Foundations Work Stream

Kick-off Interactive Workshop on Saturday 28 Jan 2023

Oli de Weck
FuSE Foundations Lead

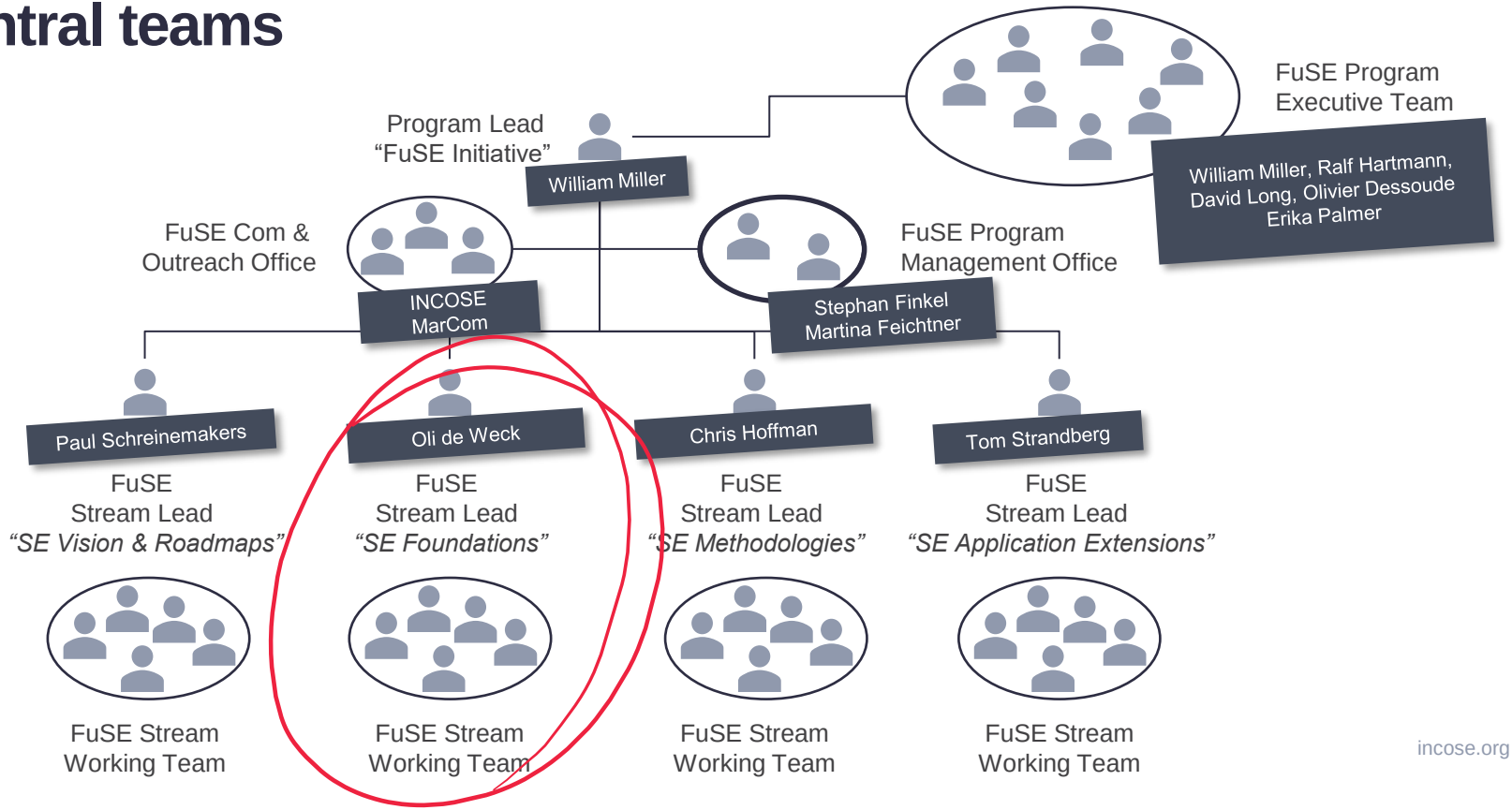
Agenda.

