UNIVERSITY OF TWENTE.

SYSTEM DESIGN'S THREE PILARS: PROCESS, TOOLS AND THINKING TRACKS

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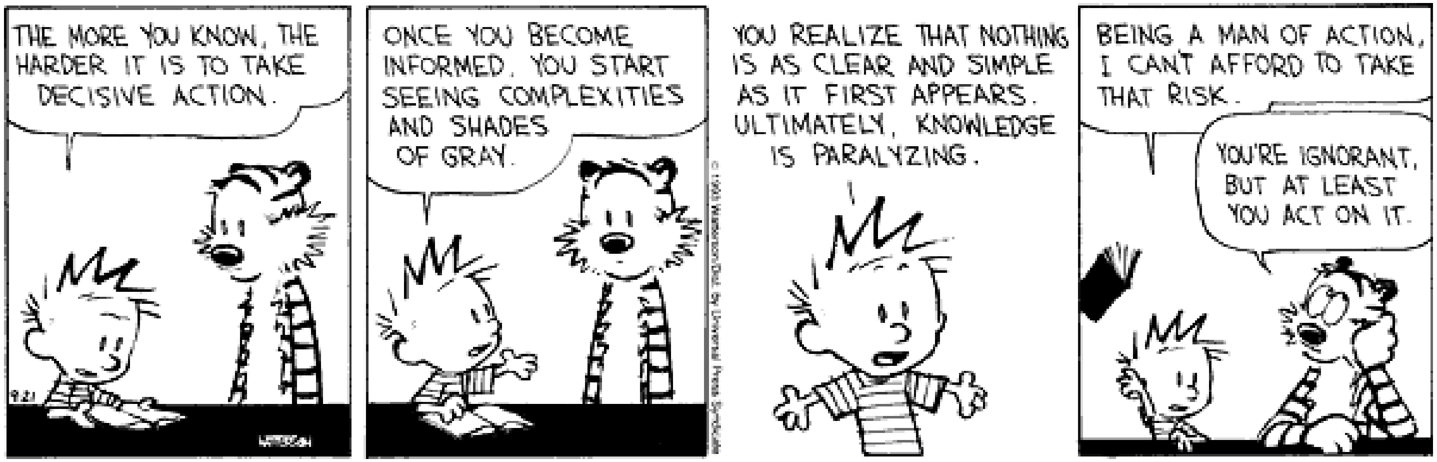
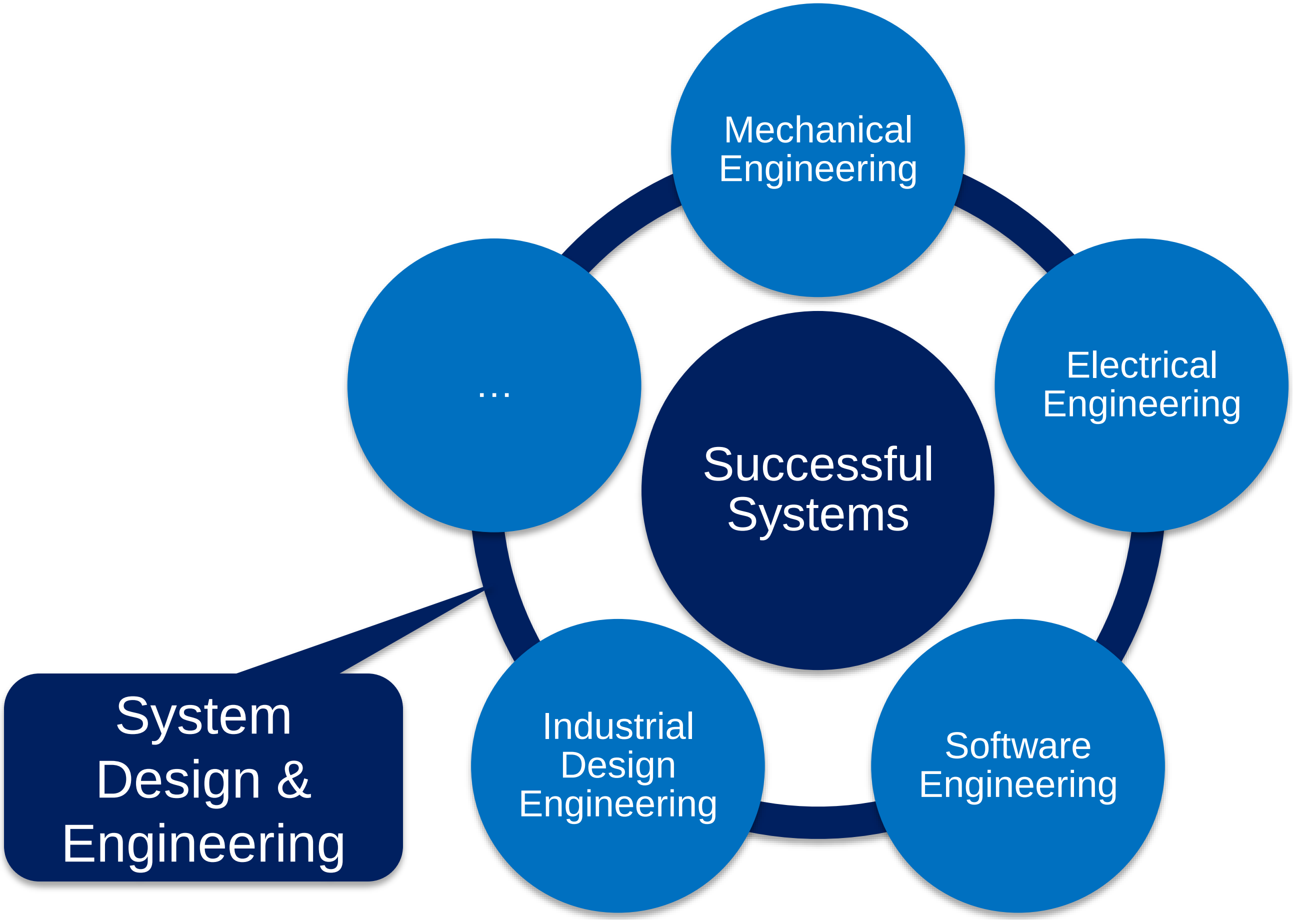
Contents

- Engineering and/or Design
- Communication
- Three Pillars
- Zooming in on Systems Thinking
- Back to the Big Picture
- Conclusions


THE MORE YOU KNOW, THE HARDER IT IS TO TAKE DECISIVE ACTION.
ONCE YOU BECOME INFORMED, YOU START SEEING COMPLEXITIES AND SHADES OF GRAY.
YOU REALIZE THAT NOTHING IS AS CLEAR AND SIMPLE AS IT FIRST APPEARS. ULTIMATELY, KNOWLEDGE IS PARALYZING.
BEING A MAN OF ACTION, I CAN'T AFFORD TO TAKE THAT RISK.
YOU'RE IGNORANT, BUT AT LEAST YOU ACT ON IT.

