33rd Annual INCOSE international symposium

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Toward Systems Engineering Meta-Methodology

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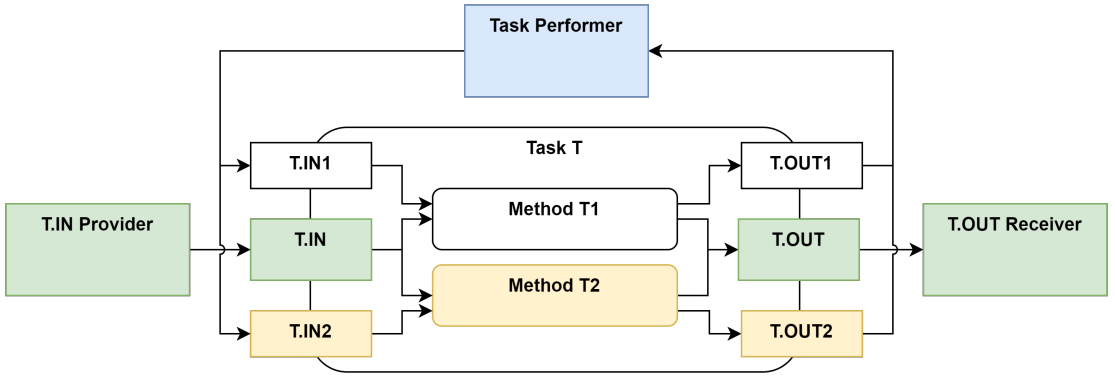
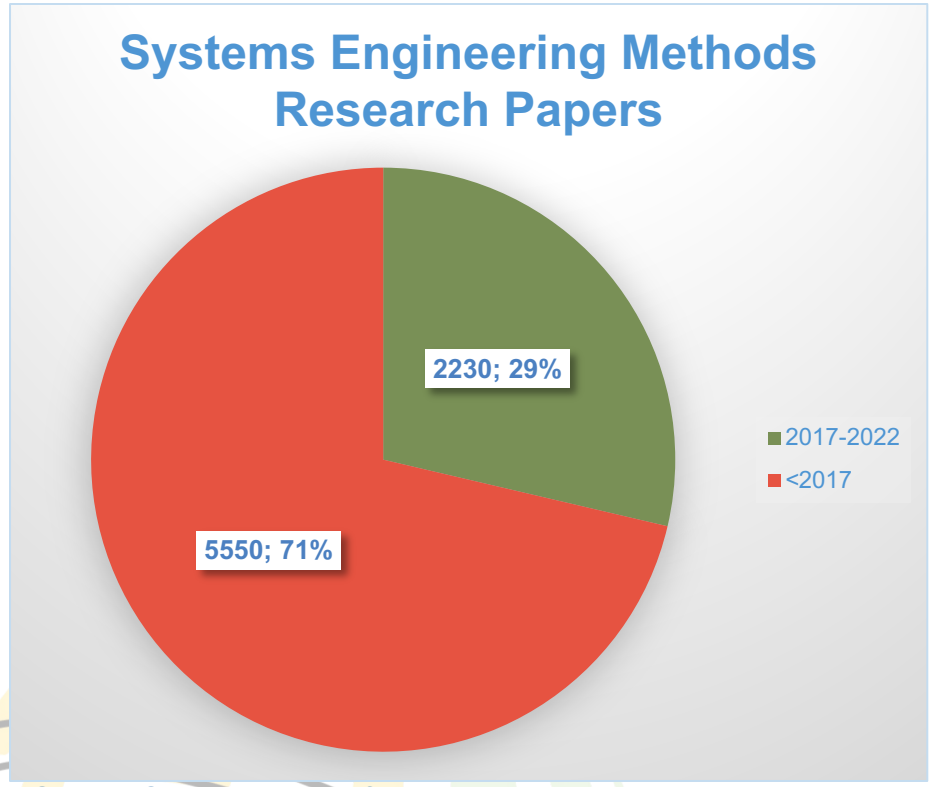


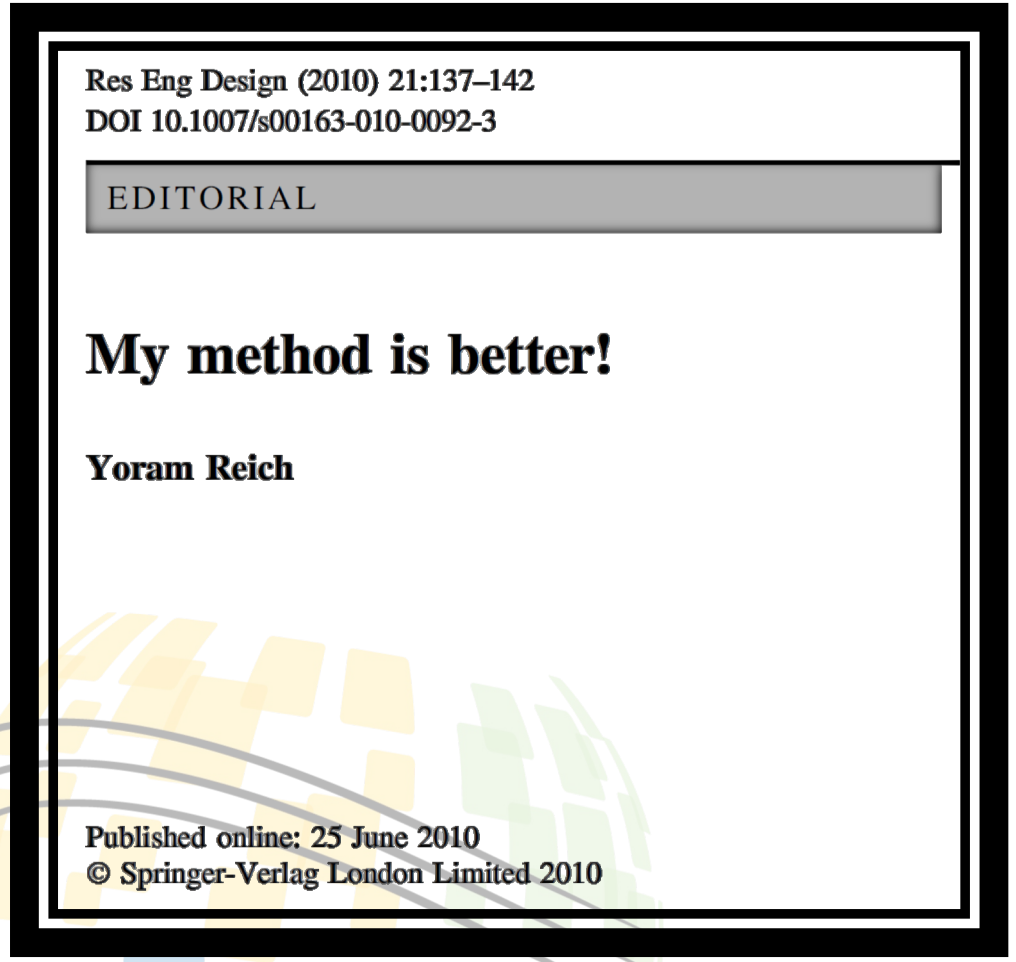
Systems Engineering Methods Research is Booming
An annual average of 446 scholarly publications