- Stream Intro (10 min)
  General overview of the SE Foundations stream
- Experiment Introduction (10 min)
  Introduction of a simple experiment related to System Complexity
- Experiment (30 min)
  Carry out experiment at tables in teams of 2 or 3
- Debriefing (10 min)
  Feedback and Q&A related to the experiment
- Closure

Agenda.

- **Stream Intro (10 min)**
  General overview of the SE Foundations stream
- Experiment Introduction (10 min)
  Introduction of a simple experiment related to System Complexity
- Experiment (30 min)
  Carry out experiment at tables in teams of 2 or 3
- Debriefing (10 min)
  Feedback and Q&A related to the experiment
- Closure

The FuSE program is organized in 4 streams with additional central teams



Key Insights of SAT FuSE Sessions

Vision & Roadmaps

Session Topic:
Introduction, Activities for 2023, Prioritization of roadmap topics to be addressed

Key Insight:
The highest priority for the Vision & Roadmaps stream is to **make the roadmap goals measurable.**
The **reason-why** behind the goals needs to be clear.
Soft skills and outreach will play an important part in the Future of Systems Engineering and needs to be fostered in the vision.

Foundations

Session Topic:
Frame SE Foundations in terms of First Law
Conducted complexity experiment to collect data

Key Insight:
INCOSE members were highly engaged (40+20=~60)
Generated about 300 data points to be post-analyzed
Valuable feedback received for making "SE" Experiments more realistic (e.g. introduce unexpected nodes in the system, show value of MBSE human augmentation)

Methodologies

Session Topic:
Introduction, Activities for 2023, Initial feedback, Opt-in participation

Key Insight:
What does INCOSE want to be in terms of methodology.
If INCOSE wants to be more prescriptive about the how – are we ready to take the leap?

Application Extensions

Session Topic:
Introduction, Feedback on Stream scope and planned Activities

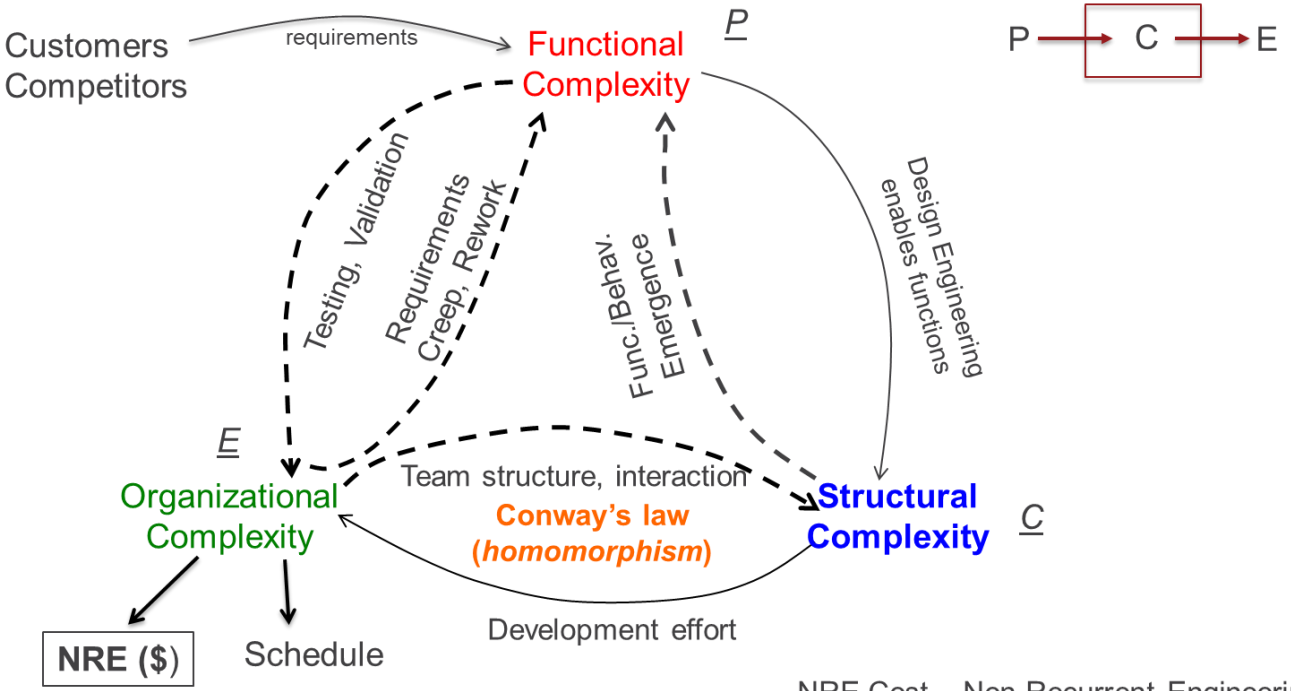
Key Insight:
Small group, a lot of energy and useful output, including:
Extending the application of SE into new domains requires a clear and simple message tailored to domain;
We also need to conduct joint activites with external organizations creditable in the domain to prove the value SE.