Systems Engineering or Systems Design?



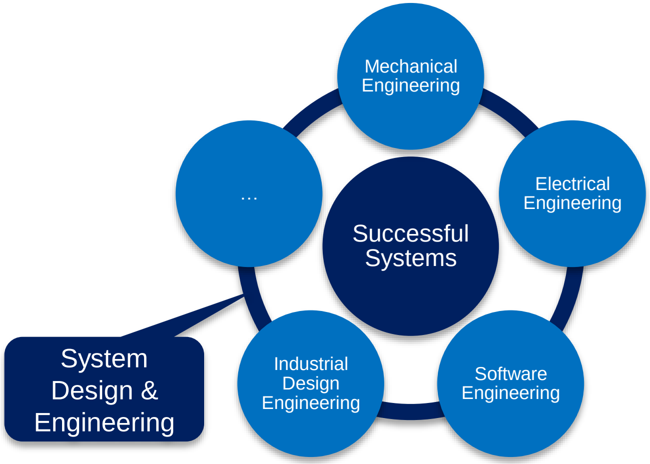
Communication

Conclusion from research projects:

- Communication is essential for system design
- Communication between disciplines is hard

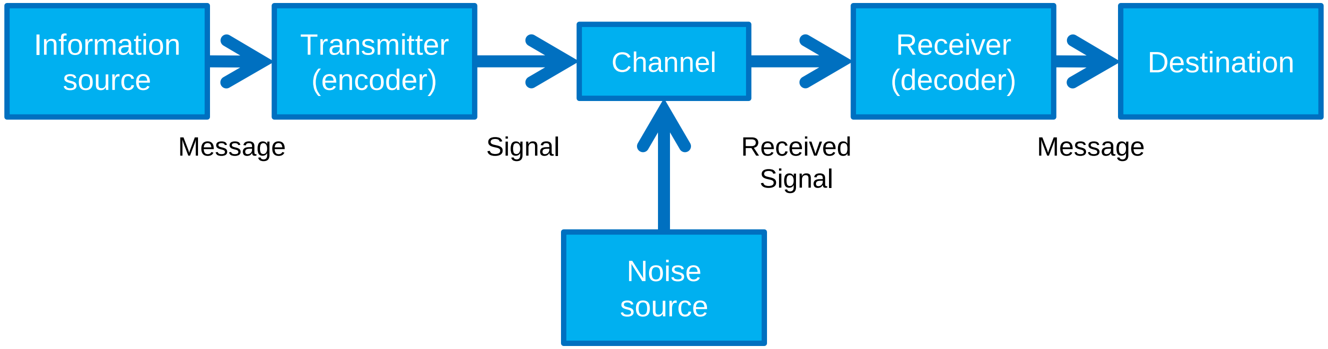
- Therefore:

  Let's have a look at "communication"