Google Scholar search for precise expressions like "systems engineering methodology", "systems engineering method", "systems engineering framework"

- Collopy (2015):
  - Lack of a formal theoretical basis for many systems engineering activities leads to failure and poor performance.
  - We need a more rigorous methodology – methods for requirements specification, risk management, verification and validation, and contract management.
- Systems engineering meta-methodology: the scientific study of how to design systems engineering methods.
- Meta-methodological (second-order methodological) study of systems engineering is not unheard-of, but much smaller than first-order methodological study
- Literature is surprisingly scarce.
  - Combined keyword search+citation based search: : <100 results, very small group of researchers (Reich, Salado et al. are leading)

What's so bad about lots of methods?



Res Eng Design (2010) 21:137–142
DOI 10.1007/s00163-010-0092-3

EDITORIAL

My method is better!

Yoram Reich

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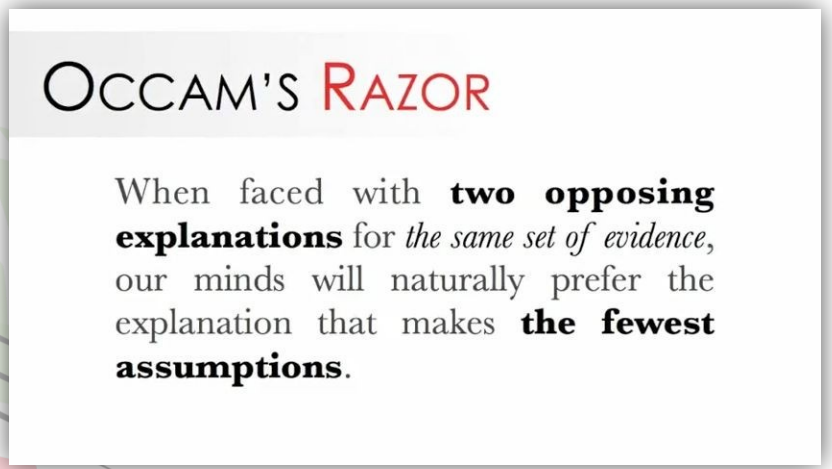
- The flood of methods **overwhelms the practitioners**.
- More methods = **less commonality**.
- More methods = higher likelihood of **duplication**, **divergence**, and **deviation** from normative references.
- **Subjective bias and conviction** about the superiority of some methods drives perspective.
- Method-driven approach focuses on **the method as an end** rather than the means to an end.
- Methods are built with **insufficient awareness of methodology building methods** and practices.
- Most methods are **validated on a small set of cases**.
- Practitioners may not have the luxury of verifying the method superiority or suitability for their own case.

What makes a good method?

- **Help the user achieve results in a task**.
  - The task defines what to do
  - The method specifies how to do it
- **Solve a problem** or **overcome some challenge**.
- **Achieve the same or better results** by applying an innovative approach or a new technology.
- **Fit within the bigger picture**, process, or plan.

- Method designers must demonstrate :
  - **Some significant advantage** or **added value**.
  - **Ease of adoption**
  - **Worthwhile switch** to the new method
  - Fit within the scope of supported steps
  - **Integrability and interoperability** with other methods.



- ***Unfortunately, that is rarely the case…***

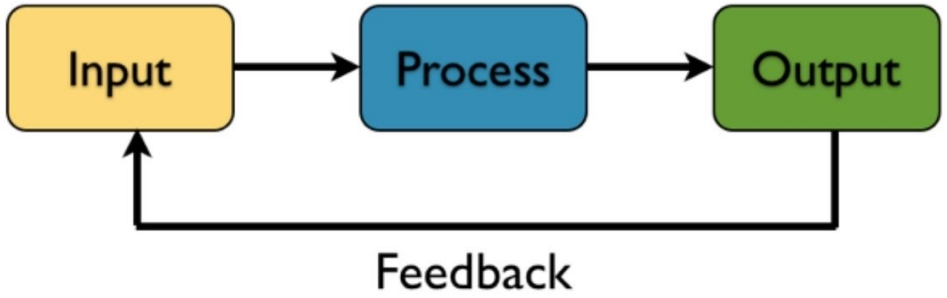
Meta-Methodology

- Scientifically and linguistically, ***methodology*** means *method science*.
- **Meta-Methodology: An Overview of What It Is and How It Was Developed (J. Thomann, 1973)**
  - Meta-methodology: a methodology for building methodologies.
  - Three critical success factors for methodology building:
    - a. Determine and understand the **purpose of the methodology**,
    - b. Develop **steps that make up the methodology**—the process, and
    - c. **Test the methodology**, prove it accomplishes its purpose.
  - Additional criteria: **desirability**, **operability**, **practicality**, and **sufficiency**.
  - **Missing a systems approach and tool-based implementation.**
- **Systems Metamethodology** [chapter in Facets of Systems Science, (G.J. **Klir , 1991**)
  - Systems meta-methodology: the study of systems methods and methodologies.
  - The purpose of systems meta-methodology: Define processes of systems science, such as the study of complex phenomena, the understanding of complexity, generality, and method performance in prediction of behaviors and patterns
  - No specific guidance on how to build a methodology for systems analysis of complex phenomena.
- **Meta-Methodology as a general class of methodologies** (Erro-Garcés and Alfaro-Tanco 2020).
- **Dubin's method for theory building**
  - **Theory development**: construction of propositions based on units, laws of interaction, boundaries, and system states.
  - **Theory validation**: finding empirical indicators, forming hypotheses, and testing them.
- **Design science research (DSR)**
  - **problem diagnosis**, **theory building**, **technology invention/design**, and **technology evaluation**
  - (Widmeyer 2012; Michalczyk and Scheu 2020; Kuechler and Vaishnavi 2008)
- **Methods as design artifacts** (Offermann et al. 2010):
  - purpose and scope, constructs, principles of form and function, artifact mutability, testable propositions, justificatory knowledge, implementation principles, expository instantiation, and design method evaluation criteria.
- **The Principle of Reflexive Practice (PRP)** (Reich 2017)
- **Ferris, Cook, and Honour (2005)**
  - Types of systems engineering research: scholarly exploration and understanding of scientific literature, action research, and case studies.
  - **Surprisingly, they neglected to mention methodology research as a distinct research type**

The Goals of this Study

- Introduce requirements for a method assessment method
- Introduce a simple model for understanding the task-method construct
- Provide an overview and consolidate existing meta-methodological studies
- Establish a formal notion, ontology, and research agenda
- Define and raise awareness of systems engineering meta-methodology.