The Foundations Stream's objectives during IW.

The SE Foundations stream aims to:

- Validate (or refute) the proposed First Law of Systems Science and Engineering: **"Conservation of Complexity"**
- Elaborate the drivers of *technical* complexity
- Elaborate the drivers of *organizational* complexity
- Create an *inventory* of existing SE Foundations and tag their status as: (i) proposed, (ii) validated or (iii) adopted in SE practice

Three Dimensions of Complexity in Systems Engineering



NRE Cost – Non-Recurrent Engineering Cost

Agenda.

- Stream Intro (10 min)
  General overview of the SE Foundations stream
- **Experiment Introduction (10 min)**
  Introduction of a simple experiment related to System Complexity
- Experiment (30 min)
  Carry out experiment at tables in teams of 2 or 3
- Debriefing (10 min)
  Feedback and Q&A related to the experiment
- Closure

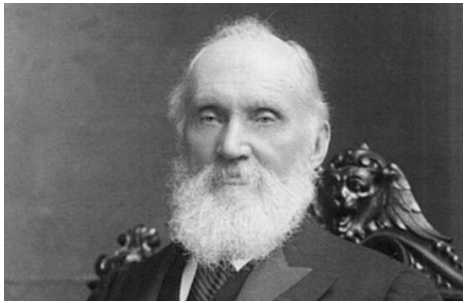
First Law of Systems Science and Engineering (proposed)

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

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

Is this "law" true?



"When you can measure what you are speaking about, and express it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarely, in your thoughts advanced to the stage of science."

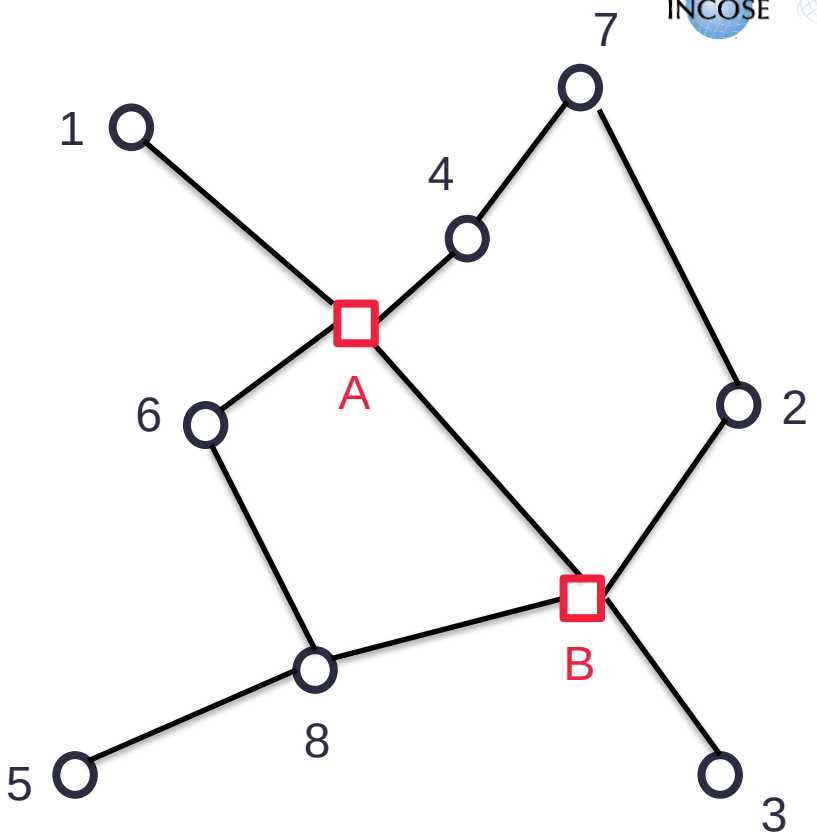
William Thomson, Lord Kelvin (1824-1907)

