# Complexity

**ONR-OSD CREATE-NAVSEA Ship Design Workshop**
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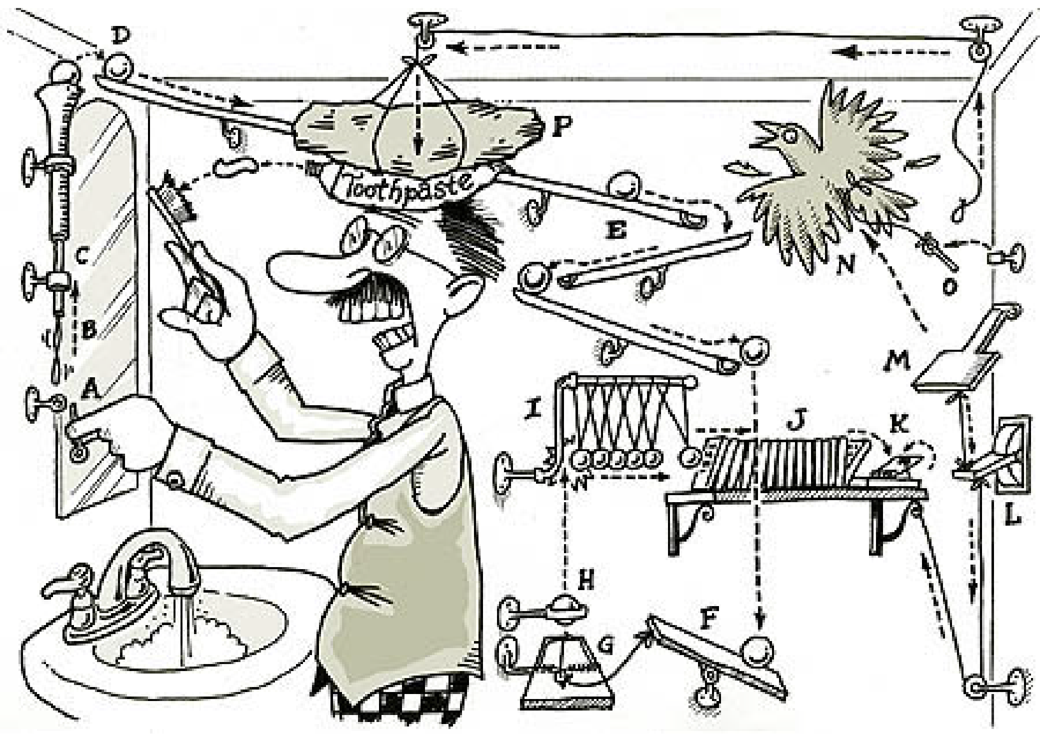
# Agenda

- The Nature of Complexity
- Design Complexity
- Production Complexity
- Modernization Complexity
- Summary




Rube Goldberg

# Trying to Define Complexity

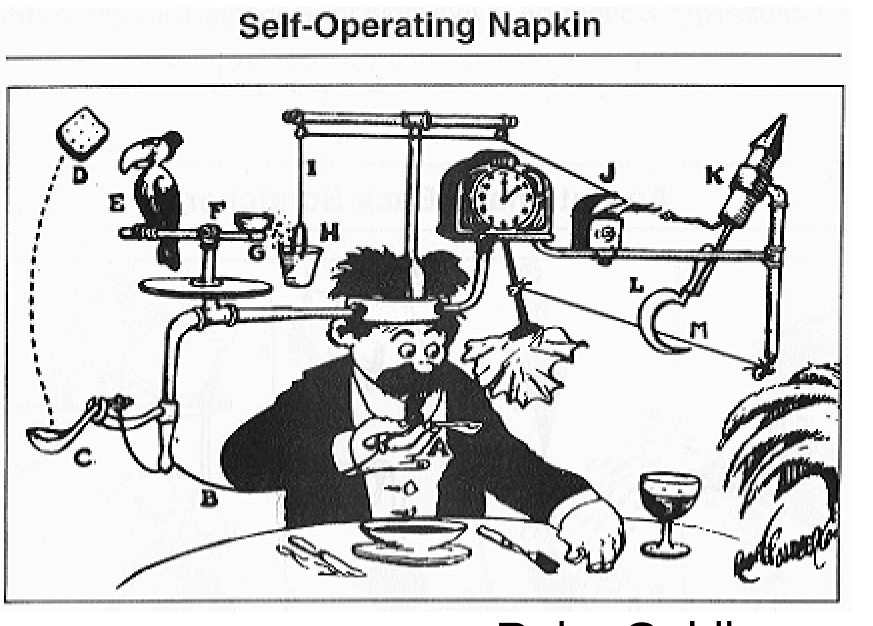
Complexity is a function of …

- "Number of ideas you must hold in your head simultaneously;
- Duration of each of those ideas; and
- Cross product of those two things, times the severity of the interactions between them."

