Using the Design Structure Matrix to Plan Complex Design Projects

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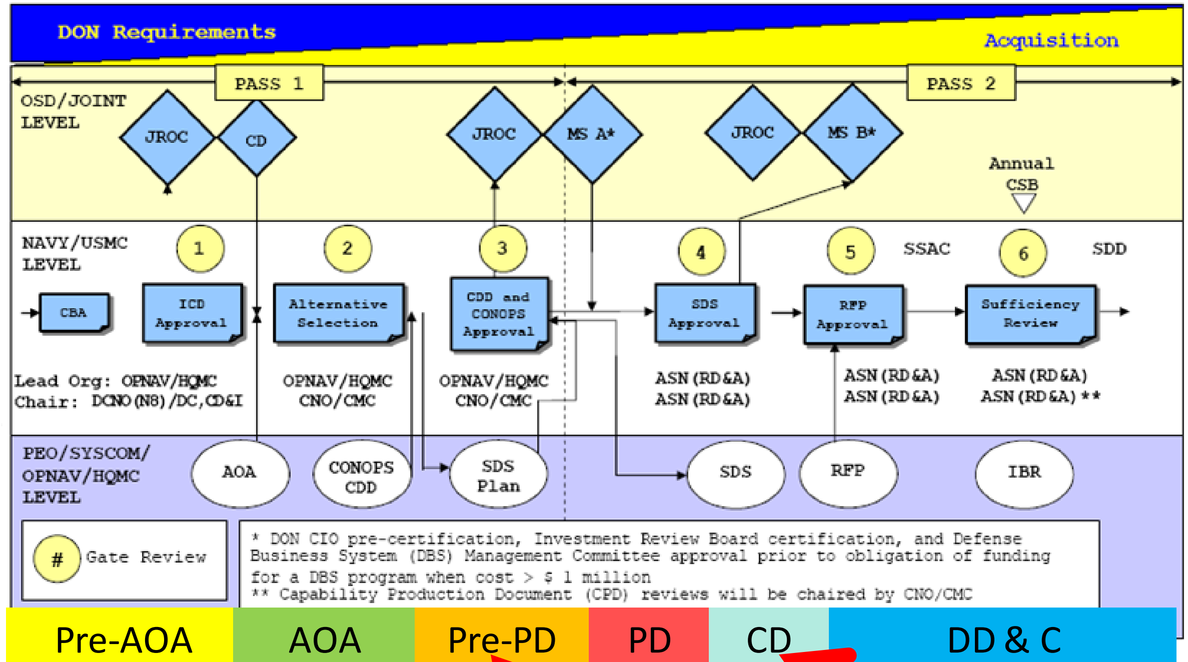
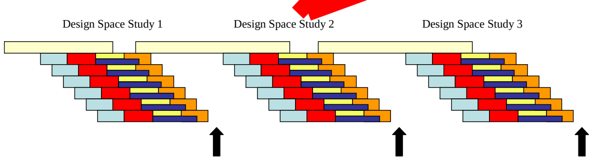
What is Design?

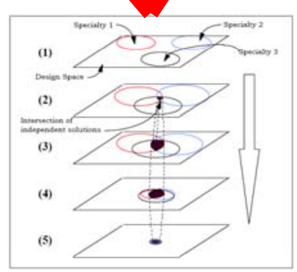
- Design is making choices and documenting those choices in an organized way to support the eventual procurement of material and creation of instructions for production workers to produce a final product that meets customer needs.
  - Each decision removes one or more degrees of freedom.
  - Decision Process should involve the appropriate Stakeholders
    - Bill Payer: Keep the product affordable.
    - Producer: Understand how the producer will make the product.
    - Tactician: Understand how the customer intends to use the product. (Concept of Operation or CONOPS)
    - Strategist: Understand how requirements could change in the future and what can be done to incorporate flexibility to address these potential changes.
    - Tester: Understand how the product will be evaluated for acceptance.
    - Scientist: Understand how new technology can help address needs of other stakeholders.
    - Maintainer Understand how the system will be maintained and modernized

