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

Design Approaches:
- Synthesis Model based Design Optimization
- Set Based Design
- Spiral Design

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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.

- **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?

<table>
<thead>
<tr>
<th>Feasibility Studies</th>
<th>Preliminary Design</th>
<th>Contract Design</th>
<th>Detail Design</th>
<th>Construction</th>
</tr>
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<tbody>
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<td>Navy</td>
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<td>SS Industry</td>
<td>DS Industry - competitive</td>
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SS Source Selection  | DS Down Select  | NN Negotiated awards

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)

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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., etc.

• 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 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” ≠ “n”

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

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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

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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
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
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.