Bob Colwell

# Complexity and its dimensions

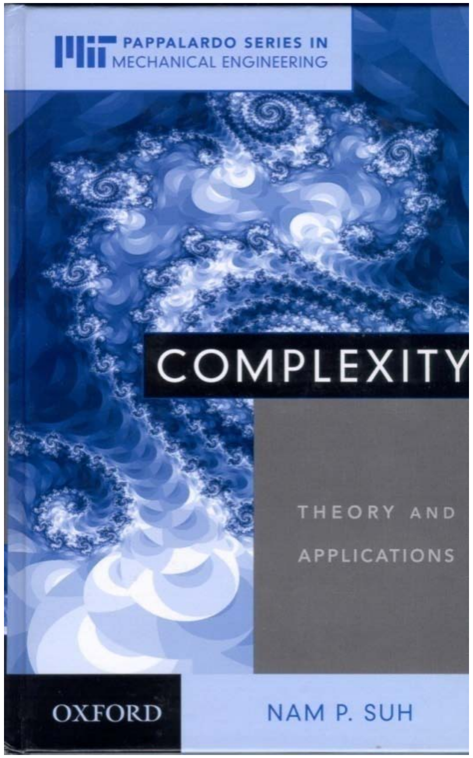
- Complexity deals with functions and the way they interact and interfere with each other to prevent achieving the overall objectives.
- Complexity can exist in multiple dimensions
  - Design (design activities)
  - Acquisition
  - Production
  - Testing
  - Operations
  - Maintenance
  - Modernization




Rube Goldberg

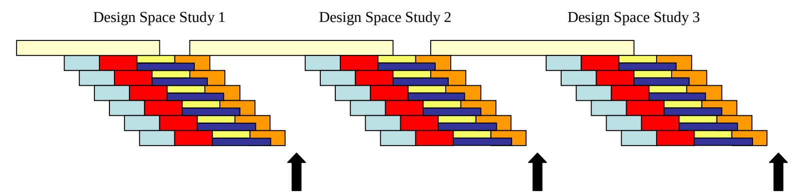
# Types of Complexity

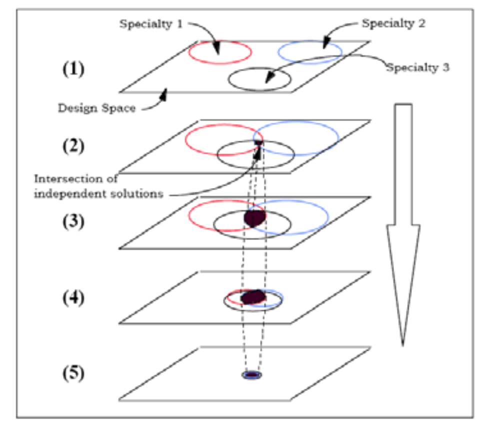
- Real Complexity
  - Measure of the uncertainty involved in achieving a task
  - Reduced by reducing variance of the individual tasks and the coupling of individual tasks
  - Lean Six Sigma
- Imaginary Complexity
  - Due to lack of understanding about the system design, system architecture, and/or system 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”