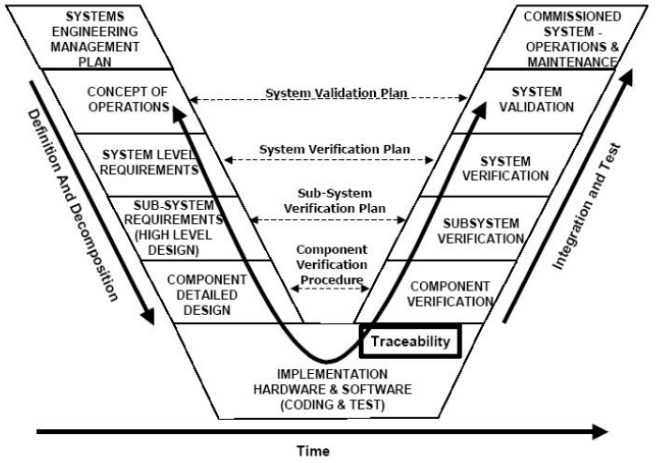
This study follows the Systems Approach

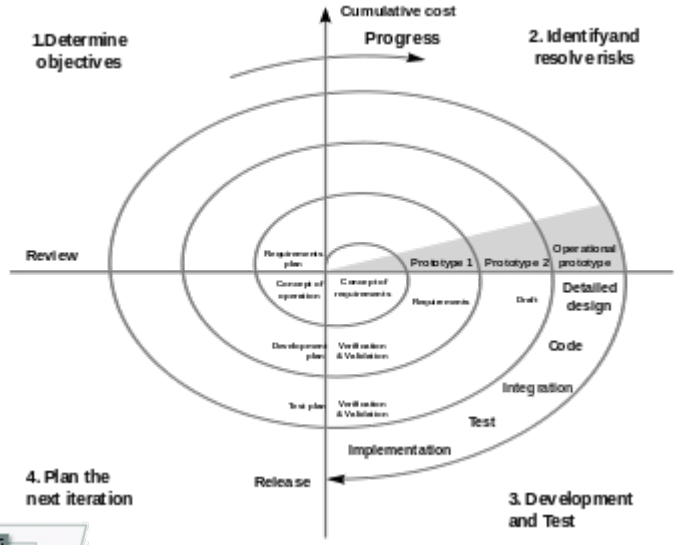


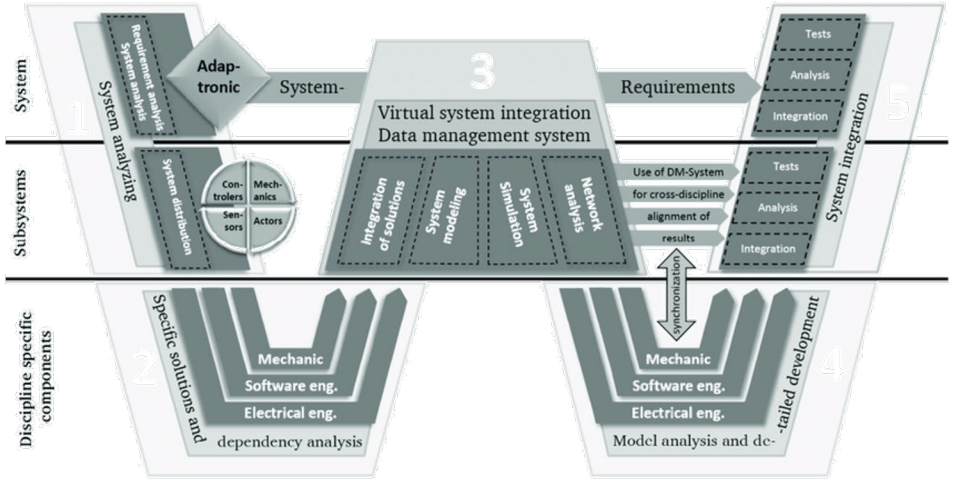
- Identify the system of interest of method building
- Identify the emergent value.
- Identify stakeholders, needs, requirements.
- Identify interfaces, inputs, and outputs.
- Decompose the main functionality of the system of interest into various activities and services.
- Identify the structures and sub-structures that support and feature these services.
- Explore the scientific principles of the engineered process, and incorporate them into the design process.

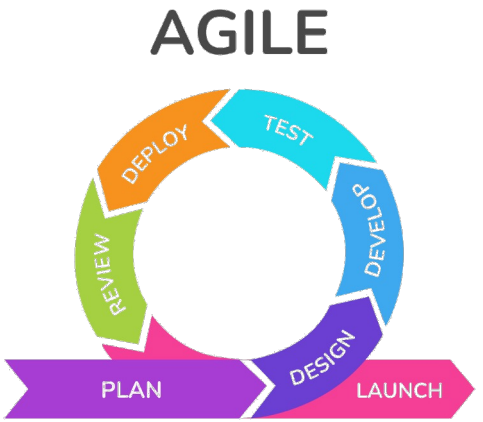
What makes a good reference for the Systems Engineering process?

