroring hypothesis"

Conway, Melvin E. (April 1968). "How do Committees Invent?" Datamation. 14 (5): 28–31



Complexity Typology for Engineered Systems

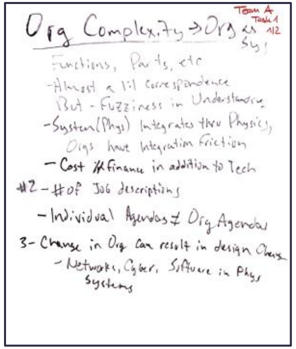


Discussion: Organizational Complexity

1. How would you define organizational complexity?
2. How do you currently quantify organizational complexity? How should it be done?
3. Has organizational complexity increased over time? What are the drivers of organizational complexity?
4. How would you actively manage organizational complexity? What is the role of methods and tools during product and system development?

Results on “Organizational Complexity” - Group breakout 1

B



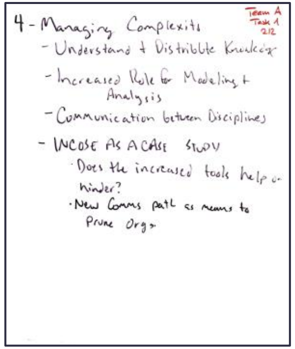
Team A Task 1 1/2

Org Complexity → Org as Sys!

Functions, Parts, etc
- Almost a 1:1 correspondence
But - Fuzziness in Understanding
- System (Phys) Integrates thru Physics, Orgs have Integration Friction
- Cost ~~/~~ Finance in addition to Tech

#2 - # of Job descriptions
- Individual Agendas ≠ Org Agendas

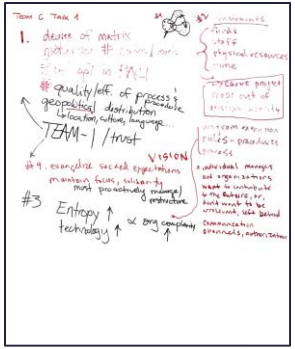
3 - Change in Org can result in design Changes
- Networks, Cyber, Software in Phys Systems



Team A Task 1 2/2

4 - Managing Complexity
- Understand + Distribute Knowledge
- Increased Role for Modeling + Analysis
- Communication between Disciplines
- INCOSE AS A CASE STUDY
  - Does the increased tools help or hinder?
  - New Comms path as means to Prune Orgs.

D



Team C Task 1

1. degree of matrix
[illegible] # [illegible]
[illegible] in [illegible]
* quality/eff. of process & procedure
geopolitical distribution
↳ location, culture, language...
TEAM - | / trust

VISION

#4. evangelize secured expectations
maintain focus, solidarity
most proactively manage/restructive

#3 Entropy ↑ technology ↑ ∝ org complexity ↑

constraints
- funds
- staff
- physical resources
- time

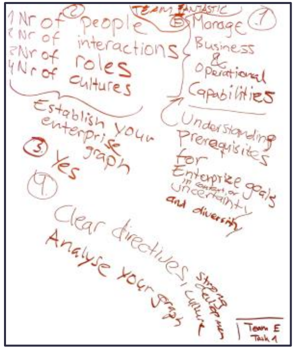
→ Carve project scope out of mission identity

uniform execution
rules - procedures
process

* individual managers and organizations want to contribute to the future, or, don't want to be irrelevant, left behind

communication channels, authorization

G



TEAM FANTASTIC

1 Nr of ② people
2 Nr of interactions
3 Nr of roles
4 Nr of cultures

Establish your enterprise graph

③ Yes

④

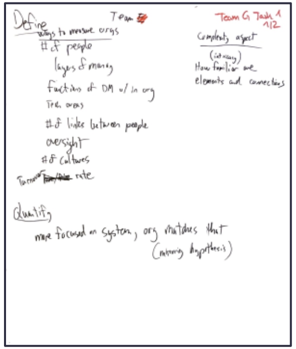
Clear directives, culture
Analyse your graph
Strong leadership

⑤ Manage ① Business & Operational Capabilities

Understanding Prerequisites for Enterprise goals in context of uncertainty and diversity