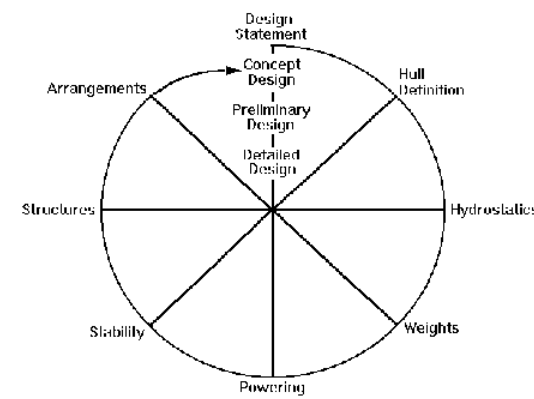


# Design Complexity

- 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



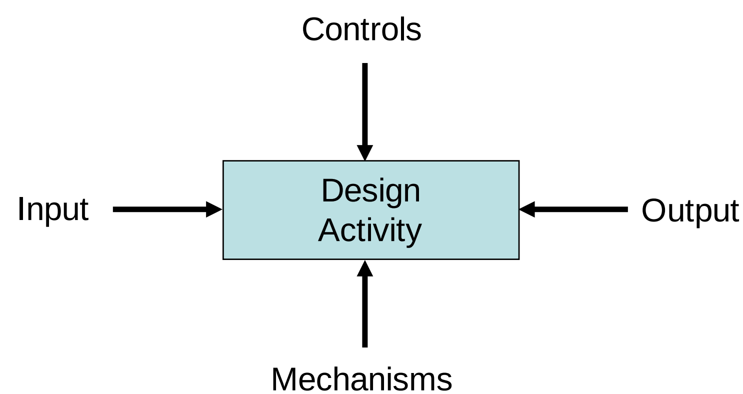



# IDEF0 Model of a Design Activity

- 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

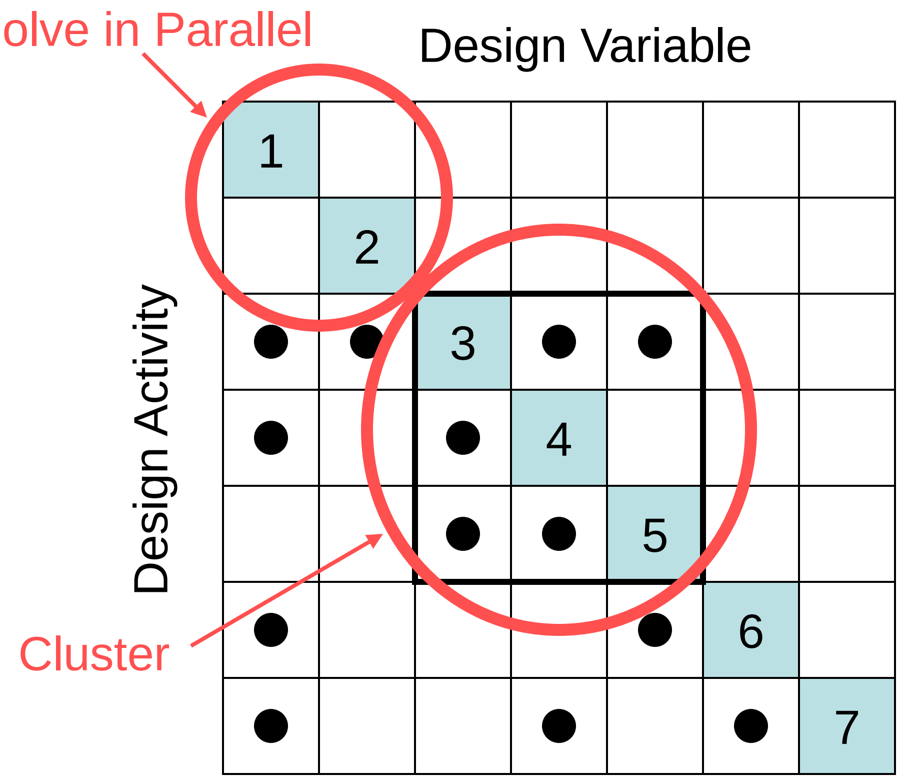
Execution Oriented

Planning Oriented



# Design 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




Controls

Input

Design Activity

Output

Mechanisms



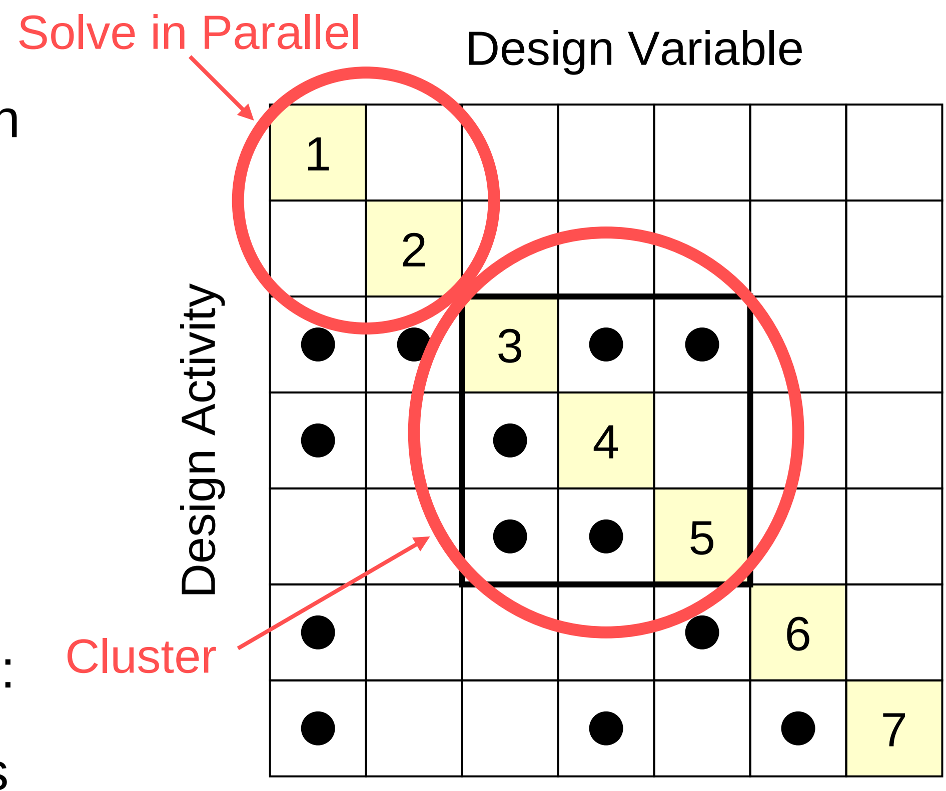
http://www.dsmweb.org/

# 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 combinatorial 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