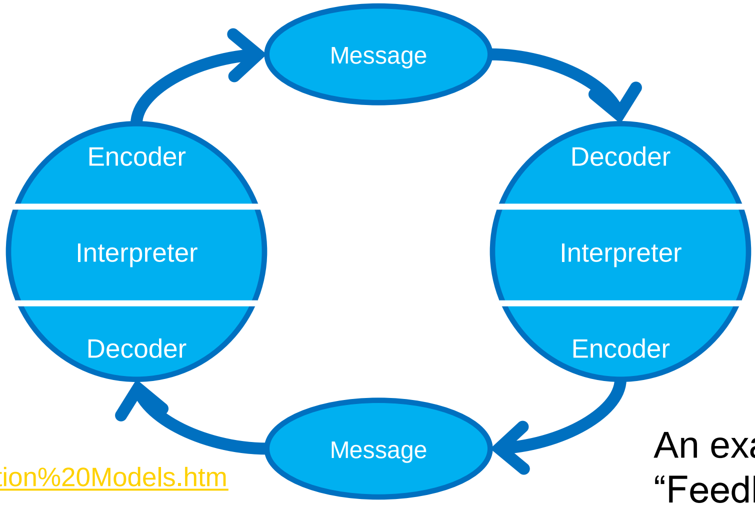


Communication: one-way vs. two-way

- Shannon-Weaver communication model



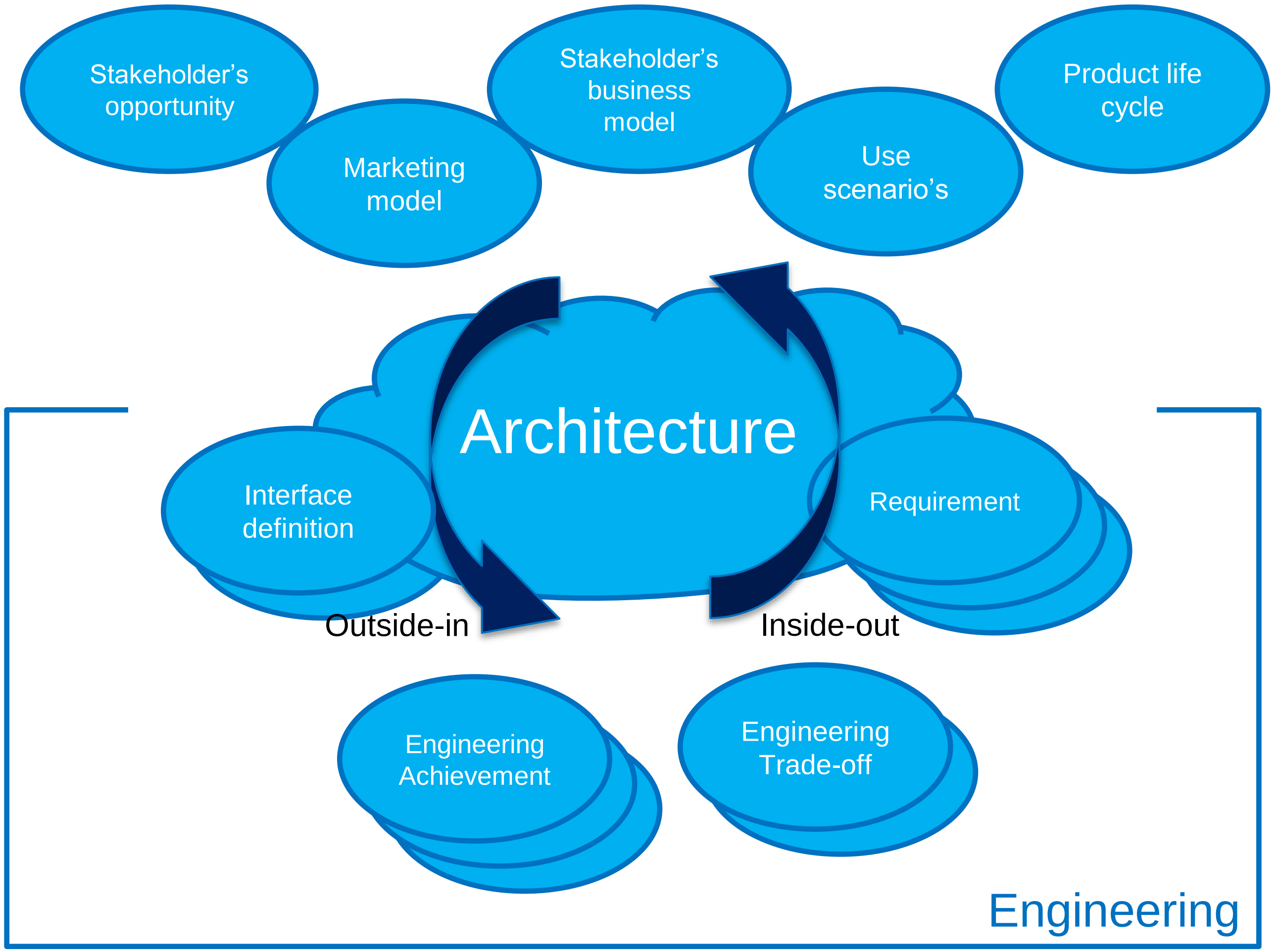
- Schramm communication model



An example of "Feedback thinking"

http://www.shkaminski.com/Classes/Handouts/Communication%20Models.htm

Communication and architecture



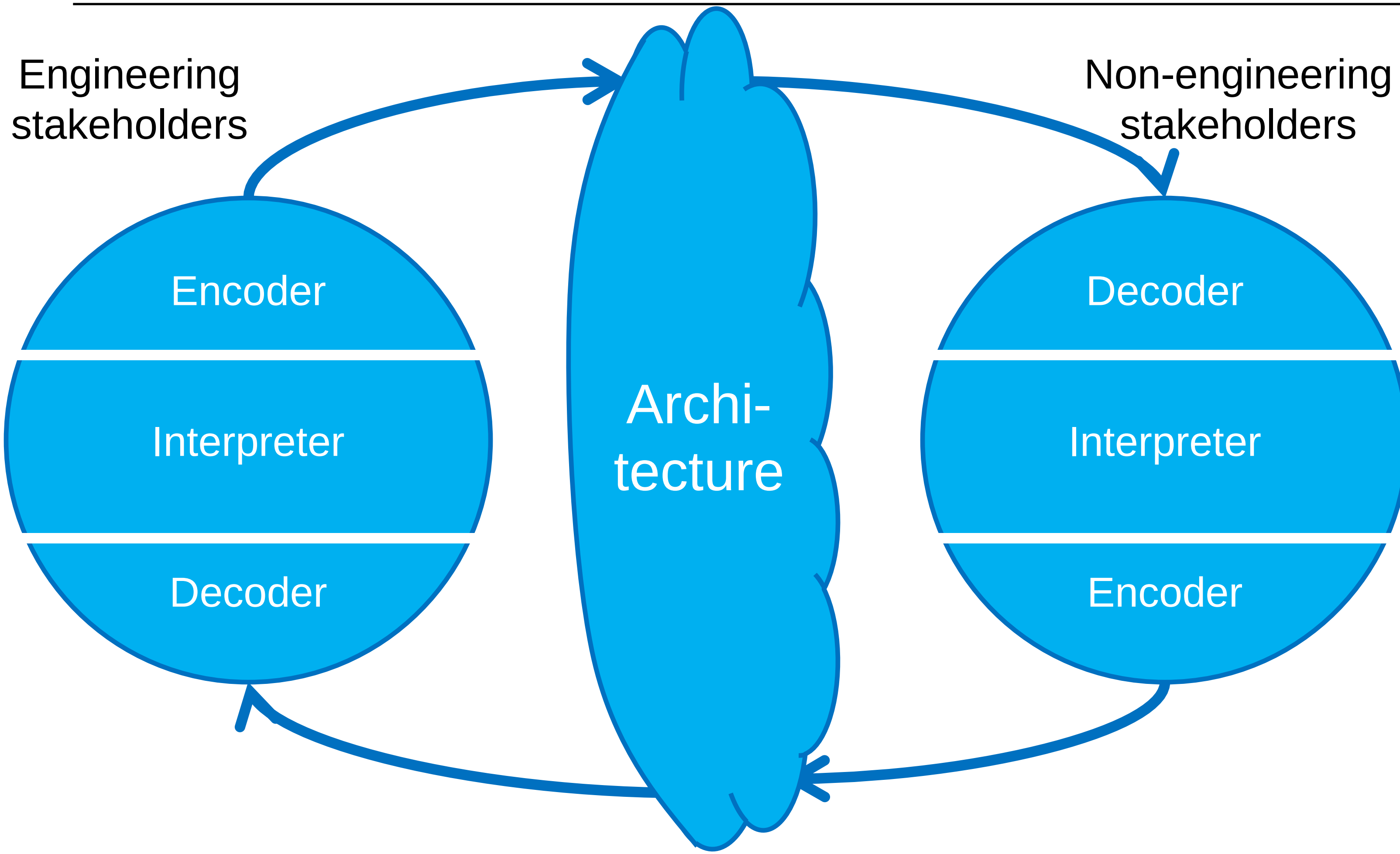
How can architecture be used as communication means?