Design Approaches and Stages

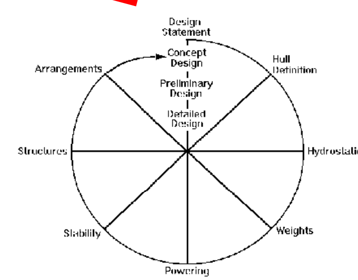




Synthesis Model based Design Optimization



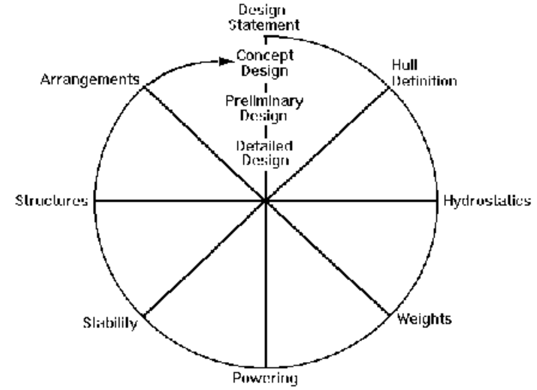
Set Based Design

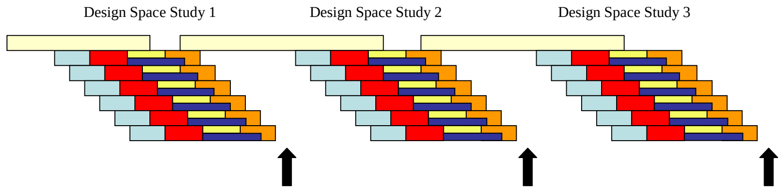


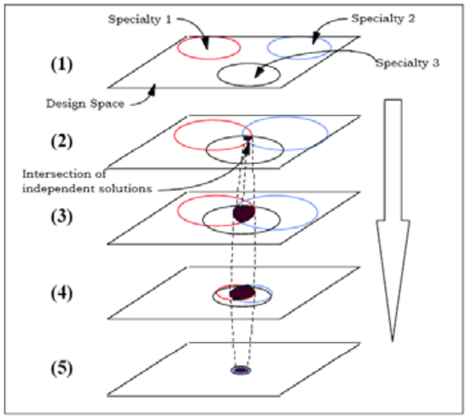
Spiral Design

Design Approaches

- Classic Design Spiral – Point based Design
  - Start with something that almost works, then sequentially modify it and analyze it until a solution is found.
    - A design iteration can be on the order of 8 to 12 weeks.
  - Works well if the starting point is good.
  - Design is complete when you run out of time.
- Synthesis Model based Design Optimization
  - Use a design Synthesis Model with an optimization algorithm to find the “best” solution.
  - Generally integrates Design of Experiments, Genetic Algorithms, and Response Surface Methods.
- Set Based Design
  - Progressively shrink an initially large design space
    - Intersections of different system / subsystem design spaces.
    - Detail increases with each contraction of design space.
  - Allows different design sub-groups to work somewhat independently