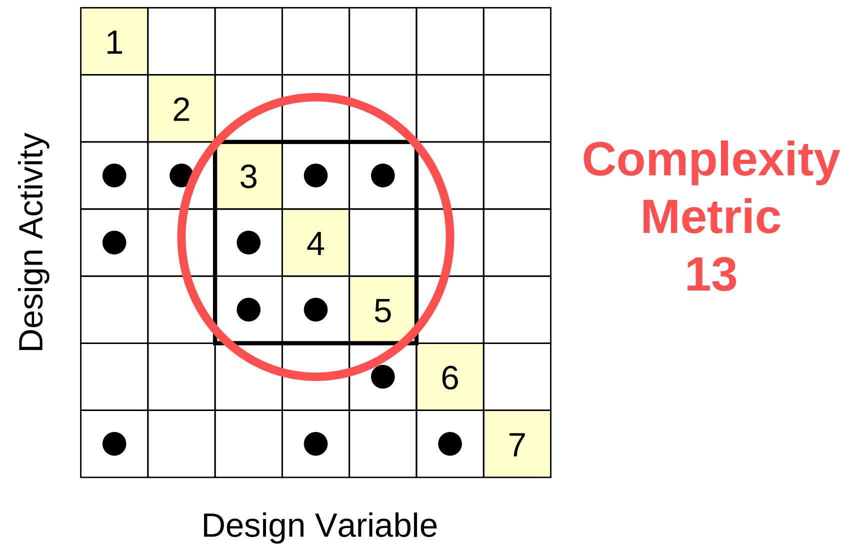

Proposed Complexity Metric =
1 + 1 + 9 + 1 + 1 =13

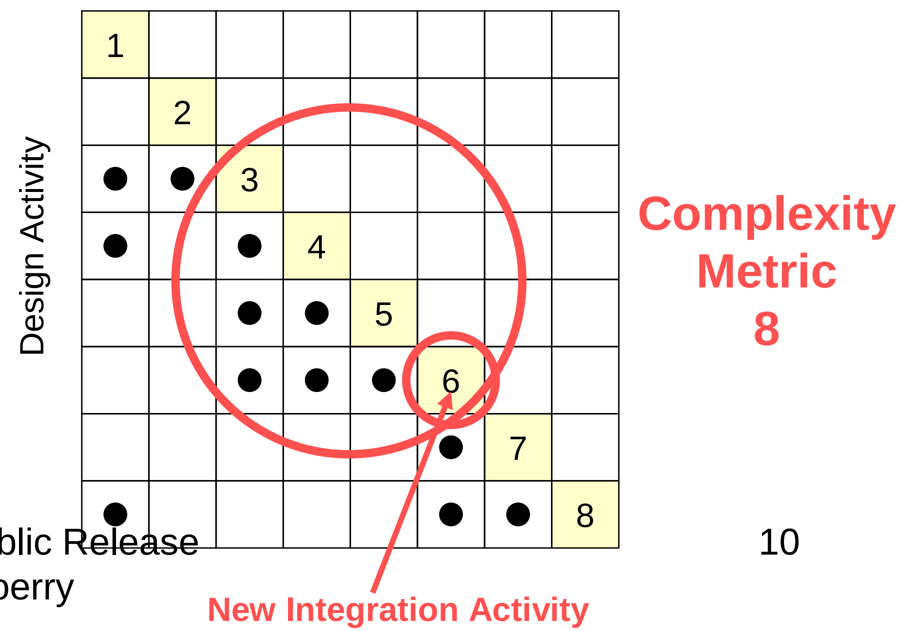
# Reducing Complexity by eliminating Clusters

- 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



# Another Design Complexity Metric?

- During Detail Design, work is organized around construction boundaries that are generally aligned with spaces.
  - Limit the number of systems that impact a space.
  - Limit the impact of changes from other spaces.
- Goal is to enable designing each space independently of one another during Detail Design.

$$SCF_i = \sqrt{\frac{1}{2}\left(\left(\frac{m_{systems\_touching}}{n_{3\_digit\_NTT}}\right)^2 + \left(\frac{m_{spaces\_impacting}}{n_{spaces}-1}\right)^2\right)}$$

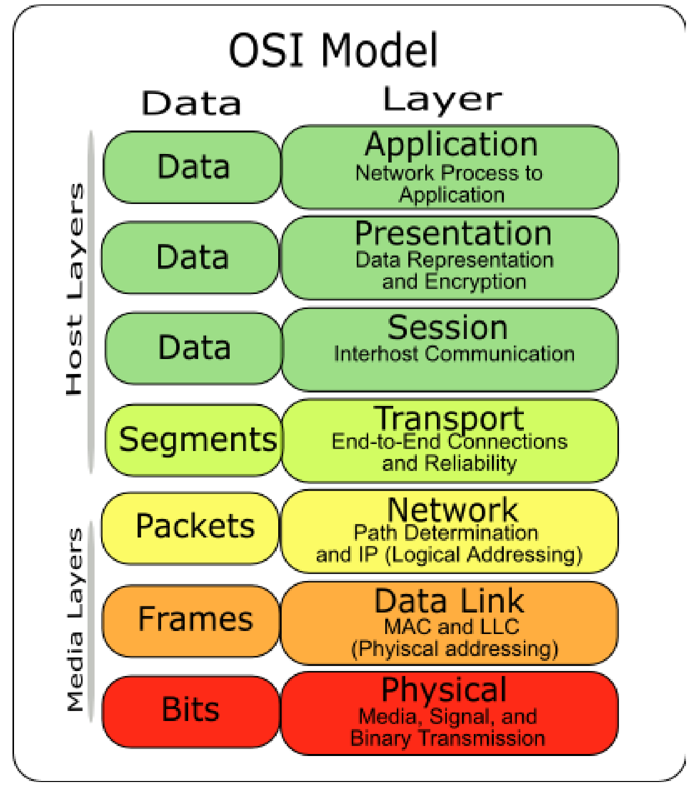
$$SCM = \sum_{i=1}^{n_{spaces}} SCF_i$$

Where:

| | |
|---|---|
| $SCF_i$ | Space Complexity Factor |
| $SCM$ | Ship Complexity Metric |
| $m_{systems\_touching}$ | Number of Systems touching a space |
| $n_{3\_digit\_NTT}$ | Number of 3 digit Tasks in the NCETL |
| $m_{space\_impacting}$ | Number of other Spaces, which if modified within limits, will impact a system within this space |
| $n_{spaces}$ | Number of spaces in the ship |

# Reduce Complexity through Design Methods and Systems Architecture

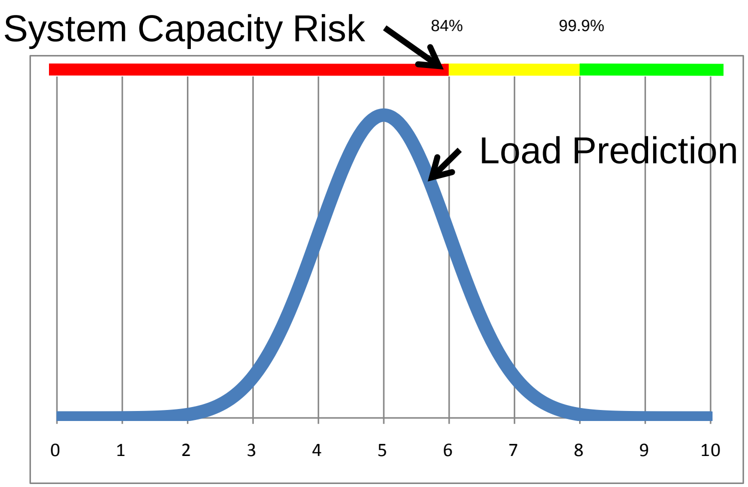
- Nam P. Suh in "Complexity Theory and Application"
  - "For a system to operate stably for a long time, functional periodicity must exist in the system or must be built into the system."
    - In Design, the periodicity is established through gates or design iterations.
  - To reduce the 'real complexity' must create an uncoupled or decoupled design
    - Uncoupled - no interaction between design activities; all design activities can be accomplished in parallel
    - Decoupled – DSM is lower triangular
- Systems architectures that enable decoupling of design activities reduce complexity.