- Technical stakeholders
- Non-technical stakeholders

How does communication affect architecture creation?

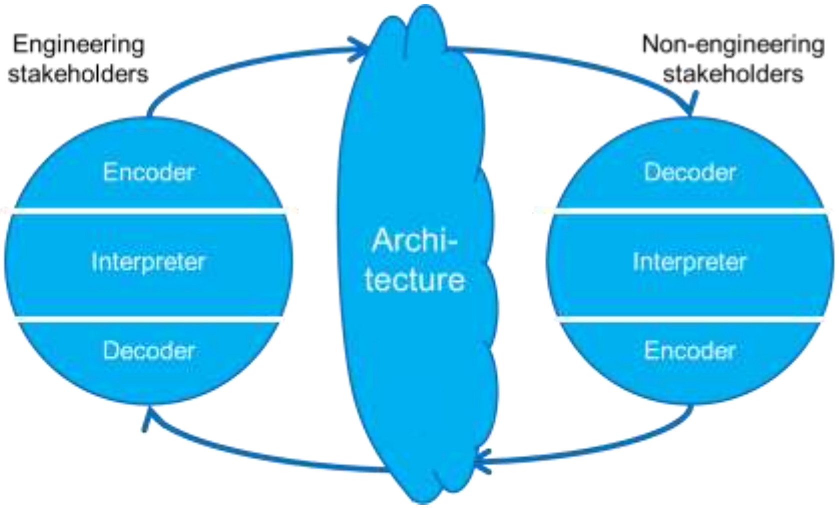
- Positively
- Negatively

What happens if we combine Schramm and Architecture?

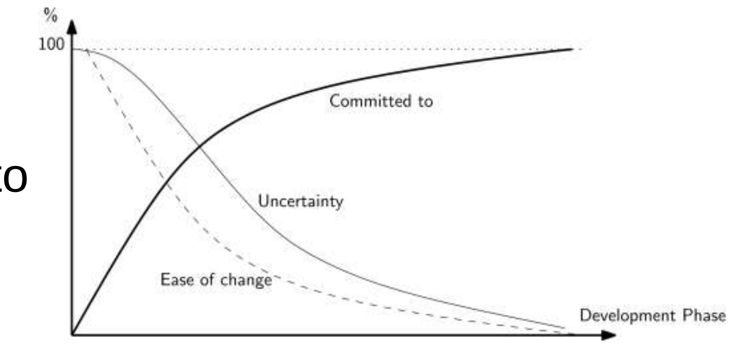


Issues to consider

- What form for the architecture provides common understanding?
- How can improving the communication, improve the architecture creation process
  - and vice versa?
- What should be included in the architecture (representation)
- What is the right depth of analysis?



Issues to consider – What should be included and to what depth…

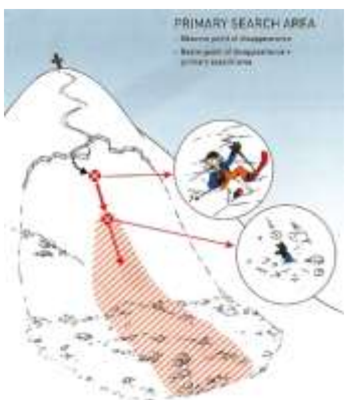


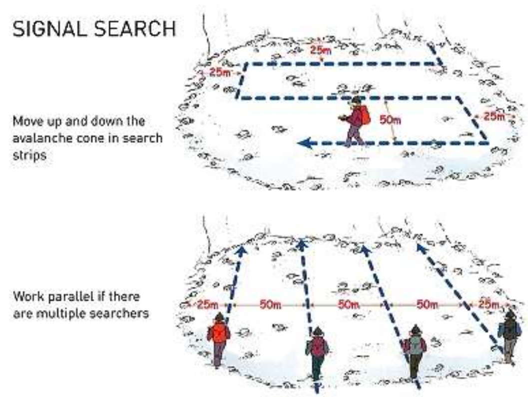
In the early phases:

- The playing field is too wide and too deep to fully comprehend
- So it has to be *probed*
- How do we know where the interesting places are?
  - Experience
  - Making a quick scan
  - Reasoning
  - Looking at what others are doing/have done

A Methaphor

- Finding a victim of an avalanche:
  - scanning the area quickly, but thorougly;
  - then zoom in on the spot of interest
- But in system design there are multiple spots of interest (many “victims”)