- Problem identification
- Requirements specification
- System architecture / high-level design,
- Subsystem design
- Development
- Testing
- Integration
- Deployment
- Operation
- Monitoring and Control
- Decommissioning









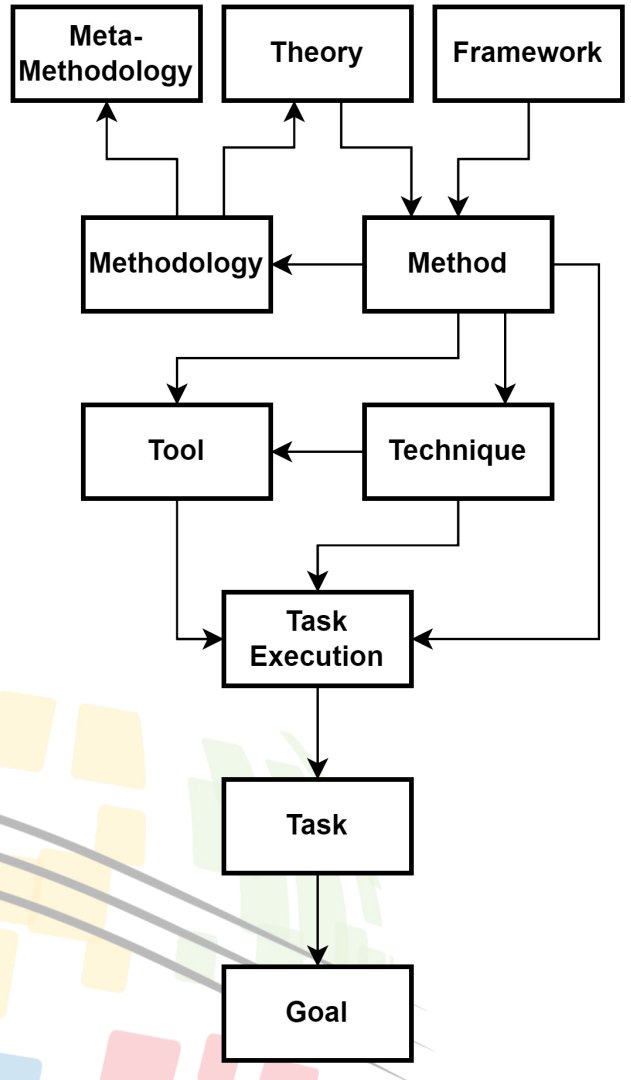
Any systems engineering method must fit within a systems engineering reference framework.

Example: Testing.

- Testing methods:
  - Requirements-driven testing
  - Functional testing
  - Non-Functional testing
  - Usability Testing
  - Performance Testing
  - Compatibility/Regression Testing
  - Negative testing
  - Etc.

- I have an idea for a new system testing method, e.g., based on a large language model (LLM).
- If my method is agnostic to the requirements' structure and format, and it will generate a result set according to a common standard, then it can simply replace or compete with the existing testing method.
- If I need to change the way I write my requirements (e.g., Test-driven design) then my method is no longer just a testing method – it is also a requirements specification method.

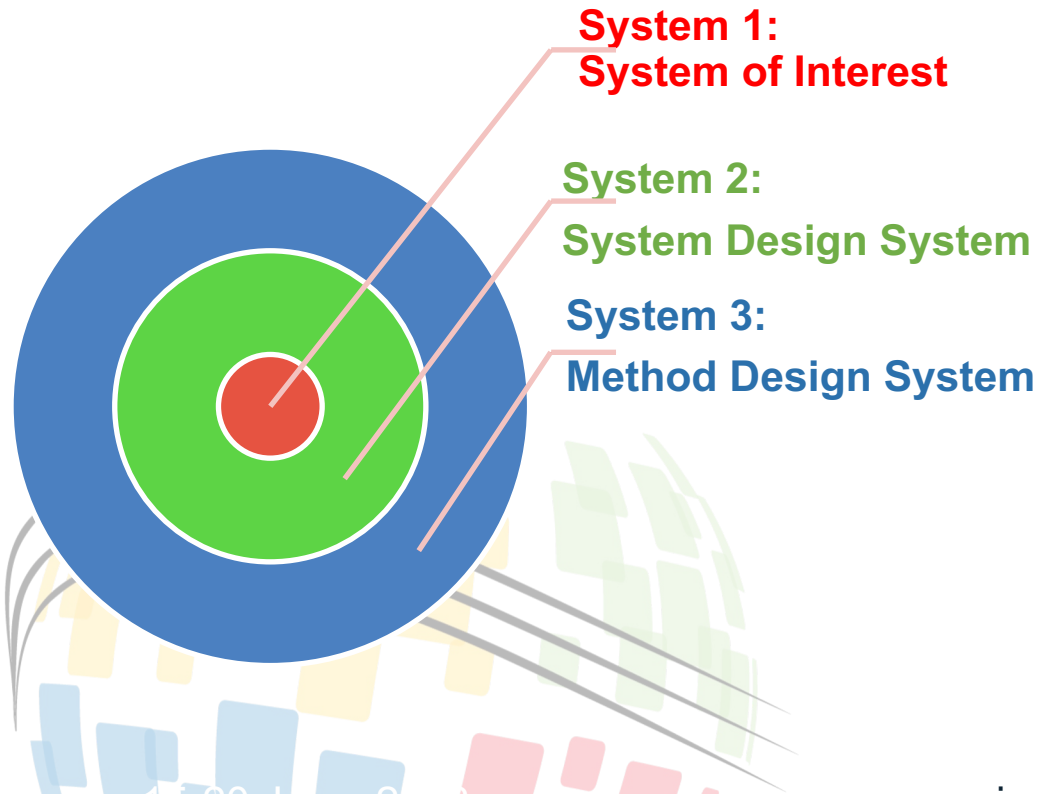
An ontological framework



- A **Method** is a way to perform a task or achieve an outcome.
- A **Methodology** is the study of a method.
- A **Framework** is a logical structure for classifying and organizing complex information (Executive Office of the President of the United States 2013).
- A **Theory** (in the context of methodology) is a claim (or hypothesis) along with the proof or demonstration of its validity, that a proposed method achieves the results of the task that it guides under a given context or set of assumptions.
- A **Technique** is a method to complete a task using a specific technology, tool, product, or service.
- A **Tool** is a physical, virtual, or cyber-physical resource that executes (i.e., automates) or helps its operator execute (i.e., assists) a task using one or more methods and techniques.
- **Meta-Methodology** is the study of methodologies, the definition and application of universal principles to the conception, formulation, specification, application, implementation, and analysis of methodologies and methods.

Any methodology should be underpinned by a theory about how the principles of the method generate value.

Systems engineering methods are systems that are designed to deliver value in the systems engineering process.