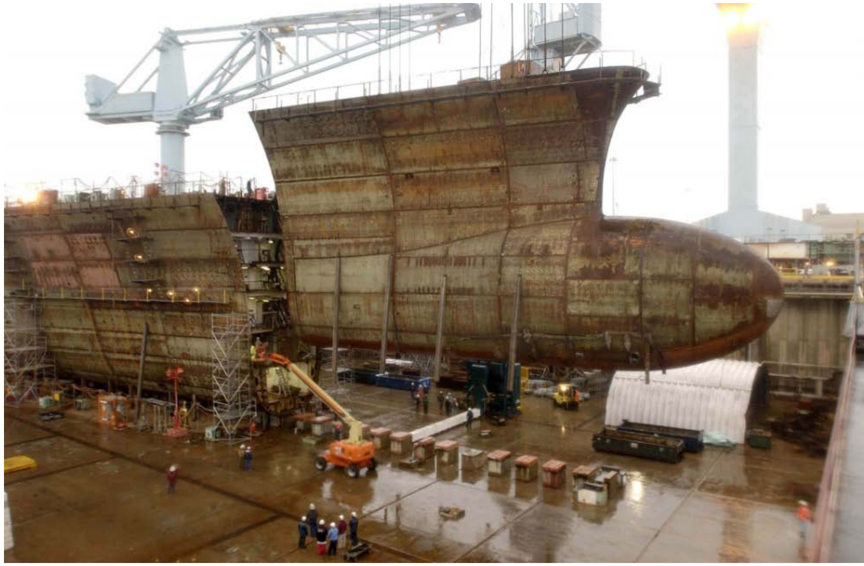



http://www.3mfuture.com/network_security/arp-guard-arp-spoofing.htm

# Isolating Design Activities to Reduce Complexity

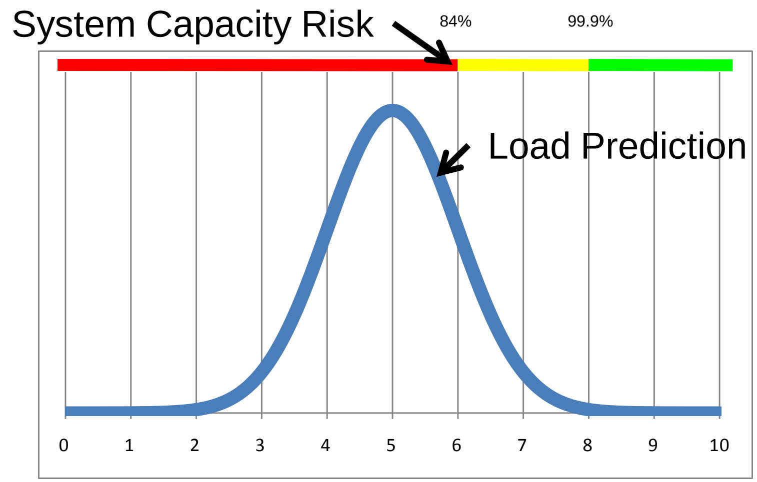
- Limiting Functions assigned to a given system.
  - Don’t use the firemain for cooling water
  - Keep the DSM lower triangular
- Use sufficient margin in distributed systems to account for uncertainty in load predictions.
- In detail design, limit degrees of freedom to those within construction units.
  - Ensure system design is complete
  - Ensure total ship properties are met
  - Ensure General Arrangements work

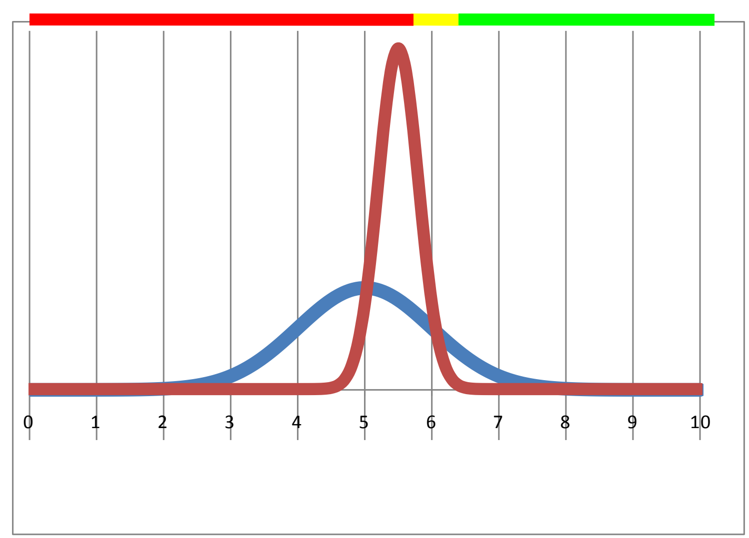


# Margin and Design Uncertainty

- Margin historically has been based on past performance
  - Tied to historical methods for estimating loads
- Margin accounts for variation in the load prediction.
  - One should be able to calculate the System Capacity risk based on an evaluation of the load prediction uncertainty
- The required system capacity above the mean estimate (margin) to achieve a low risk should be reduced if the prediction methods are improved.
- The number of “sigmas” that mark the boundary of yellow and green risk should be based on the relative difficulty of adding extra capacity. (i.e. risk outcome)



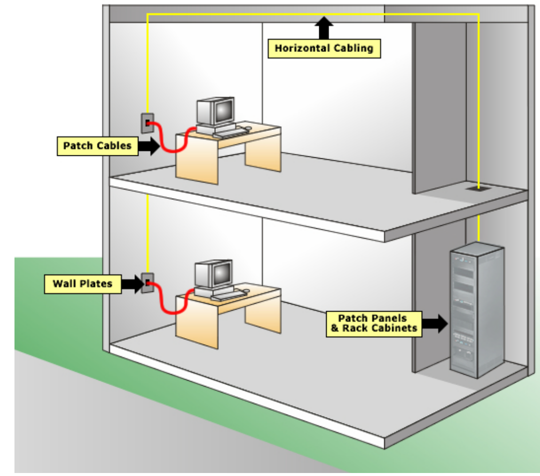



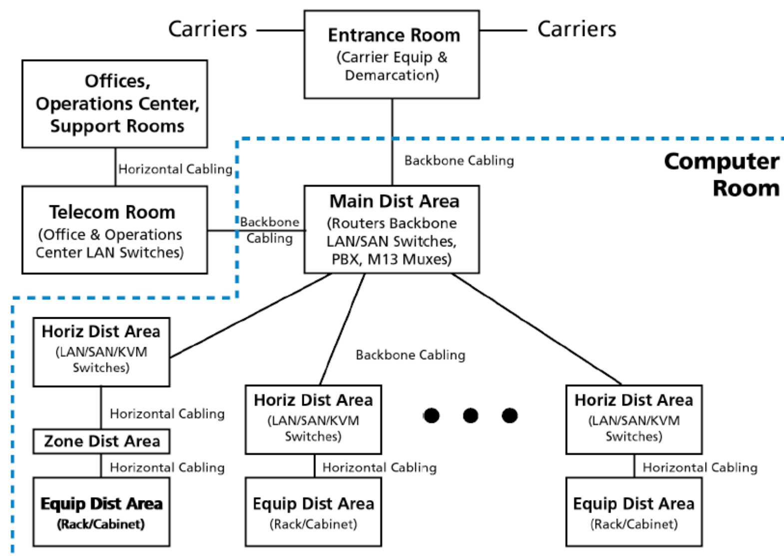
# Production Complexity

- Limit the number of trades that need to work in the same space.
  - Segregate Functions
  - Minimize “through services” in functional spaces.
- Use production processes that enable repeatable, accurate, and testable production.
  - Control the environment
  - Use good tools
  - Train the Workforce
- Use production processes that do not impact adjacent spaces
  - Avoid Hotwork if possible
- Limit components that cross construction boundaries
- Strategically use Modularity
  - Decouple system design/production from ship design/production
  - Enable efficient production and testing