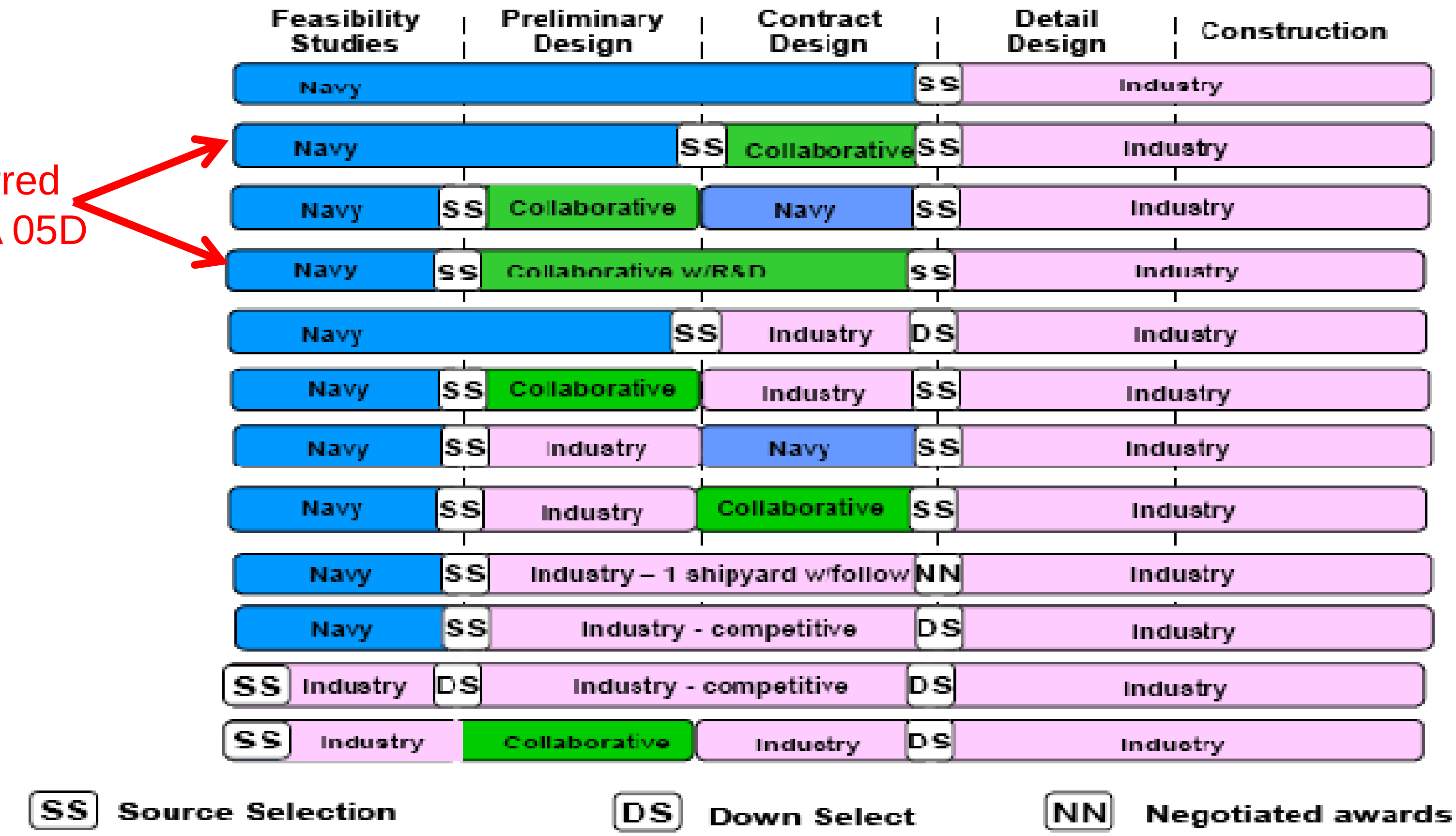






Who does the work?

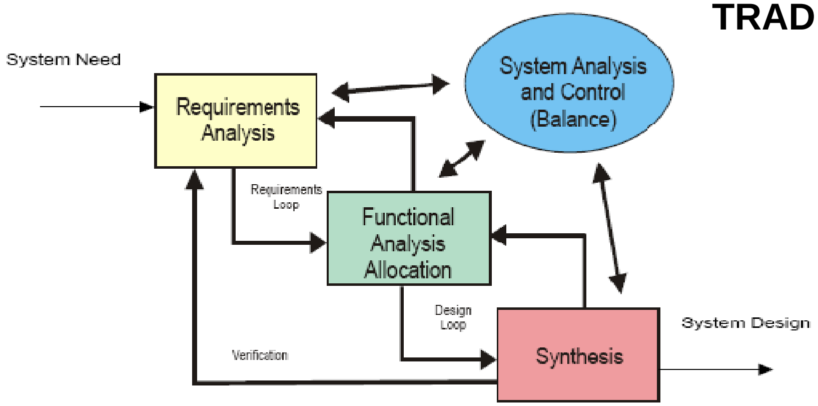
Preferred
By SEA 05D



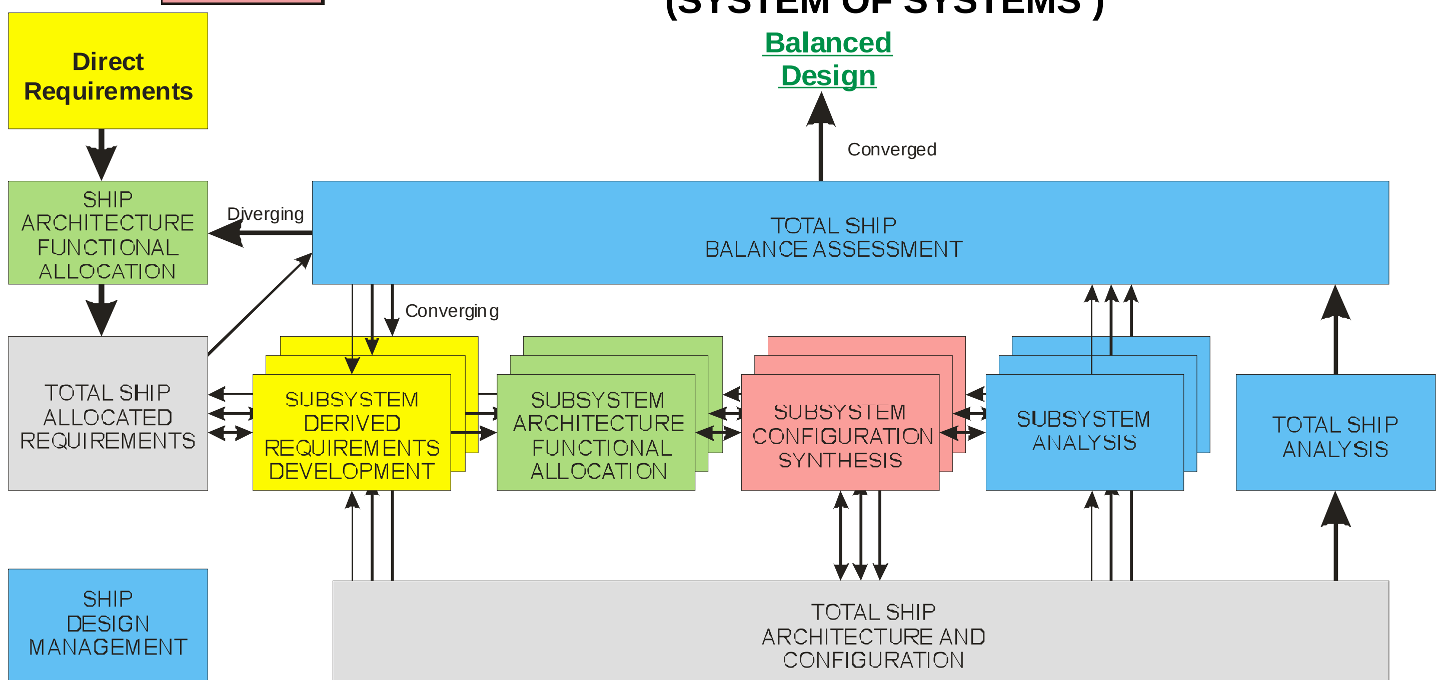
Government always responsible for Design Certification