Los Angeles “Freewaytopia”

Source: https://www.engadget.com/hitting-the-books-freewaytopia-paul-haddad-santa-monica-press-153036975.html

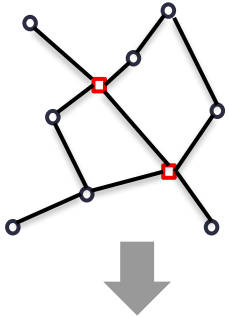
Experiment

- You are designing a new transportation system for a city.
- Given: N randomly placed origin-destination (OD) points (“o”)
- Your task: connect all points via M straight edges using a maximum of H hubs (‘☐’) such that the average travel distance between any OD pair is minimized
- Record: 1. Your final system design (on paper), 2. Clock time used, and 3. Your participant ID numbers



N=8, H=2, M=11

Postprocessing



DSM_c=

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

$$DSM_c = \begin{bmatrix} \alpha_1 & \dots & \beta_{n1} \\ \vdots & \ddots & \vdots \\ \beta_{1n} & \dots & \alpha_n \end{bmatrix}$$

$$Complexity, C = C_1 + C_2 * C_3$$

$$C_2 = \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij}, where\ i \neq j$$

$$C_1 = \sum_{i=1}^{n} \alpha_i$$

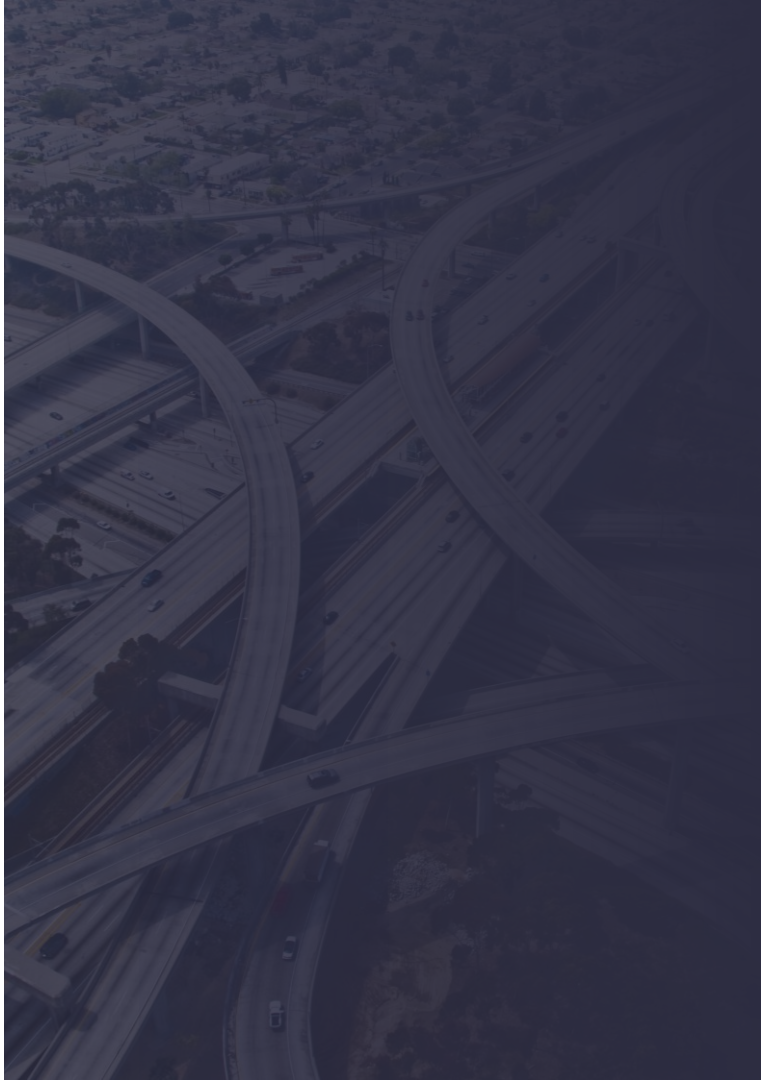
$$C_3 = \frac{1}{n} \sum S[SVD(A(DSM_c - trace(DSM_c)))]$$