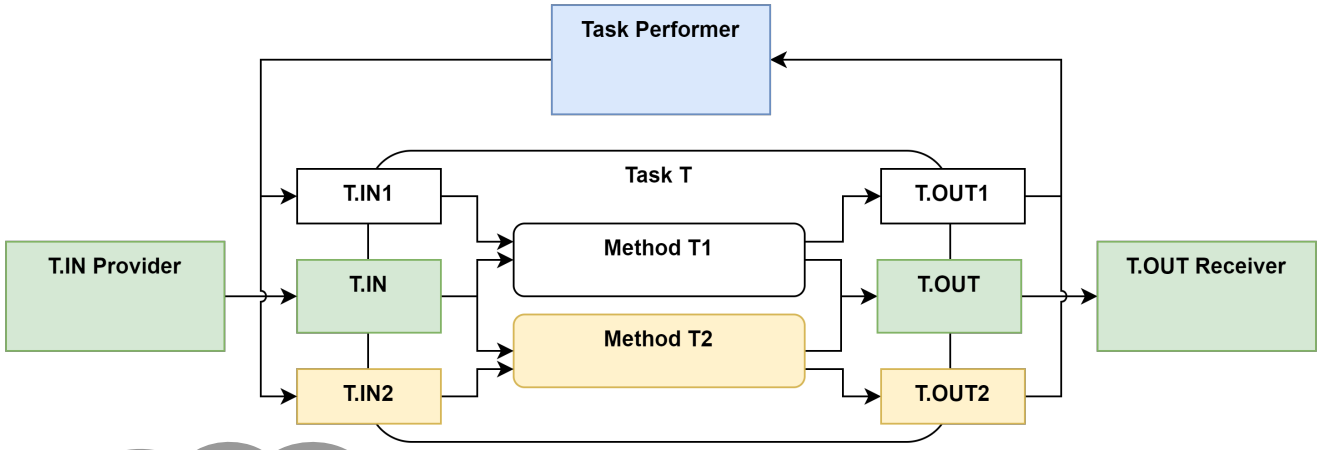


Systems Approach to Method Definition

- What is the method of interest?
- Who are the method's stakeholders, what are their goals, problems, and needs?
- What is the emergence—the added value—of the method of interest, with which it may help the stakeholders?
- What are the mandatory inputs and outputs to the method of interest, and what inputs and outputs are contingent from the introduction of the method?
- What are the environmental entities that interact with the method, provide input to the method or receive/consume/use its outputs?

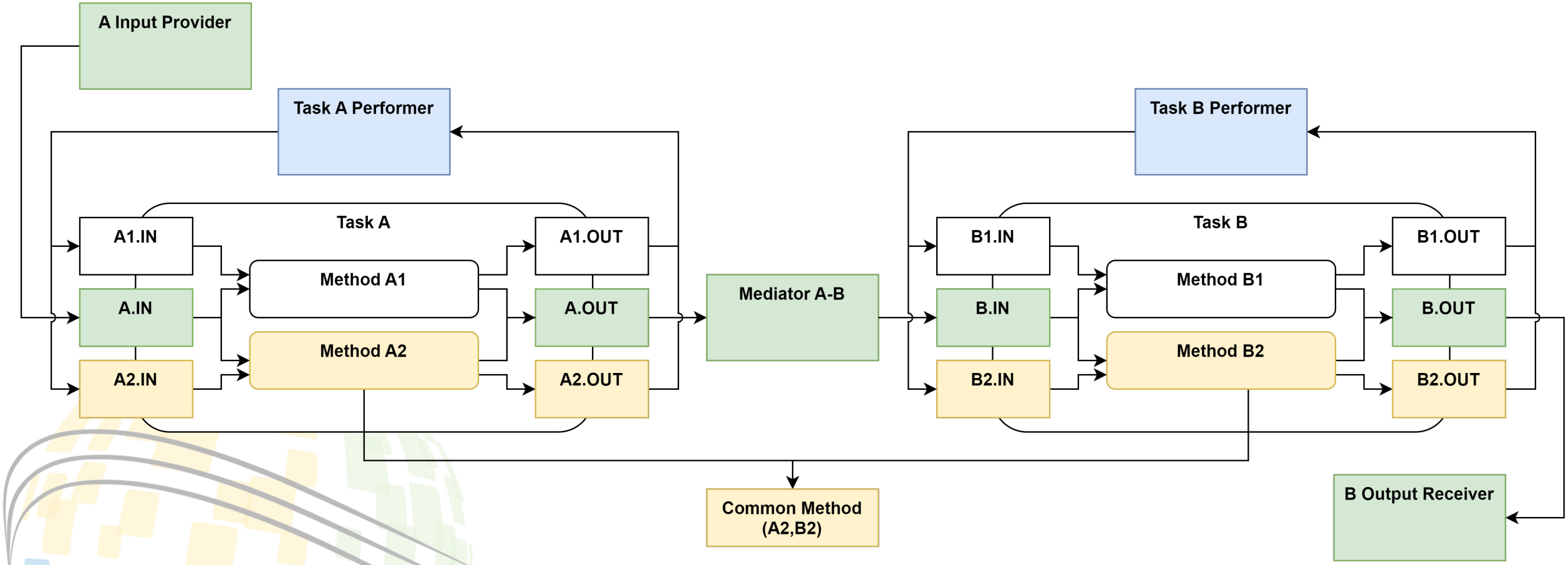
Task-Method Diagrams

- **The Task-Method Diagram (TMD) is a simple representation of the task-method duality.**
- **TMD is a block definition diagram that captures the method as a system in its environment.**
- **TMDs define the executed task in a method-agnostic way as the super-system in which the method lives.**



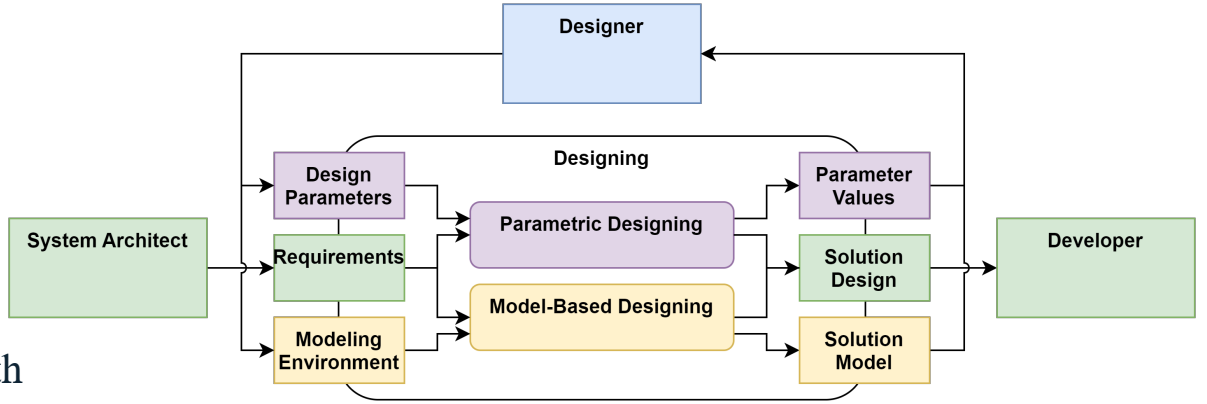
The primary beneficiary and stakeholder of the method-specific inputs and outputs is the **Task Performer** – a person, organization, or machine – who primarily benefits from being able to achieve the same result in two different ways.