http://shop.snowshepherd.co.uk/Avalanche-Search-and-Rescue

http://wakatipusar.co.nz/img/pages/Avalanche_rescue_exercise_003.jpg

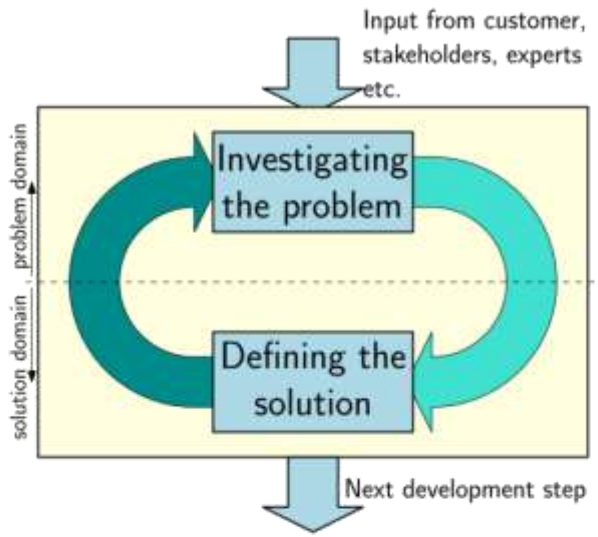
Process

Tools

Ways of Thinking

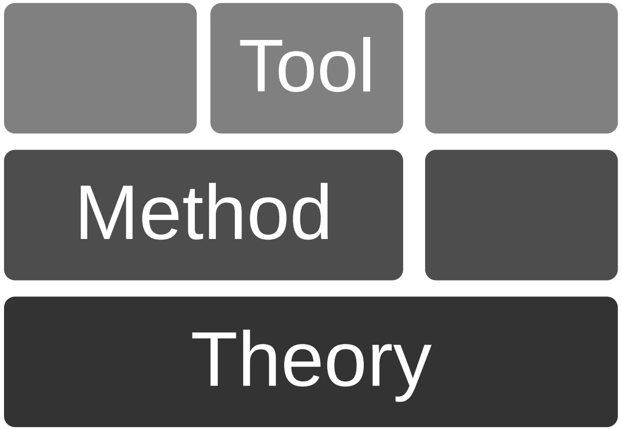
Process

- The process defines the way of working
- Structures the development
- Reduces uncertainty
- The systems engineering process is well described.
  ➔ Blanchard and Fabrycky, INCOSE handbook, etc.



Tools

- Tools as in methods that are made useable.
- Not just computer tools (Rational DOORS and the like)
- Examples:
  - A3 architecture overviews
  - N^2 diagrams
  - Requirements and tracking tools
  - Etc.



Ways of Thinking

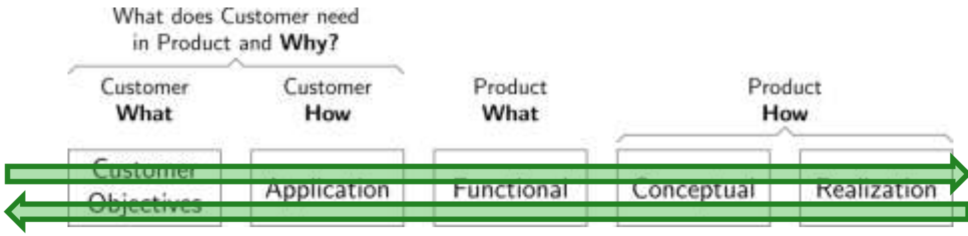
- The process and tools are well suited for trusted and (relatively) complete data, yet system design deals with *incomplete* data and *uncertainty*.
- This requires Ways of Thinking through the system, the environment, and everything that was not thought about!

> “[T]here are known knowns; there are things we know we know.
> We also know there are known unknowns; that is to say we know there are some things we do not know.
> But there are also unknown unknowns – there are things we do not know we don't know.”
>
> —United States Secretary of Defense Donald Rumsfeld
> http://en.wikipedia.org/wiki/There_are_known_knowns

Frank, M. (2006). "Knowledge, abilities, cognitive characteristics and behavioral competences of engineers with high capacity for engineering systems thinking (CEST)." Systems Engineering, The Journal of the International Council on Systems Engineering **9(2): 91-103.**

Basis for Thinking Tracks

- Gerrit Muller: CAFCR



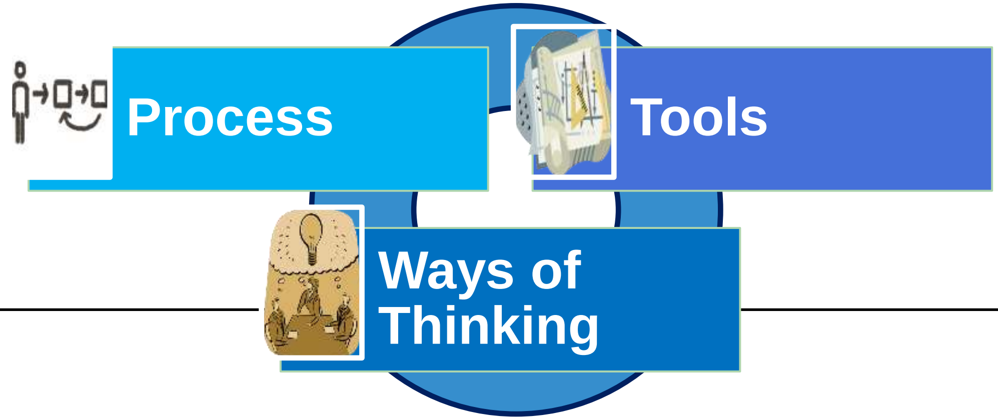
- Boardman et.al: Conceptagon

- Richmond: Systems thinking
- General creativity techniques

Muller, G. J. (2004). CAFCR: A Multi-view Method for Embedded Systems Architecting. PhD Ph.D.-thesis, Delft University of Technology.

Boardman, J., B. Sauser, et al. (2009). The conceptagon: A framework for systems thinking and systems practice. Systems, Man and Cybernetics, 2009. SMC 2009. IEEE International Conference on.

Richmond, B. (1993). "Systems thinking: Critical thinking skills for the 1990s and beyond." System Dynamics Review **9(2): 113-133.**



- The process directs the development and minimizes sidetracking
- Tools help to make well argued decisions
- Systems Thinking reveals unthought-of issues and aspects
- The process may give a false sense of security
- Tools need accurate numbers where they are not <accurate,available>
- Just Systems Thinking may not be proper goal-oriented

Therefore the combination of the three is needed
Three pillars provide a stable platform

Twelve thinking tracks

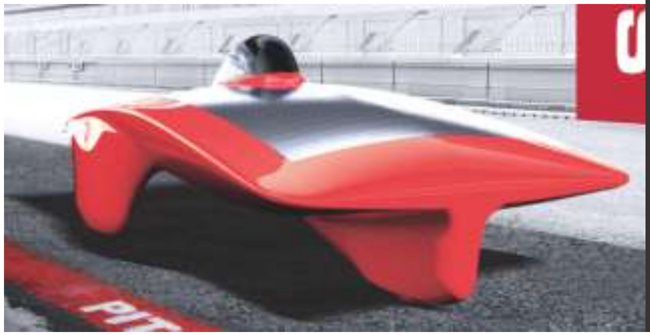
1. Dynamic Thinking
2. Feedback Thinking
3. Specific-Generic Thinking
4. Operational Thinking
5. Scales Thinking
6. Scientific Thinking
7. Decomposition-Composition Thinking
8. Hierarchical Thinking
9. Project Thinking
10. Life-Cycle Thinking
    - Product life-cycle
    - Resource life-cycle
    - Project life-cycle
11. Safety Thinking
12. Risk Thinking

These may not be exhaustive
I cannot treat all tracks in detail. So I have made a selection.