Agenda.

- Stream Intro (10 min)
  General overview of the SE Foundations stream
- Experiment Introduction (10 min)
  Introduction of a simple experiment related to System Complexity
- **Experiment (30 min)**
  Carry out experiment at tables in teams of 2 or 3
- Debriefing (10 min)
  Feedback and Q&A related to the experiment
- Closure

Instroductions

- Form groups of 2 or 3 at your table
- Come to the front and pickup an experimental envelope
- Record your start time (e.g. on your phone) on each sheet
- Work out a solution (no strict time limit)
- Draft with pencil, feel free to use erasers
- Draw your final solution using permanent marker
- Record your end time, and personal ID numbers
- Pick up a new sheet (time allowing)
- Return your solution envelope to the head table



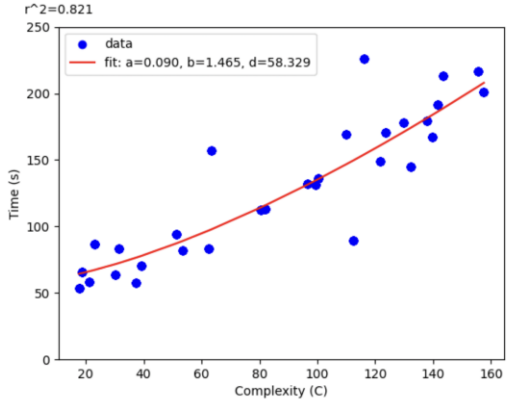
Agenda.

- Stream Intro (10 min)
  General overview of the SE Foundations stream
- Experiment Introduction (10 min)
  Introduction of a simple experiment related to System Complexity
- Experiment (30 min)
  Carry out experiment at tables in teams of 2 or 3
- **Debriefing (10 min)**
  Feedback and Q&A related to the experiment
- Closure

Hypothesis

We expect these results

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



Bortot Hopker, Ricardo. "A Canonical Experiment on System Complexity Metric and Its Impact on Engineering Management." SM diss., Massachusetts Institute of Technology, 2022.

Results are expected to be stochastic given the inherent variability of human performance

Feedback on Experiment

- What was the best part of the experiment?
- Do you believe that the experimental results will support or refute the First Law of SE?
- What could be changed or improved about the experiment?