# Structured Wiring Systems

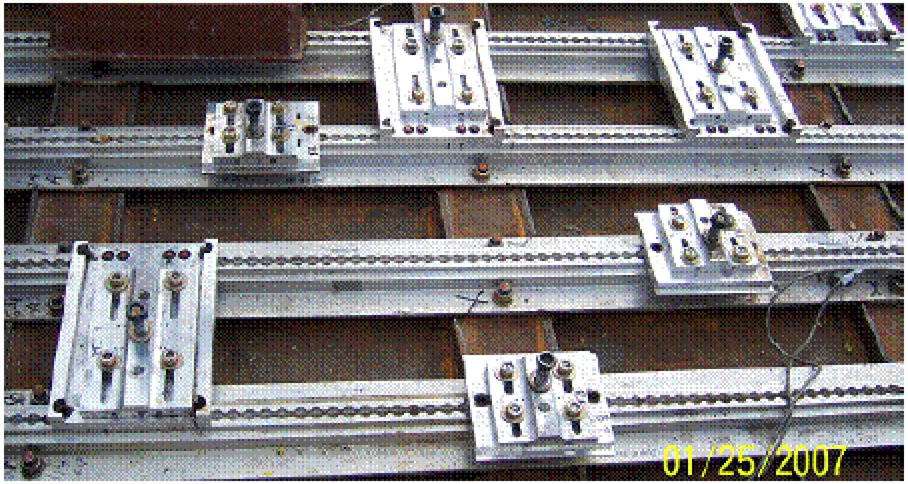
- Use local scalable nodes to connect to individual loads
- Minimize distributed systems crossing construction boundaries
  - Feeder cables ideally would only run within a construction boundary
  - Only “mains” cross construction boundaries

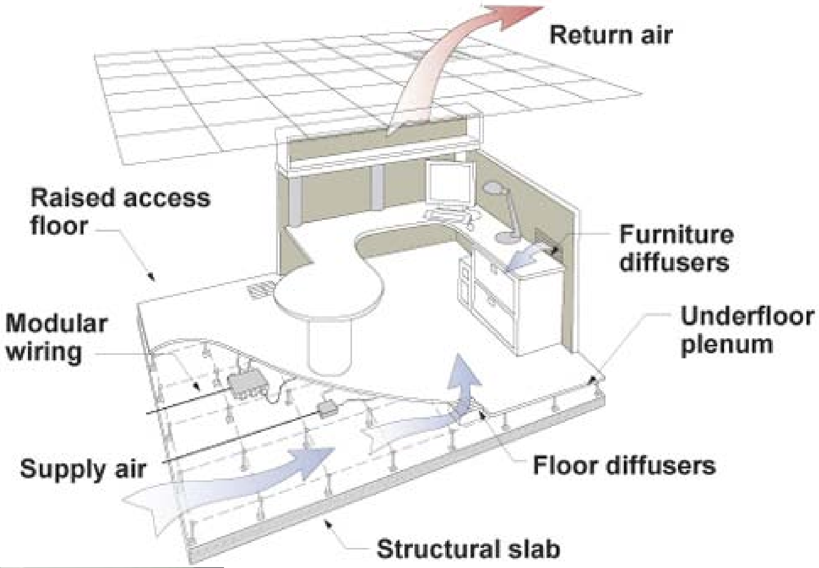



ADC, “TIA-942 Data Center Standards Overview”

# FlexTech type solutions




DeVries, Richard, Andrew Levine, and William Mish Jr., “Enabling Affordable Ships through Physical Open Systems,” ASNE ETS 2008, 23-25 Sept 2008, Falls Church, VA.

# Modernization Complexity

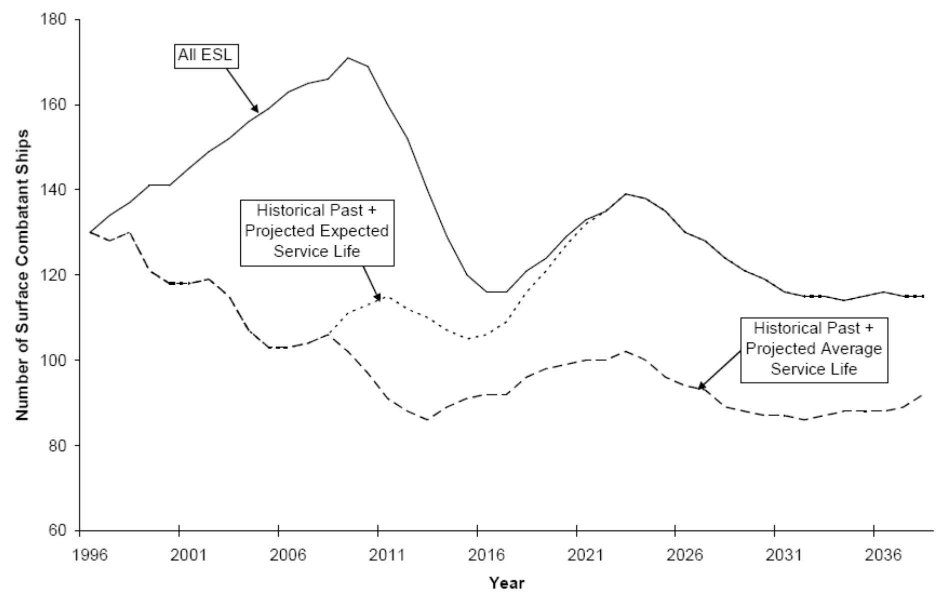
- Ships are modernized for a variety of reasons
  - The threat changes, so improved systems are needed to maintain mission
  - Systems become obsolete
  - External interfaces become obsolete
  - New missions
  - Reduce Total Ownership Cost
  - Laws and Treaties force a change
- Modernization Complexity deals with the difficulty in responding to modernization needs.