Systems Engineering
Complex Systems

TRADITIONAL SYSTEMS ENGINEERING PROCESS
(AS TAUGHT BY DAU)

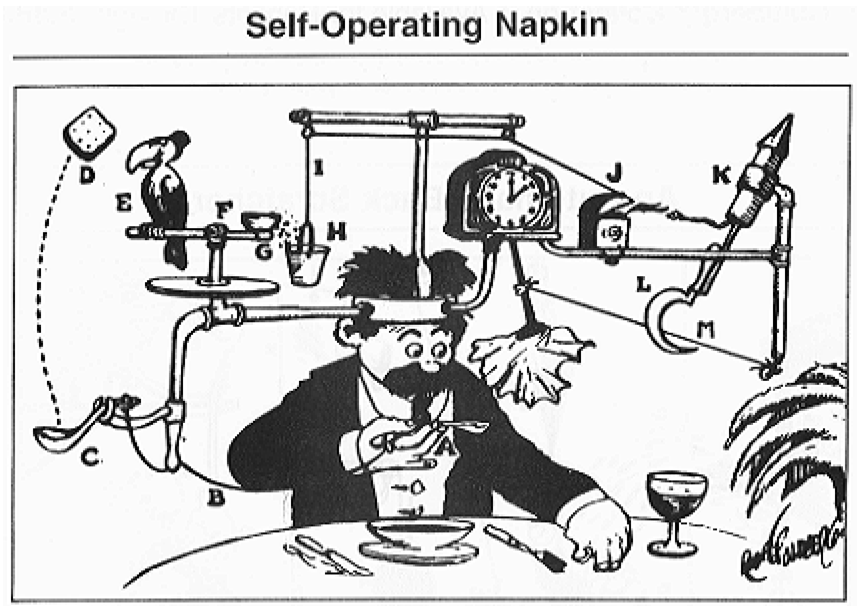


SYSTEMS ENGINEERING PROCESS
FOR A SHIP
(SYSTEM OF SYSTEMS)



Complexity and its dimensions

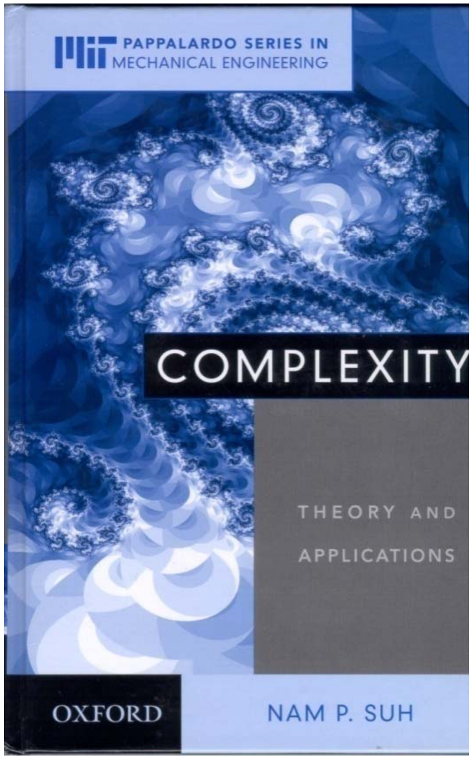
- Complexity deals with functions and the way they interact and interfere with each other to prevent achieving the overall objectives.
- Complexity can exist in multiple dimensions
  - Design (design activities)
  - Acquisition
  - Production
  - Testing
  - Operations
  - Maintenance
  - Modernization



Rube Goldberg

Types of Complexity

- Real Complexity
  - Measure of the uncertainty involved in achieving a task
  - Reduced by reducing variance of the individual tasks and the coupling of individual tasks
  - Lean Six Sigma
- Imaginary Complexity
  - Due to lack of understanding about the system design, system architecture, and/or system behavior (learning curve)
  - Reduced by documenting activities, training, & experience
  - ISO 9000, DODAF, DSM, etc., l
- Combinatorial Complexity
  - The accuracy or properties of the system change with time – either due to internal (wear) or external (threat evolves) reasons such that the system can no longer reliably achieve its objectives. (Diverging ship design)
  - Reduced by converting to Periodic Complexity and by improving robustness (including margin)
  - Maintenance, Modernization, Design Iterations, Architecture, Margin Policy
- Periodic Complexity
  - Systems with Combinatorial Complexity are “reinitialized” based on a “functional period”