Team E Task 1

E



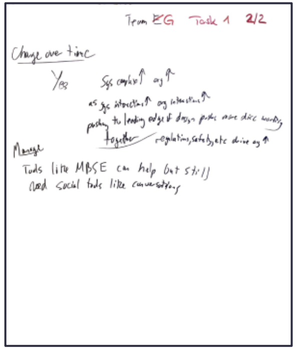
Team ~~E~~

Team G Task 1 1/2

Define
ways to measure orgs
- # of people
  - layers of mgmt
- Functions of DM w/in org
- Tech areas
- # of links between people
- oversight
- # of cultures
- Turnover ~~[illegible]~~ rate

Complexity aspect
(intimacy)
How familiar are elements and connections

Quantify
more focused on system, org matches that (mirroring hypothesis)



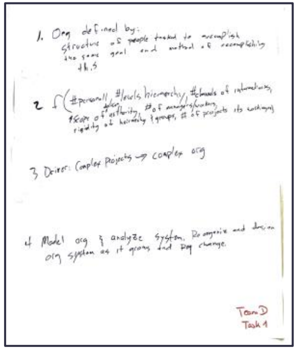
Team EG Task 1 2/2

Change over time

Yes Sys complex ↑ org ↑
as sys interactions ↑ org interactions ↑
pushing the leading edge of design pushes more disc working together
regulations, safety, etc drive org ↑

Manage
Tools like MBSE can help but still need social tools like conversations

C



1. Org defined by: structure of people tasked to accomplish the same goal and method of accomplishing this

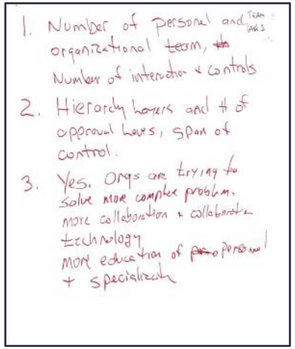
2 f(#personnel, #levels hierarchy, #channels of interactions, #scope of delegation authority, # of managers/workers, rigidity of hierarchy + groups, # of projects its working)

3 Driver: Complex Projects → complex org

4 Model org & analyze system. Re organize and design org system as it grows and Reg change.

Team D Task 1

A

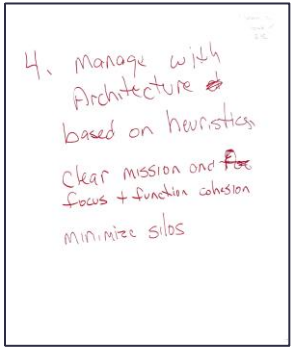


TEAM Task 1

1. Number of personal and organizational team, ~~th~~
Number of interaction & controls

2. Hierarchy layers and # of approval Levels, span of control.

3. Yes. Orgs are trying to solve more complex problem.
more collaboration + collaborate technology
more education of ~~[illegible]~~ personnel + specialization



4. Manage with Architecture ~~[illegible]~~
based on heuristics

clear mission and ~~[illegible]~~ focus + function cohesion

minimize silos

How to define and quantify “organizational complexity”?

Basically the same way as technical complexity, i.e. # nodes, # interactions, etc.

What are **potential drivers** to consider:

- # people
- # roles / job descriptions
- # channels of interaction
- # levels of hierarchy / approval
- # scope of authority (for roles / for teams)
- # cultures
- # span of controls
- # transactional cost

Challenges in measuring organizational complexity

- much more fuzziness
- individual agendas don’t line up with organizational agenda
- many people in multiple roles
- end up with much more emergence

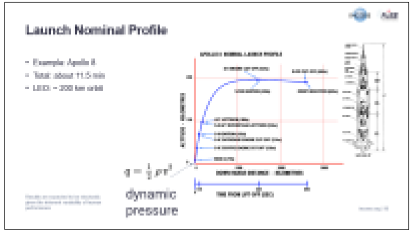
What are drivers for increased “organizational complexity”?

- more complex problems to solve
- culture shift how we work
- grown educational level
- grown specialization
- increase of collaboration tools
- grown formality, e.g. reviews, etc., working on artifacts that are not solving the problem
- increased agency complexity

What are levers to manage “organizational complexity”?