Developing a solar racer – the 21Connect

- Developing a solar racer integrates multidisciplinary technology with marketing
- Previous versions of the Twente Solar racer have resulted in lots of data and experience (but no victory ☹)

Characteristic	Value	Unit
Total length	3010	km
Number of race days	7	
Race day	8:00-17:00	h
Maximum speed	130	km/h (NT)
	110	km/h (SA)
Total budget	1	M€
Development time	14	months
Team size	18	students



Dynamic Thinking

Questions to ask:

- How does the system change over time?
- How does the environment change over time?
- When a change in input/output occurs, what are the effects?

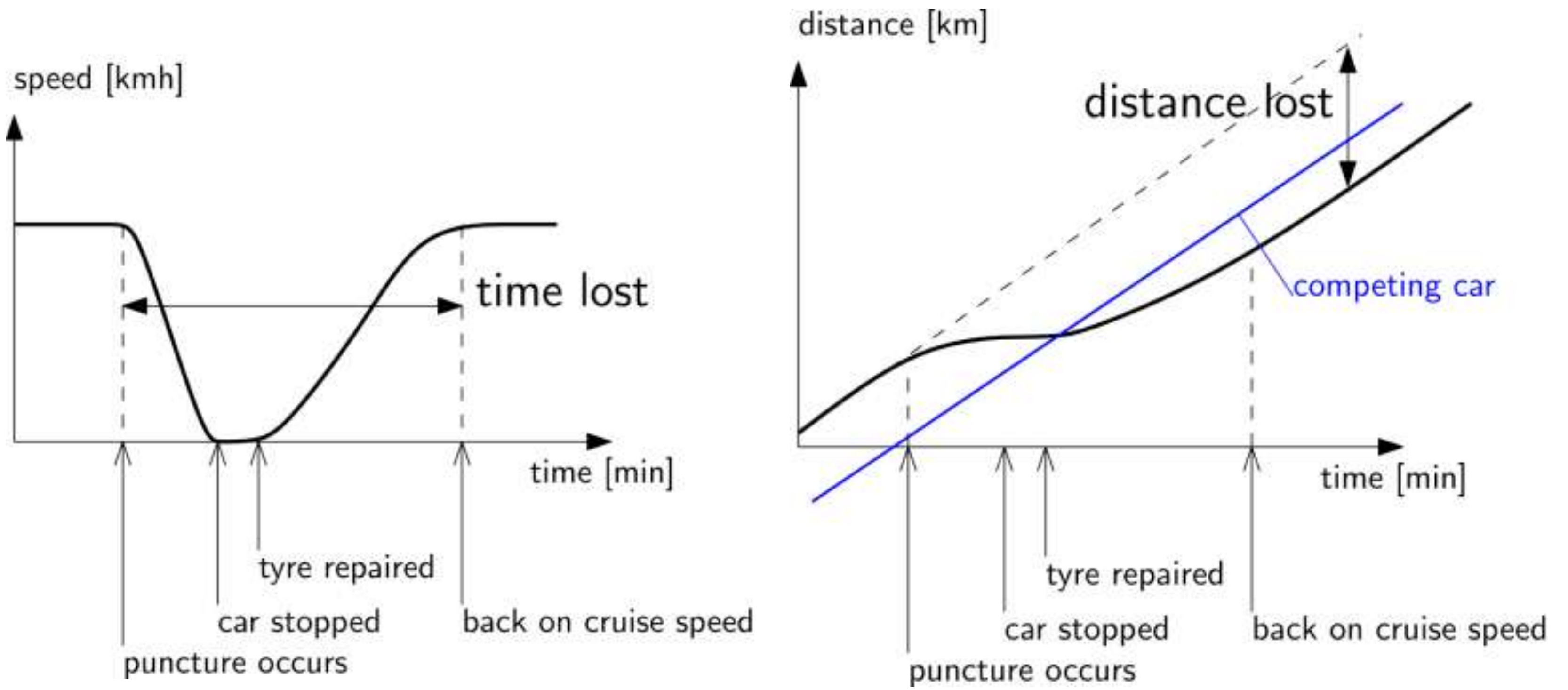
- Use different time scales

Example: the Twente Solar Racer 21Connect

Time scales:

- seconds: vibrations/unbalances/road damages?
- minutes: weather change, wind gusts, puncture?
- hours: driver behavior and short-term strategy;
- days: overall strategy and race planning,
- weeks: project planning and manufacturing,
- months: finances, motivation, training and project plan