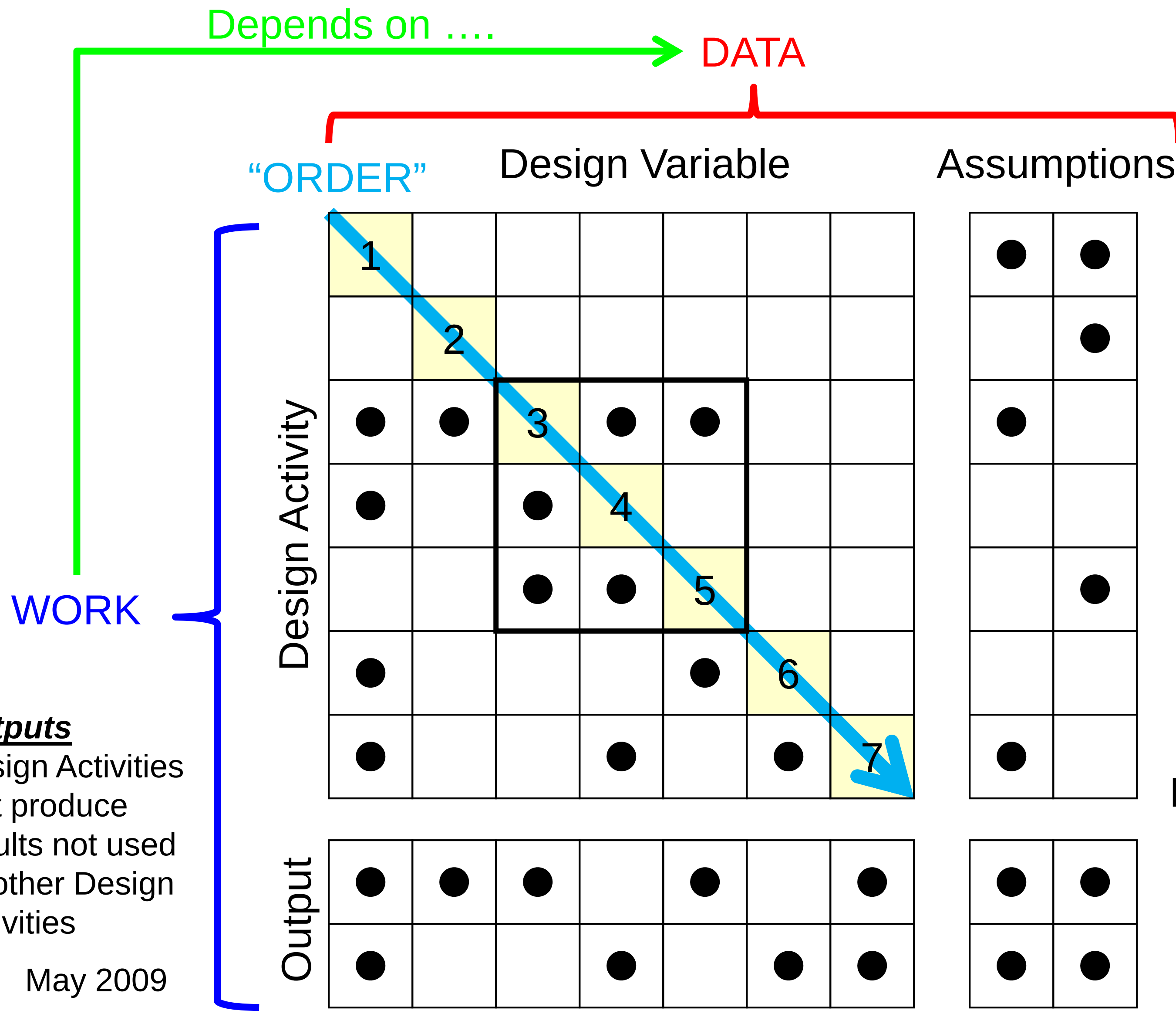


Planning Complex Projects

Planning Complex Projects is Hard!