- w/ clarity on vision, mission, and focus
- w/ communication btw disciplines and new comm paths as means to prune organization
- w/ architecture, i.e. functional cohesion, minimization of silos
- w/ knowledge, i.e. understand & distribute knowledge
- w/ MBSE, is like using a bulldozer, i.e. more powerful, but brings own complexity

Key note 2 on “Organizational Complexity” at a Glance

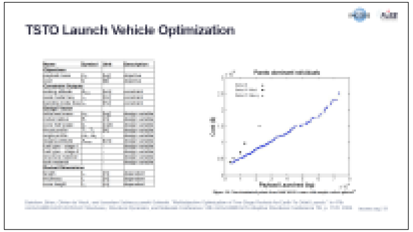


Launch Nominal Profile

- Example: Apollo 8
- Total: about 11.5 min
- LEO: ~200 km orbit

$q = \frac{1}{2}\rho v^2$

dynamic pressure



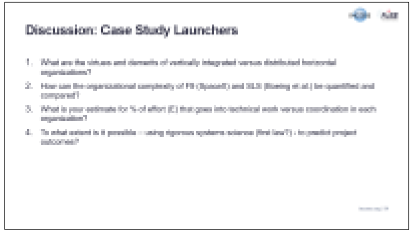
TSTO Launch Vehicle Optimization

Falcon-9 FT

- Falcon-9 is developed and manufactured by SpaceX using a vertically integrated organization
- Commercially led
- 170 Launches (FT)
- 0 Failures
- Cost per launch: $67M
- Capacity to LEO: 22,800 kg
- Cost per kg: ~$3k
- Schedule: 2005-2010 (5y)
- NRE (v1.0): $300M (vs. $4B* had it been cost-plus)

SLS

- The Space Launch System (SLS) is developed and manufactured by a large consortium in a horizontal distributed organization
- Government led
- 1 Launch so far (6 planned)
- Cost per launch: $2B
- Capacity to LEO: 95,000 kg
- Cost per kg: ~$21k
- Schedule: 2011-2022 (11y)
- NRE: $27.9B (FY 2022)

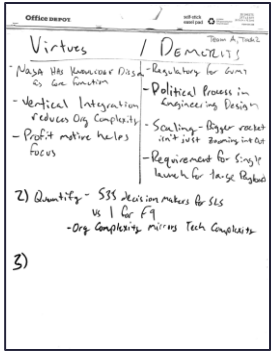


Discussion: Case Study Launchers

1. What are the virtues and demerits of vertically integrated versus distributed horizontal organizations?
2. How can the organizational complexity of F9 (SpaceX) and SLS (Boeing et al.) be quantified and compared?
3. What is your estimate for % of effort (E) that goes into technical work versus coordination in each organization?
4. To what extent is it possible – using rigorous systems science (first law?) - to predict project outcomes?

Results on “Organizational Complexity” - Group breakout 2

T1



Office DEPOT

Team A, Task 2

Virtues / Demerits

- Nasa Has Knowledge Dissem as Core function
- Vertical Integration reduces Org Complexity
- Profit motive helps focus

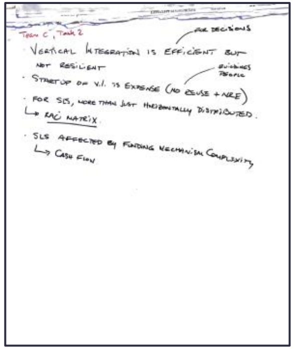
- Regulatory for Gov't
- Political Process in Engineering Design
- Scaling - Bigger rocket isn't just Zooming in & Out
- Requirement for Single launch for large Payload

2) Quantify - 535 decision makers for SLS vs 1 for F9

-Org Complexity mirrors Tech Complexity

3)

T2



Team C, Task 2

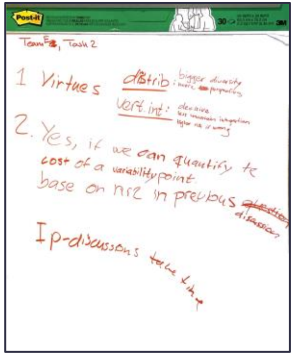
- Vertical Integration is efficient for decisions but not resilient
- Startup of V.I. is expense (no reuse + NRE) buildings people
- For SLS, more than just horizontally distributed.