Representing complex methods that support multiple tasks with compositional TMDs.



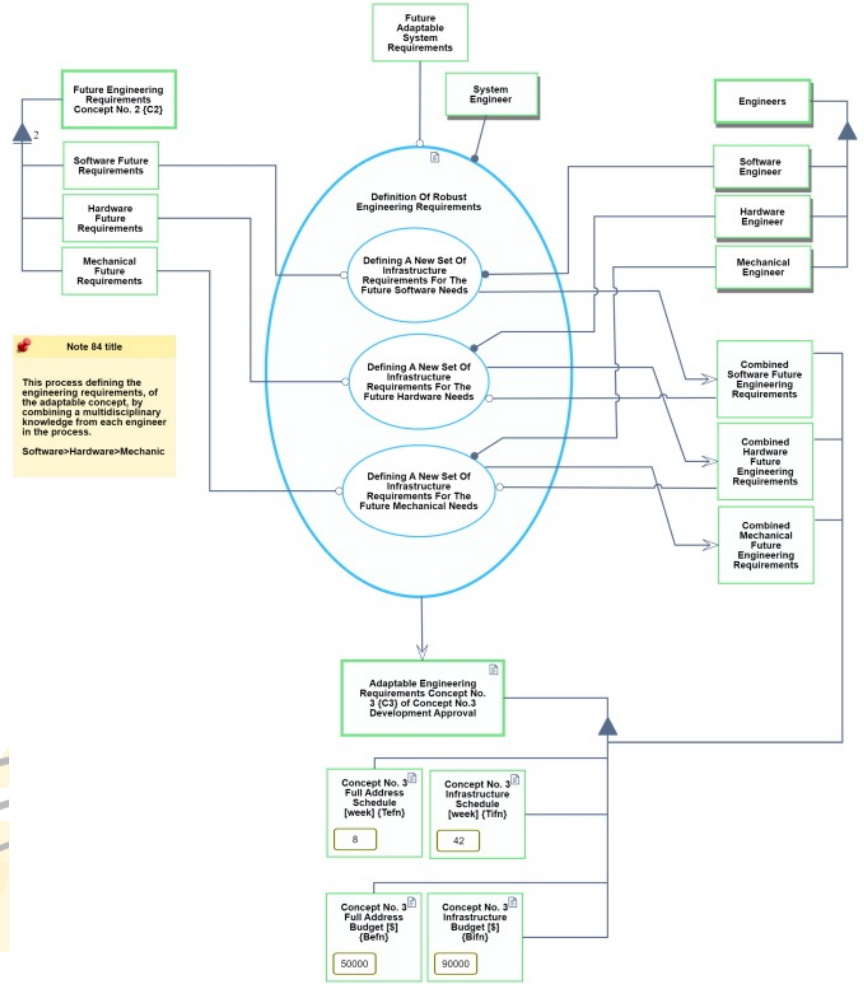
Example:
Parametric Design vs Model-Based Design

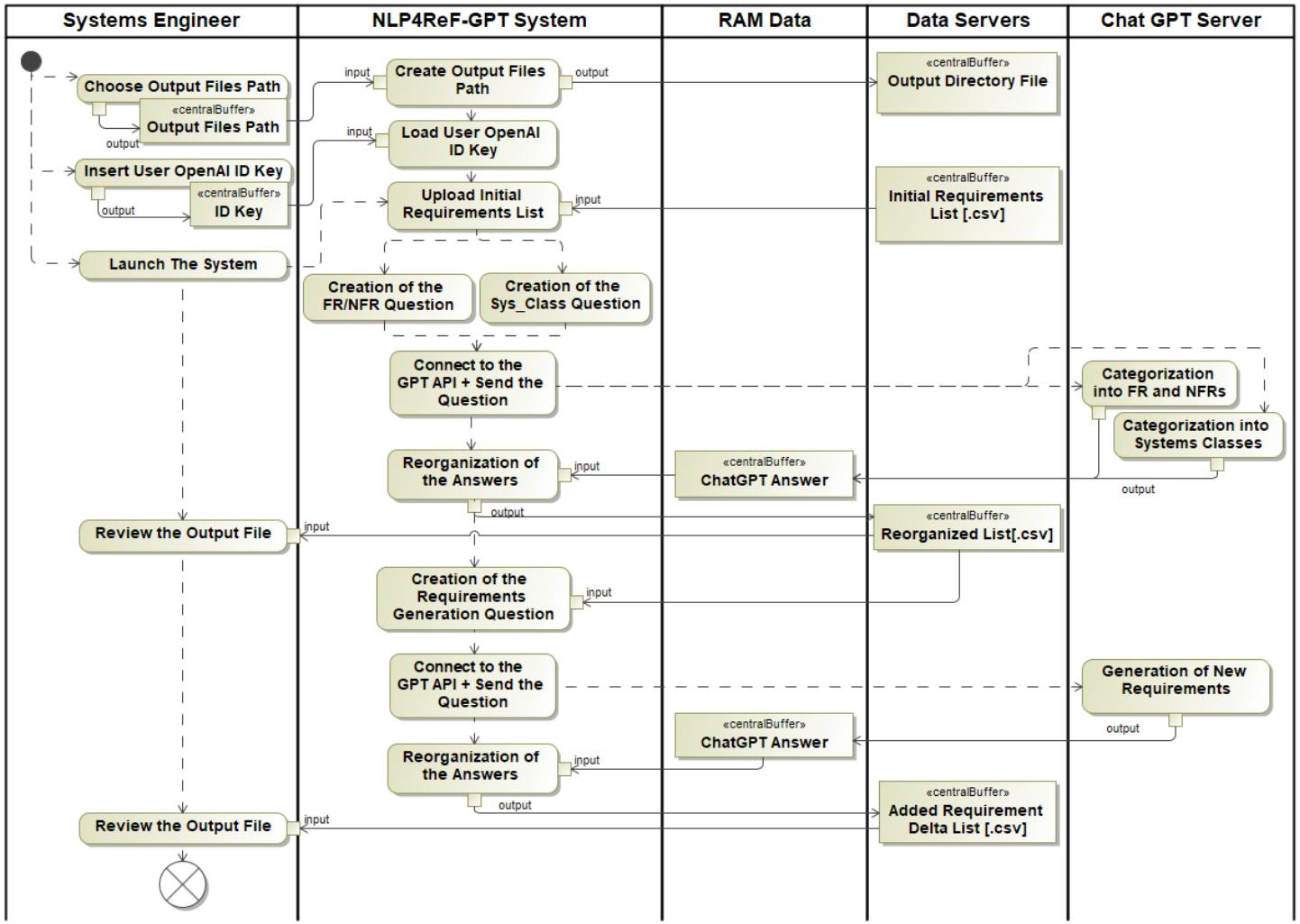
- **Task: designing a solution** based on a set of system requirements.
- The **requirements** are provided by the **system architect**.
- There **should not be any change to the requirements** set.
- The **system architect** is the **input beneficiary** of the designing task.
- The **output** of the task is a **solution design**.
- The **developer** is the **output beneficiary** of the designing task.
- The **structure and format of the solution design**, must be in line with what **the developer can read**, understand, and implement.
- **Both design methods** – parametric and model-based – **primarily serve the designer.**
- **The designer must provide the relevant inputs to each method** so that it can provide its output:
  - For parametric design: the **design parameters**.
  - For model-based design: a **model-based design environment**
- Any **method comparison** would be primarily related with the ability of both methods to **receive requirements** and **generate solution design**.