- Multiple Organizations with multiple design / production activities
- Unique aspects of each design preclude exact reuse of previous plans
- The design activity interdependency may change with increased design fidelity
- Traditional Scheduling and Earned Value Management does not track design convergence and does not handle conditional design activities well.
- Inability of one person to fully understand the entire project
- Still need to accurately predict schedule and cost

Design Process Model



Assumptions
Data needed by Design Activities but not produced by other Design Activities. No work is associated with producing assumptions

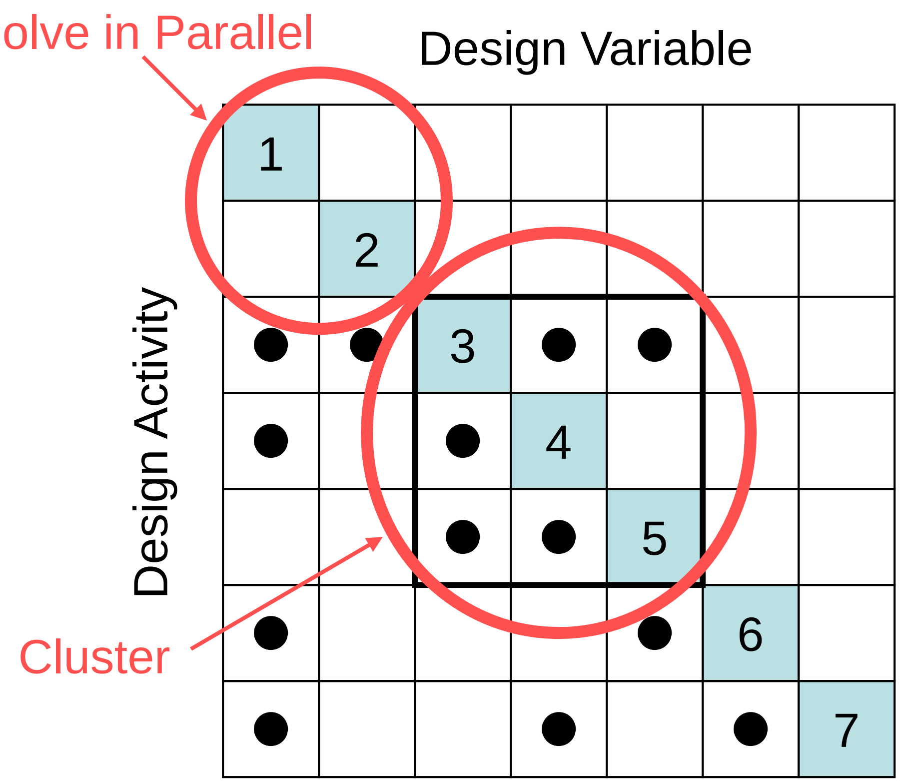
Design Activity “n” Produces Design Variable “n”

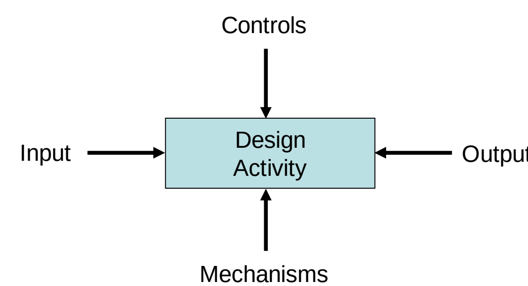
Design Activity “n” Depends on Design Variable “m” where “m” $\neq$ “n”

Outputs
Design Activities that produce results not used by other Design Activities

Design Structure Matrix in one slide

- Design Activities defined by IDEF0 Models
  - Inputs, Outputs, Constraints, and Mechanisms
  - Each Output corresponds to a Design Activity
  - A design activity can have multiple inputs
- Inputs can be provided
  - By other Design Activities
  - Assumed (Process Input)
- The DSM describes the inter-relationships of Design Activities
  - Identifies which outputs from other Design Activities are needed
- Standard Matrix operations can identify
  - The optimal ordering of tasks
  - The set of tasks that can be done in parallel
  - The set of tasks that must be solved together (a cluster)
- Can also be used to
  - Develop Schedules and cost
  - Discrete Event Simulation to determine expected duration
  - Identify optimal IPT structures





http://www.dsmweb.org/

Design Process Model – Why?

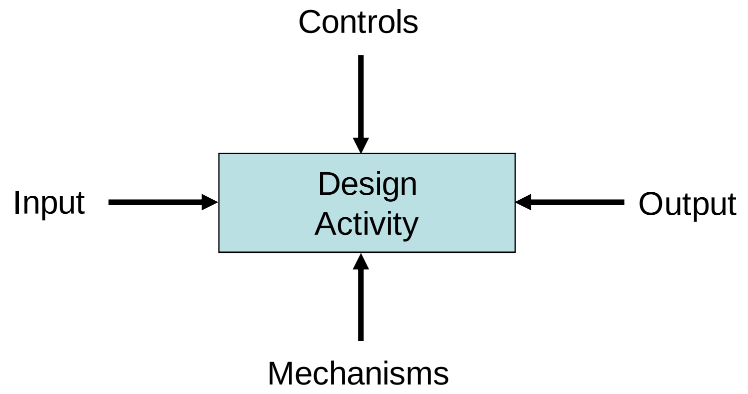
- Get the order of design activities right
  - Simple Matrix operations
- Understand inter-dependencies
  - Design Activities can require additional inputs as the design matures and the “fidelity of output” control is dialed higher
    - Potentially changes design structure
  - “Clusters” can be dealt with by …
    - Co-locating design teams performing design activities
    - Creating an Integrated Product Team (IPT) for the cluster
    - Automating data interchange within the cluster
    - Redefine Design Activities to eliminate “Clusters”
- Provide basis for discrete event simulation
  - Develop an engineered estimate for duration and cost of the design process