↳ RACI MATRIX

- SLS affected by funding mechanism complexity

↳ Cash Flow

T3



Post-it

Team E, Task 2

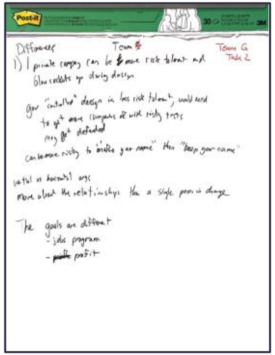
1 Virtues distrib: bigger diversity more perspectives

vert. int: decisive less uncertain integration higher risk if wrong

2. Yes, if we can quantify the cost of a variability point base on nre in previous ~~question~~ discussion

Ip-discussons take time

T4



Post-it

Differences

Team G Task 2

1) private company can be more risk tolerant and blow rockets up during design

gov "controlled" design is less risk tolerant, would need to get more companies with risky tests may get defunded

can be more risky to "make your name" then "keep your name"

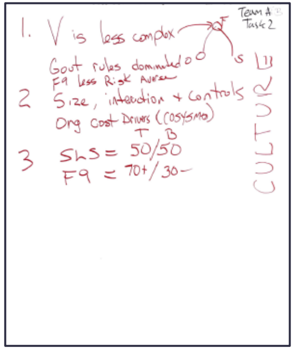
vertical vs horizontal orgs

more about the relationships than a single person in charge

The goals are different

- jobs program
- ~~profit~~ profit

T5



Team A B Task 2

1. V is less complex → F

Govt rules dominated S

F9 less Risk Averse

2 Size, interaction + controls

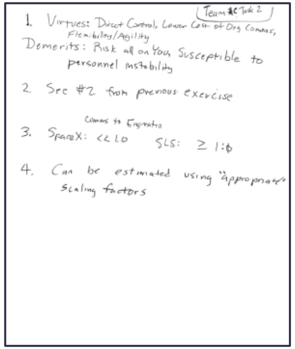
Org Cost Drivers (COSYSMO)

3 SLS = 50/50 (T B)

F9 = 70+/30-

CULTURE

T6



Team C Task 2

1. Virtues: Direct Control, Lower Cost of Org Comms, Flexibility/Agility

Demerits: Risk all on You, Susceptible to personnel instability

2. See #2 from previous exercise

3. SpaceX: << 1.0 SLS: ≥ 1:0 (Comms to Eng ratio)

4. Can be estimated using "appropriate" scaling factors

What are virtues and demerits of vertical integration?

Virtues of vertical integration

- NASA has knowledge dissemination as core function
- Vertical integration reduces org complexity
- Profit motive helps focus
- Is efficient for decisions, is decisive
- Less uncertain integration
- Private company can be more risk tolerant
- Direct control and lower cost of org comm
- Flexibility / Agility

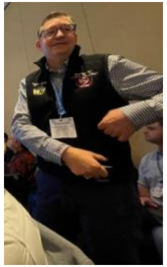
Demerits of vertical integration

- Regulatory for government
- Political process in engineering design
- Scaling bigger rocket isn’t just zooming in out
- Requirements for single launch for large payload
- Is not resilient
- SLS affected by funding mechanism complexity
- SLS is not just horizontally distributed
- Higher risk if wrong, risk all on yours
- Less perspectives, less diversity
- Susceptible to personnel instability

How to compare organizational complexity of SLS vs. F9?

- Number of decision makers
- Cost of a variability point
- Size, interaction and controls
- Org cost drivers (COSYSMO)

Impressions on “Organizational Complexity”



Let’s connect.