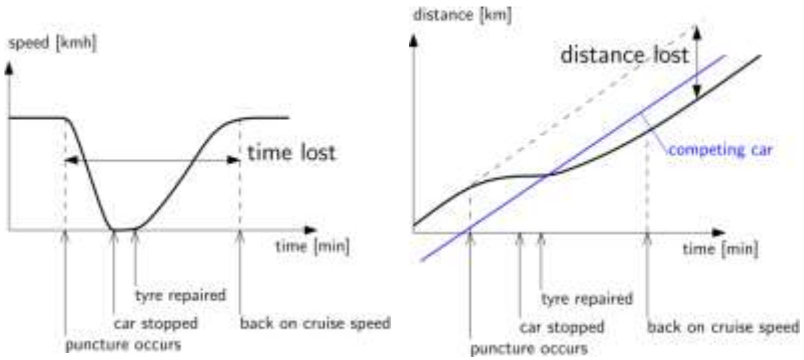
Dynamic Thinking – tool support



In general: modelling and simulation tools

- Time domain
- Frequency domain

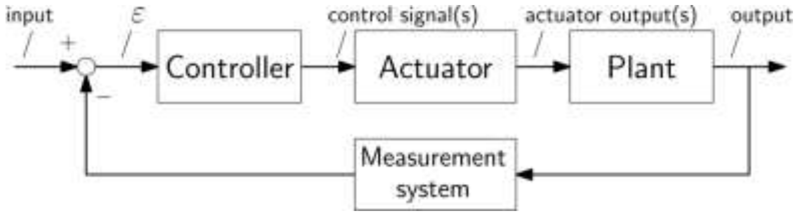
Dynamic thinking – Design impact



- Reducing tyre repair time helps
  - ➔ quick release wheels
- Acceleration helps
  - ➔ boost mode
- Deceleration helps
- A short period of higher cruise speed helps
  - ➔ aerodynamic impact

Feedback Thinking

- Many systems, subsystems and projects can be seen as feedback loops



- Also on project level!
  ➔ Lean manufacturing
  ➔ Knowledge based production

- What is the process to be controlled (the *plant*)?
- What is the quantity to be monitored (the output)?
- What is the desired value?
- Is there an accurate measurement system?
- What is the response time of the measurement system?
- Is the plant controllable?
- Can a controller be devised?

Feedback thinking

Concrete examples 21Connect

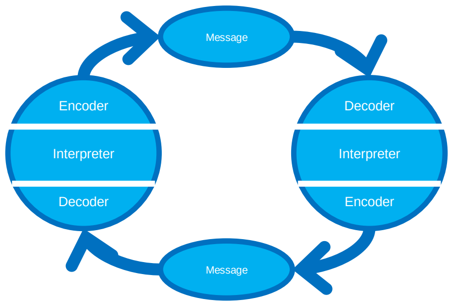
- Cruise control
- Include more to improve race strategy:
  - controlling the speed (output) based on
  - energy level (state)
  - energy income (input)
  - weather forecast (prediction)
- Finances: sponsor income

Also usable in politics

- NL: roadtaxes depend on “greenness” of cars

And interpersonal communications

- Did you understand what I said, the way I meant it?



Operational Thinking

- How is it done “in the real world”?
- System designers need to consider reality.

“Get their hands dirty”

- Not only Excel-engineering, or SysML-processing.
- In particular:
  - exceptions
  - start-up
  - shut-down

Tools:

- Functional models
- Test-rigs
- Experiments
- Scenario’s

http://www.youtube.com/watch?v=0X4798zXE6Y

Operational Thinking – a race day

- Racing is done between 8:00 and 17:00
- So at 8:00 the solar car, and two accompanying cars have to be ready
- Sun rise is earlier, it is a waste to not use those rays of light!

- waking up, making and eating breakfast;
- aligning the solar panel with the sun the moment the sun rises;
- starting up the solar car's systems;
- technical check of the solar car;
- updating all model parameters (weather, competitors, etc.);
- sending press updates;
- packing the cars and setting up the convoy;
- taking down the tents and cleaning the area;
- health and safety checks;

And practice it!

Decomposition – Composition thinking

- Education is – still – very much reductionistic oriented: explaining the whole from studying the parts
- The Big Picture is often moved to the background
- The system is taken down into sub-systems (and sub-sub-systems, and even further)
- How to re-compose the system is left to later: the integration phase

- Decomposition – Composition thinking takes this integration into account all the time

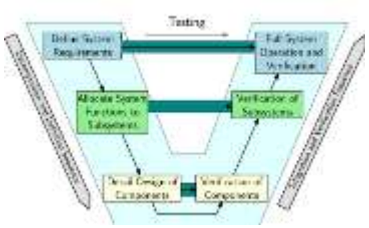
Bonnema, G. M. (2011). "Insight, innovation, and the big picture in system design." Systems Engineering **14(3): 223-238.**

Decomposition – Composition thinking

Formal and logic

- Splitting in sub-systems: what interfaces are created (D: Schnitt-stelle)
- How is the functionality allocated over the system

➔ support by documentation and computer tooling



Less formal and intuitive

- How do we put this together?
- How to check it will fit?
- How to check it is finished?
- Pre-assembly testing?

➔ let designers draw their views (communication issues)

➔ N^2 diagrams

➔ A3 Architecture Overviews

Specific – Generic Thinking

- Reasoning about the scale of the problem and the scale of the solution

➔ exception handling or dealing with normal operation?

http://nos.nl/artikel/372438-wiigame-voor-chirurgen.html

Create system budgets:

- Error budget (what is the problem)
- Cost budget (what will the solution cost)
- Balance the budgets

- Allocate budgets to functions
  ➔ FunKey architecting
  ➔ Quantification

Problem / **Solution**	Specific	Generic
Specific		
Generic		

Scales Thinking

Finding nuances in arguments and avoiding opposing camps:

- Switching between black/white-scales and shades of grey
- Understanding limits of known (often assumed linear) relationships/scales/assumptions:
  - Known technologies
  - Known paradigms

Solar racer:

- 2005, 2007, 2009 GaAs panels:
  - highest efficiency.
  - area limited by regulations
- 2011 option:
  - $3m^2$ GaAs or
  - $6m^2$ Si
- Again: numbers are your friend.