FuSE at IW 2023 overview

	SAT	SUN	MON	TUE
08:00		FuSE Stream Working Sessions 4 rooms (in person only)	FuSE Stream Working Sessions 4 rooms (in person only)	
08:30				Wrap-up FuSE (for participants)
09:00				
09:30	Break			
10:00	FuSE Kick-off	Break		
10:30				
11:00				Wrap-up FuSE
11:30				
12:00	Lunch			
12:30				
13:00				
13:30				
14:00	FuSE Stream Working Session 4 rooms (in person only)			
14:30		B		
15:00	Break			
15:30	FuSE Steam Working Session 4 rooms (in person only)			
16:00				
16:30				

Rooms for FuSE Stream Sessions:

Vision & Roadmaps Stream: Ballroom

Foundations Stream: Salon A

Methodologies Stream: Salon D

Application Extensions Stream: Salon C

Systems Engineering Foundations Stream

Oli de Weck
Stream Lead “SE Foundations”

e deweck@mit.edu

In order to yield predictable results Systems Engineering methods and tools need to be built on foundational principles that are provably true and based on laws and axioms that can be tested for falsifiability similar to those in other well-established disciplines of science and engineering like Chemical Engineering, Electrical Engineering or Biological Engineering. This stream will formulate a set of candidates underlying Laws of Systemics, the science at the foundation of Systems Engineering.

The IW 2023 goal is to assess the foundational value of the “Conservation of System Complexity,” which parallels the Conservation of Energy in the First Law of Thermodynamics and the Conservation of Mass in continuum mechanics.

	SAT	SUN	MON	TUE
08:00		FuSE Interactive working session on technical complexity	FuSE Working Sessions on organizational complexity	
08:30				Wrap-up FuSE (for participants)
09:00				
09:30	Break			
10:00	FuSE Kick-off	Break		
10:30				
11:00				Wrap-up FuSE
11:30				
12:00	Lunch			
12:30				
13:00				
13:30				
14:00	FuSE Interactive working session Conduct complexity experiment Frame SE Foundations			
14:30		Break		
15:00	Break			
15:30	FuSE Interactive working session Conduct complexity experiment Frame SE Foundations			
16:00				
16:30				

Systems Engineering Foundations Stream

Oli de Weck
Stream Lead "SE Foundations"

e deweck@mit.edu

In order to yield predictable r
Engineering methods and too
on foundational principles tha
and based on laws and axior
tested for falsifiability similar
well-established disciplines
engineering like Chemical E
Engineering or Biological En
stream will formulate a set o
underlying Laws of Systemi
foundation of Systems Engi

The IW 2023 goal is to ass
value of the "Conservation
Complexity," which parallel
Energy in the First Law of T
the Conservation of Mass in continuum
mechanics.

	SAT	SUN	MON	TUE
08:00				
08:30		FuSE Interactive working session on technical complexity	FuSE Working Sessions on organizational complexity	Wrap-up FuSE (for participants)
				Wrap-up FuSE
16:00	Frame SE Foundations			
16:30				

IW PLAN

Sunday – Dedicated to Technical Complexity

- Case Study: Evolution of Aircraft Engines (Pratt & Whitney)
- 8AM-10AM – Discussion

Monday – Dedicated to Organizational Complexity

- Overview of existing Foundations (Systems Science Working Group): Collect inventory of SE Foundations from Audience
- Case Study: NASA SLS vs SpaceX Falcon9
- 8AM-10AM – Discussion

Tuesday – FuSE Wrap-up Session (Bill Miller)

Agenda.

- Stream Intro (10 min)
  General overview of the SE Foundations stream
- Experiment Introduction (10 min)
  Introduction of a simple experiment related to System Complexity
- Experiment (30 min)
  Carry out experiment at tables in teams of 2 or 3
- Debriefing (10 min)
  Feedback and Q&A related to the experiment
- **Closure**

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

INCOSE

ENHANCED BY Google

CONNECT STORE JOIN Login

FuSE
Future of Systems Engineering

Return to INCOSE Home

FUTURE OF SYSTEMS ENGINEERING (FUSE)

Vision: Inspire the global community to realize the SE Vision

Home / About Systems Engineering / Future of Systems Engineering - FuSE

The FuSE Program is organized in 4 streams.

Vision & Roadmaps

Foundations

Methodologies

Application Extensions