Or find us on www.incose.org/fuse

Bill Miller
FuSE Program Lead

e William.Miller@incose.net

Stephan Finkel
PMO Contractor | 3DSE

e Stephan.Finkel@incose.net

Martina Feichtner
PMO Contractor | 3DSE

e Martina.Feichtner@incose.net

Paul Schreinemakers
Stream Lead “SE Vision & Roadmaps”

e paul.schreinemakers@incose.net

Oli de Weck
Stream Lead “SE Foundations”

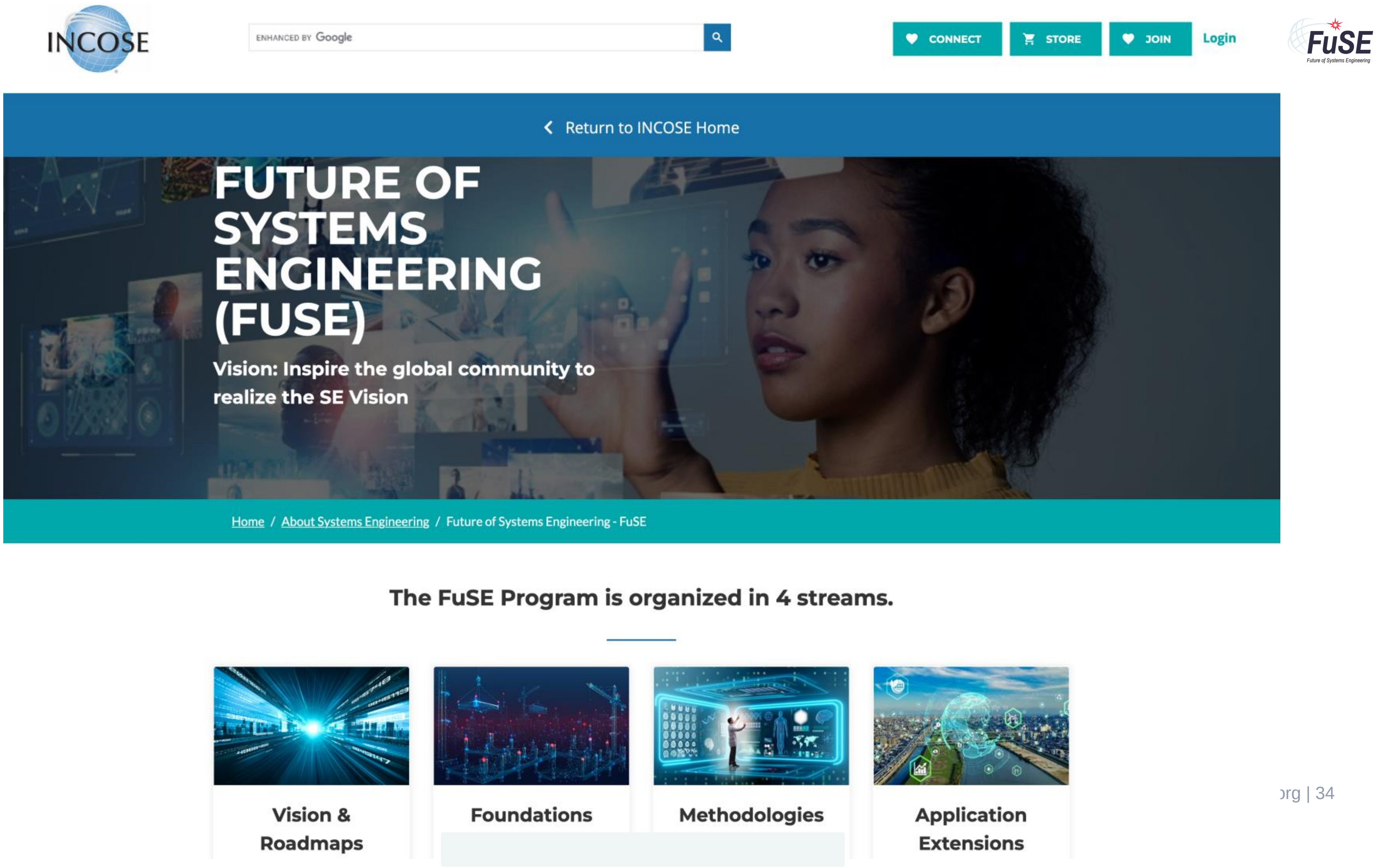
e deweck@mit.edu

Chris Hoffman
Stream Lead “SE Methodologies”

e christopher.hoffman@incose.net

Tom Strandberg
Stream Lead “SE Application Extensions”

e tom.strandberg@incose.net



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