Life-cycle Thinking

Three life-cycles:

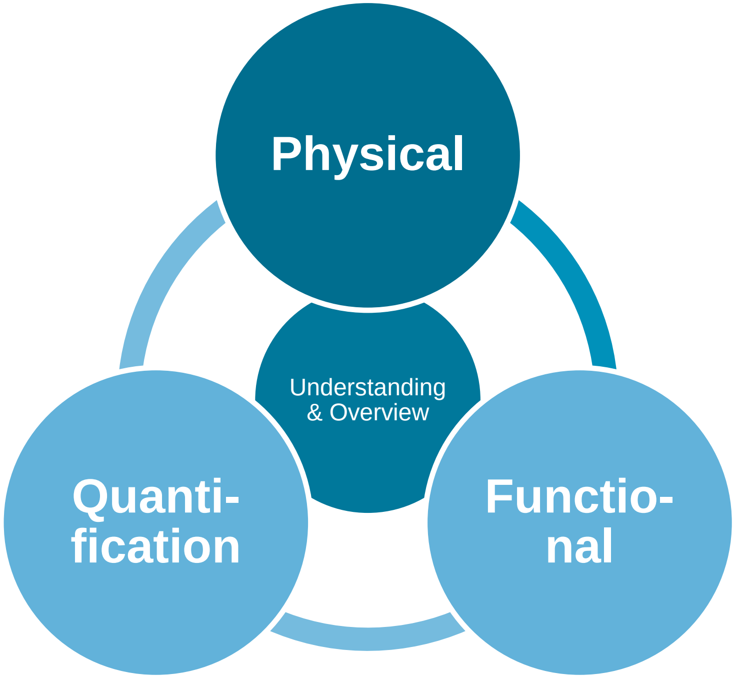
- Product life-cycle
  (design, production, deployment, use, retirement)
- Resource life-cycle
  (material, energy and other resource usage)
- Project life-cycle
  (the project organization that is instantiated to create and sustain the system)

- Decision for the use phase can impact the production phase

- Carbon monocoque structure for solar racer impacts whole production cycle
  => test rig needed
- Railway material:
  - 30 year lifespan
  - Maintenance cost is twice purchase cost

Conclusions From Research Projects

"Any intelligent fool can make things bigger and more complex...
It takes a touch of genius - and a lot of courage
to move in the opposite direction."
(Albert Einstein)

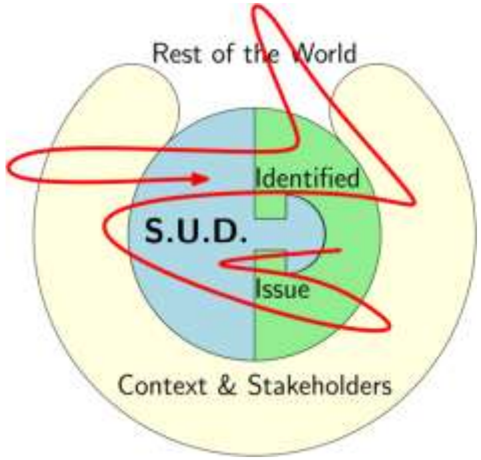


- Useable models of the system are as simple as possible, but not simpler.
- Formality comes at a cost:
  - multidisciplinary understandability
  - reduced overview (the "big picture" is lost)
- Quantification is essential
(what works on one scale, doesn't work for another)
- Three types of interconnected models

That brings us to the theme of this KSEE

Broad

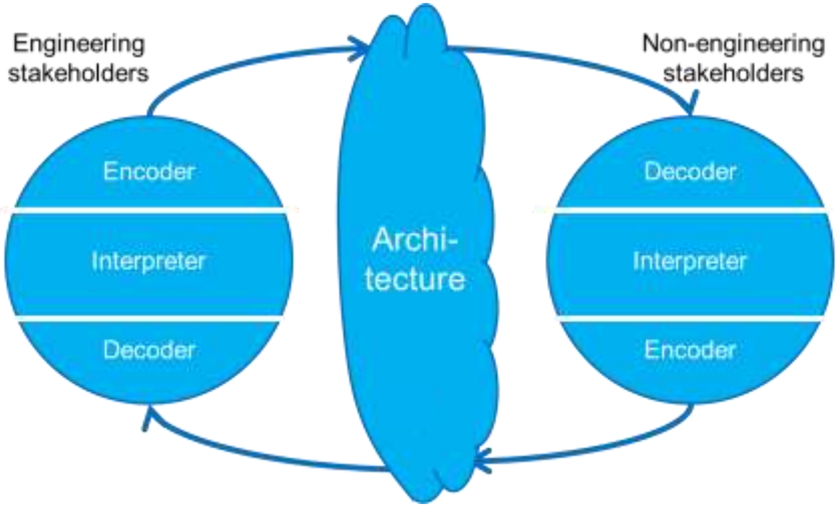
- The thinking tracks help to sample
  - the life cycle,
  - the system,
  - the environment
  - time, etc.



Deep

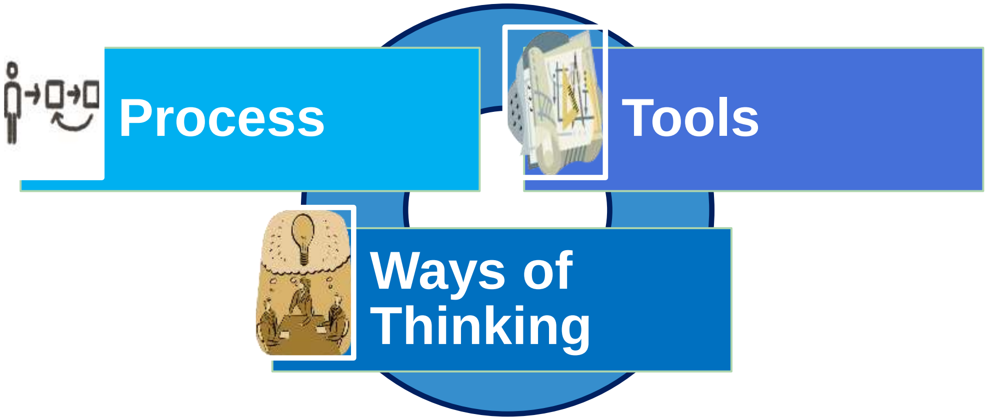
- When needed tools can be used to go into depth
- Tools like:
  - 9-windows diagram
  - context diagram
  - scenario's
  - N^2 diagram
  - system budgets
  - FMEA
  - Risk management tools
- Present the essential results

- Communicate the results
- Reiterate if necessary
- Adjust process/design if needed



Conclusions

- Systems Design is more than Systems Engineering
- Systems Engineering provides one of the pillars of good system design
- The other are:
  - Tools
  - Systems Thinking
- Binding element is Communication



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THANK YOU

ANY COMMENTS AND OR QUESTIONS?