The method with which the design was generated by the designer is immaterial to the architect and immaterial to the developer.

Modeling the Engineering Process without and with the method





Method Requirements Specification

- **A method must have requirements.**
- The requirements **must specify what the method should achieve**, i.e., **what tasks** it is supposed to support or implement.
- The requirements **may specify method-implementing solutions**.
- The requirements should **reflect the scope of the method**: **universal**, **general-purpose**, **domain-agnostic**, **domain-specific**, or **problem-specific**.
- Requirements specification helps method designers **ensure that the method is purpose-built** for solving the problem.
- The requirements **should adhere to an ontology** of meta-methodology (e.g. the proposed ontology, or any other common ontology).

- Requirements can be written as textual "shall statements" followed by required functionality.
  - **"The methodology shall…"**
  - **"The method shall…"**
  - **"The framework shall…"**
- …or as plain command-style statements:
  - **"Capture knowledge"**
  - **"Execute models"**
  - **"Prioritize considerations"**
  - **"Check coverage", etc.**

“You get what you measure”

Method Assessment Method

a) A meta-methodological procedure for method assessment
b) A critical enabler of applying meta-methodological thinking in method design

We defined a set of requirements for a systems engineering method assessment method, adapted and extended mostly from FEMMP

- FWMMP is a MBSE framework evaluation framework (Maio et al. 2021), https://mbse-methodologies.org/
- FEMMP does not specify requirements.
- We reverse-engineered FEMMP’s description and assessment criteria.
- We abstracted FEMMP’s tool-related specs to refer to methods.

Method Assessment Method: The Requirements

- Provide a catalog of standard criteria to assess the practical use of a systems engineering method
- Allow the assessor to add specific criteria and eliminate some irrelevant or non-applicable criteria
- Allow the assessor to determine or change the relative importance of each criterion or group of criteria
- Provide a set of reference case studies that systems engineering methods can be applied to for the purpose of the assessment
- Assess the learning curve of the method
- Assess the ease of understanding of the method for novices
- Assess the amount of training experienced SEs require to implement the method correctly
- Assess the industry domains that the method support particularly well and how well does it fit a given domain
- Assess the extent to which the method fosters creativity
- Assess the standards and norms that the method support and how well does it fit a given standard
- Assess the ability of the method to capture the information generated throughout the process
- Assess the distinction between logical elements and visual elements
- Assess the compliance of the method with ISO 15288
- Assess the compliance of the method with reference architecture frameworks – DoDAF, MODAF, UAF etc.
- Assess the method's support for abstraction
- Assess the existence of an ontological framework of the method
- Assess the strictness of the method's execution process/ algorithm
- Assess the flexibility of the method's execution process/ algorithm
- Assess the amount of automation provided by the method
- Assess the speed with which the method can be executed completely

Method Assessment Method: The Requirements

- Assess the readability of the outcome of the method
- Assess output compatibility with the required output structure
- Assess the input compatibility with the required input structure
- Assess the method's expectation for and facilitation of collaboration
- Assess the suitability of the method for project types such as scientific research, innovation, new product development, product improvement, refactoring, reverse engineering, integration, business process introduction, etc.
- Assess the configurability of the method by the user
- Assess the method's dependency on and sensitivity to interrupts from external methods
- Assess the method as a modeling method
- Assess the method as a simulation method
- Assess the method as an analysis method
- Assess the method as a documentation method
- Assess the method as a control method
- Assess the method as a data management method
- Assess the method as a decision-making/ decision support method
- Assess the scalability of the method
- Assess the method's facilitation of re-use
- Assess the method's interconnectivity of artifacts
- Assess the method's formality
- Assess the quality of the documentation of the method
- Assess the method's compliance with meta-methodological principles, including self-assessment or independent assessment according to this specification

We are now ready to assess new systems engineering methods more consistently and constructively.