IDEF0 Model of a Design Activity

- Design Activity
  - Work done by one organization to convert Inputs into Outputs
  - Generally described in one statement of work
- Input
  - Design Data and Requirements needed to perform the Design Activity
  - Can have multiple inputs
- Output
  - Design Data created by the Design Activity
- Controls
  - Modify the way work is accomplished
    - Fidelity of Output
    - Architecture selection
    - Risk tolerance / margin
- Mechanisms
  - Describe resources needed to accomplish the work
  - Include trained workforce, tools, and supporting data sets

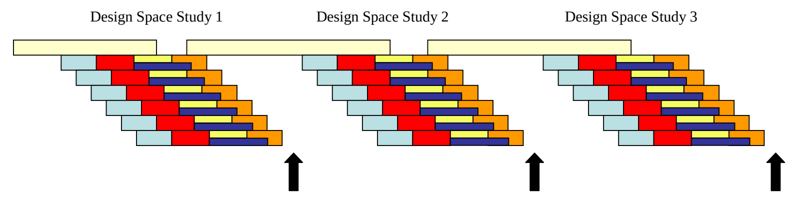
Execution Oriented

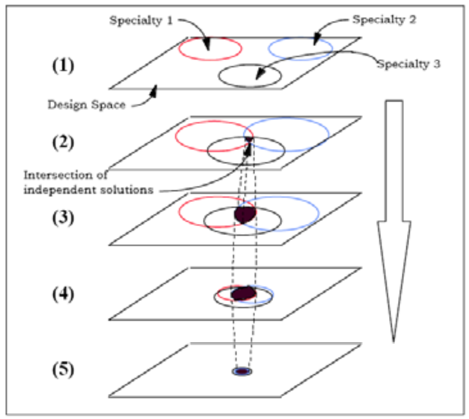
Planning Oriented

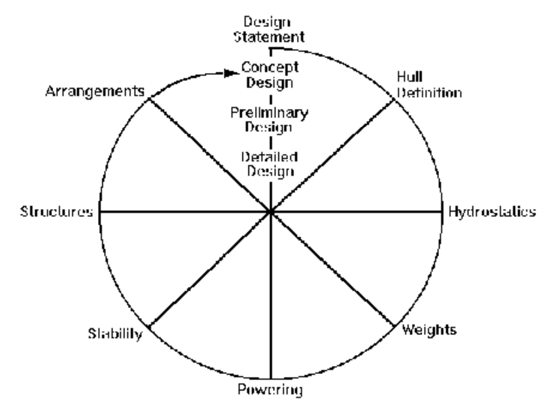


Design Complexity

- Interested in those things that get in the way of having a converged design delivered on time and meeting customer expectations.
- Real Complexity
  - Choosing the proper design activities and design methods
- Imaginary Complexity
  - Design Structure Matrix
  - Training
- Combinatorial / Periodic Complexity
  - Design Iterations
  - Design Margin
  - Architectural Robustness





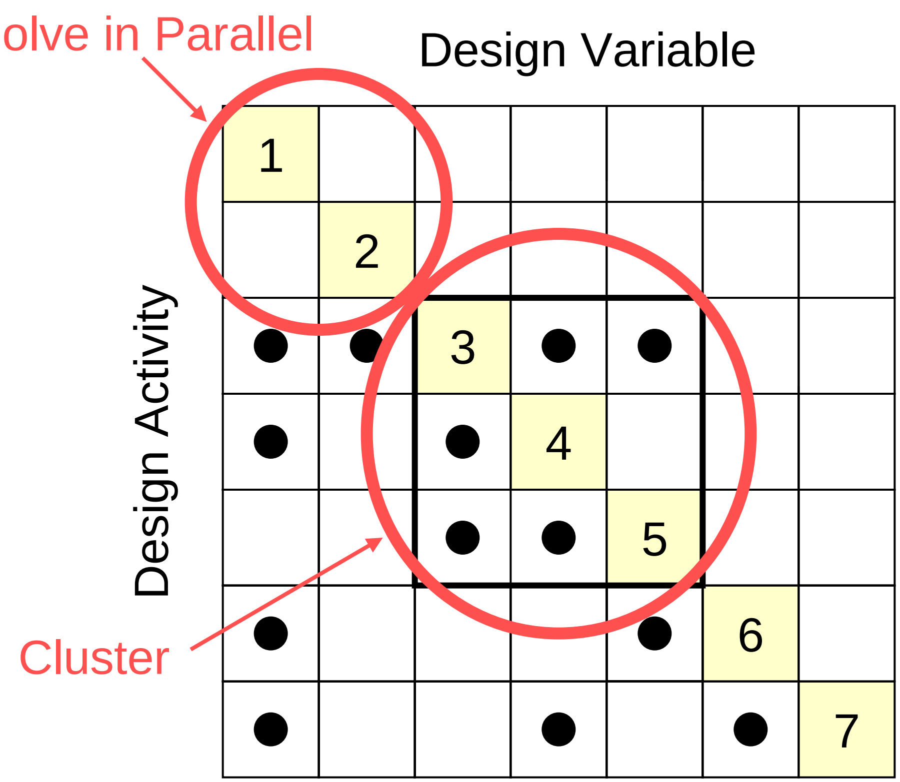


Complexity and the DSM

THEORY: The total number of design activities and the number and size of the clusters is likely a good indicator of the design complexity.

- Large clusters increase complexity more than increasing the number of design activities

PROPOSED COMPLEXITY METRIC: Sum of the square of the cluster sizes of all the clusters in a DSM



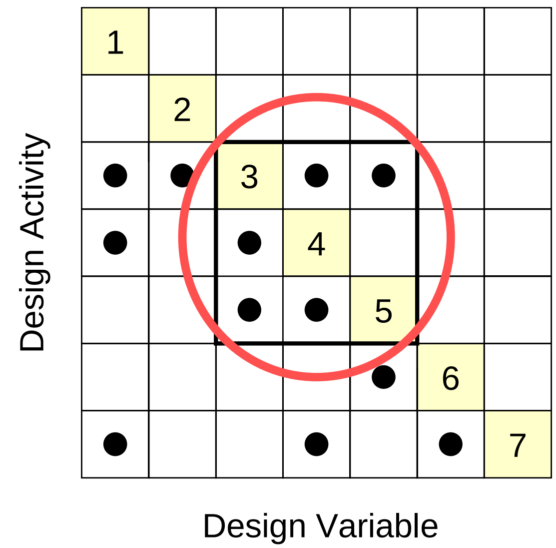
Proposed Complexity Metric =
1 + 1 + 9 + 1 + 1 =13

Reducing Complexity by eliminating Clusters

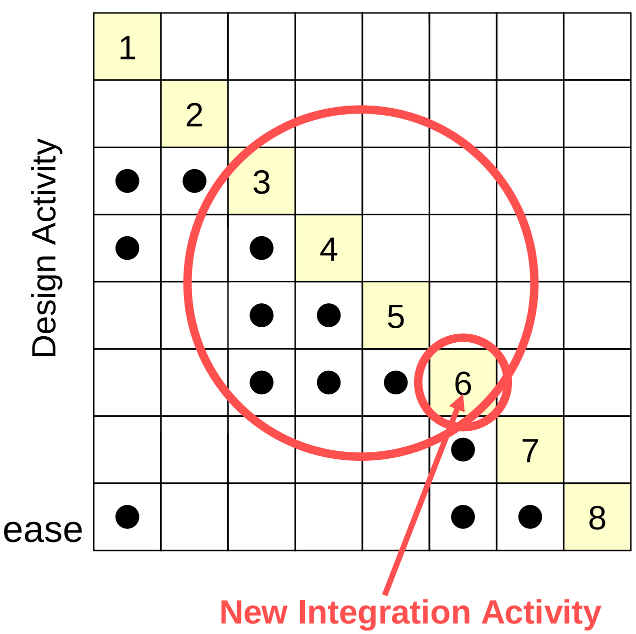
- Redefining Design Activities and adding an additional one can significantly reduce complexity

  $N + 1 < N^2$

- To reduce complexity,
  - Redefine the product of design activities in a cluster to be response surfaces
  - Add an "Integration" design activity to find the intersection of the response surfaces



Complexity Metric 13



Complexity Metric 8

DSM and Design Methods

- Classic Design Spiral
  - Eliminate “Clusters” by assuming data values from previous iterations as needed.
  - Use DSM to minimize the number (and severity) of assumptions that must be made.
  - Identify “natural IPTs”
- Synthesis Model based Design Optimization
  - Optimize data flow between design tools.
  - Trade-off model fidelity with analysis confidence level.
- Set Based Design
  - Understand inter-relationships between different disciplines and how they evolve as fidelity is improved.
  - Identify “natural IPTs”

Summary

- Three approaches to Design
  - Synthesis Model based Design Optimization
  - Set Based Design
  - Classic Design Spiral
- Design Structure Matrix
  - Compactly represents the relationships of design activities
  - Enables identification of the optimal ordering of design activities
  - Enables identification of “clusters” of design activities that must be solved together
  - Provides a means of quantifying design complexity
- Complexity
  - Is a function of how design activities relate to one another
  - Methods exist to identify and reduce complexity.