Discussion and Conclusion

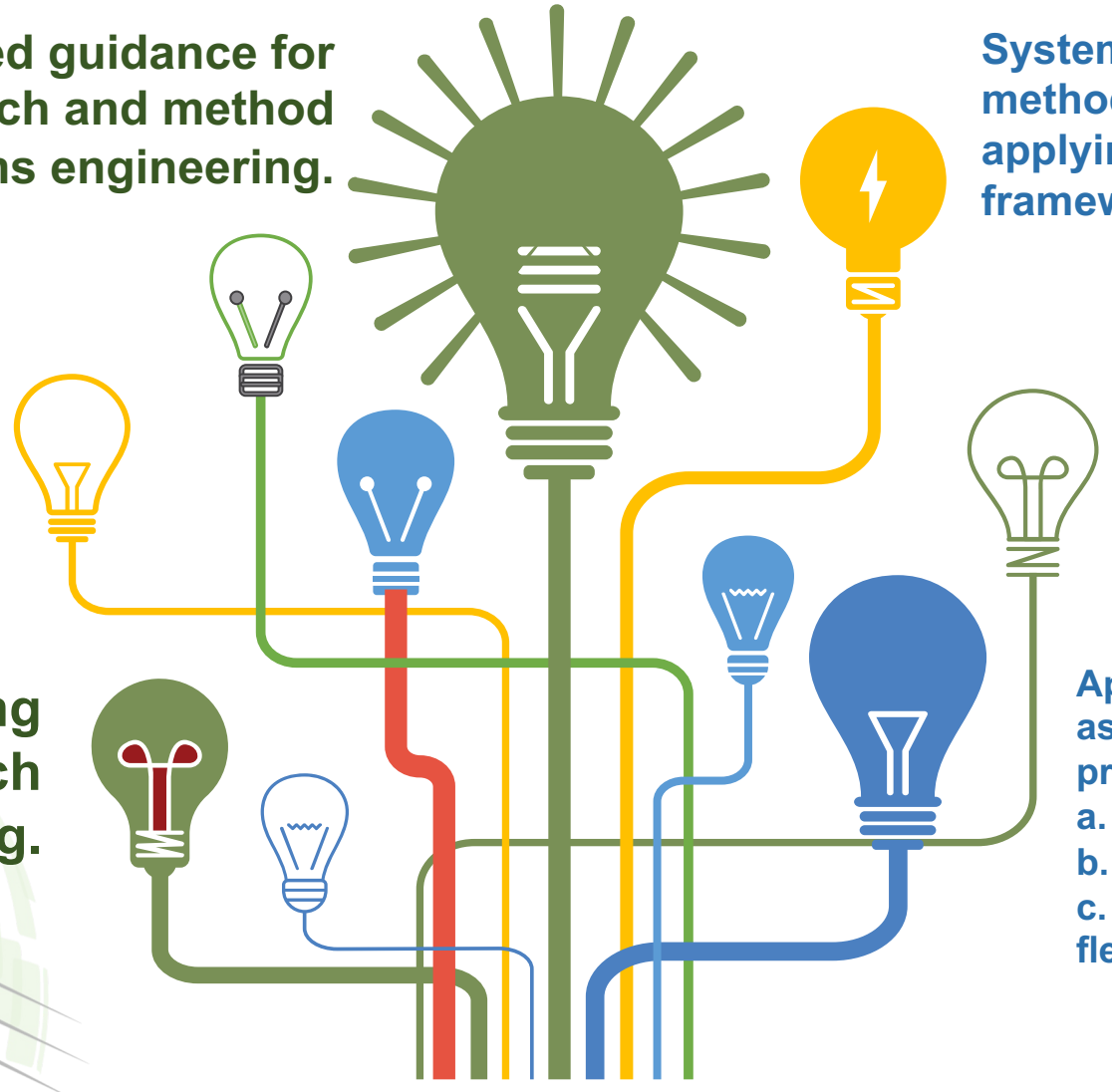
Researchers need well-formed guidance for methodological research and method design in systems engineering.

Systems engineering methodology and methods can be greatly improved by applying a meta-methodological framework.

Consolidating and converging systems engineering method design has become imperative.

Well-guided methodological research leads to clearer method specifications, faster completion of methodology design projects, and better method integration.

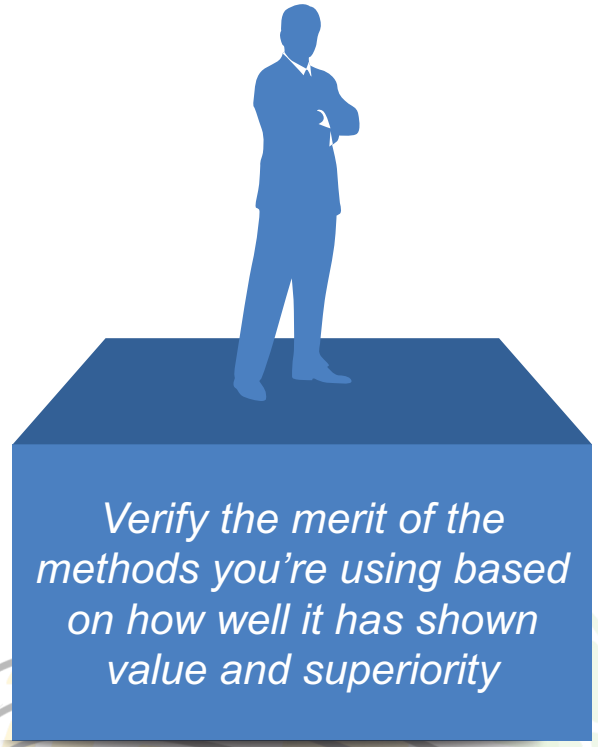
Systems engineering methodological research is booming.



Application of method building and assessment practices in three ongoing projects:
a. Safety requirements specification,
b. AI-assisted requirements discovery,
c. Techno-economical analysis of flexibility and adaptability.

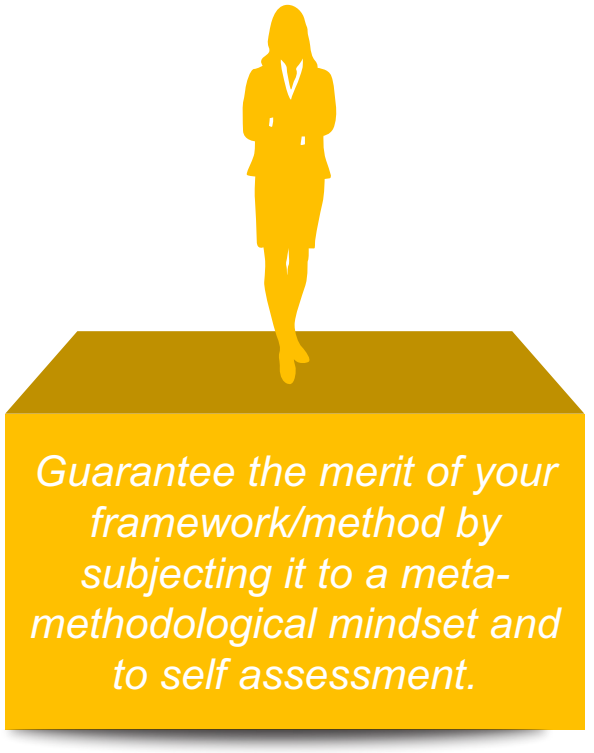
Key Takeaways

Systems engineer



Verify the merit of the methods you're using based on how well it has shown value and superiority

Method designer



Guarantee the merit of your framework/method by subjecting it to a meta-methodological mindset and to self assessment.

Reviewer

Challenge the methodology research you're reviewing to foster and demonstrate awareness of the need for a meta-methodological approach.

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THANKS!!

To continue the discussion please reach out
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