Photo # K-15383 USS New Jersey at sea in the Pacific, 1944-45

U.S.S. New Jersey July 1986

# Why is Modernization Important?

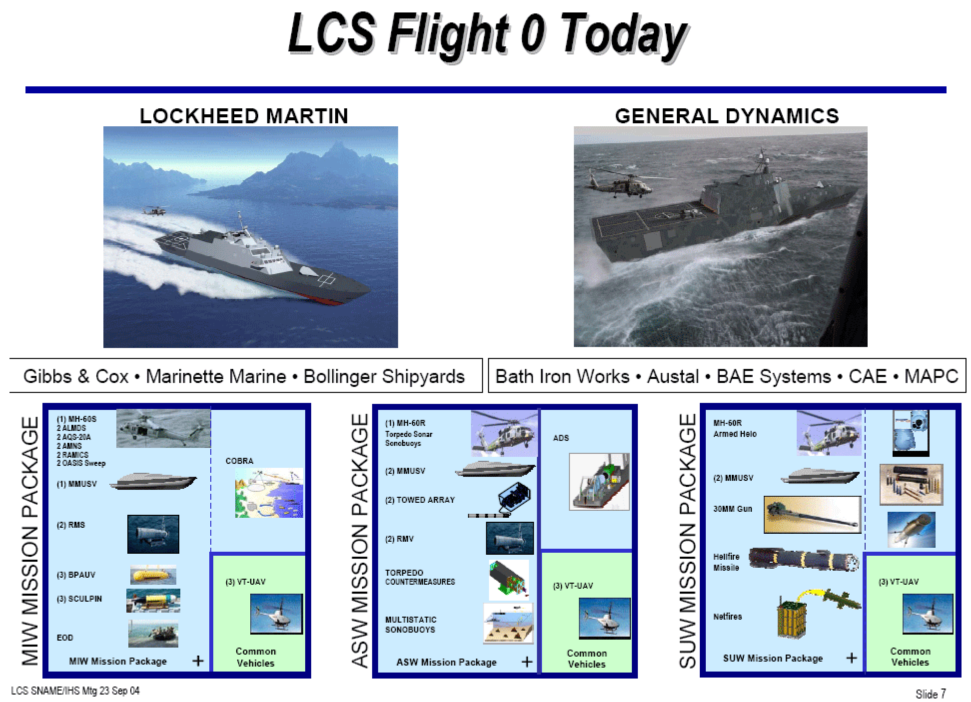
- Surface Combatants have typically been retired before their Expected Service Life
  - The cost of modernization is often cited as a reason
- The 313 ship Navy includes 143 Surface Combatants
- We will never achieve 143 Surface Combatants if our ships do not reach the end of their Expected Service Life

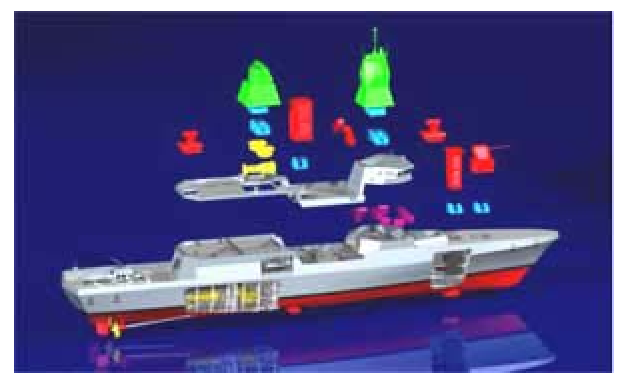



*Koenig, Dr. Philip, Don Nalchajian, and John Hootman, "Ship Service Life and Naval Force Structure,"* ASNE ETS 2008, 23-25 Sept 2008

# Strategies for reducing Modernization Complexity

- Use Mission Modules
  - Littoral Combat Ship
  - MEKO Modules
- Use Appropriate Service Life Allowances
  - Where Difficult to add additional capacity
- Use Modular Open Systems
- Use Space and Weight Reservations
- Where possible assign only one mission function to a space
- Preserve Equipment removal routes

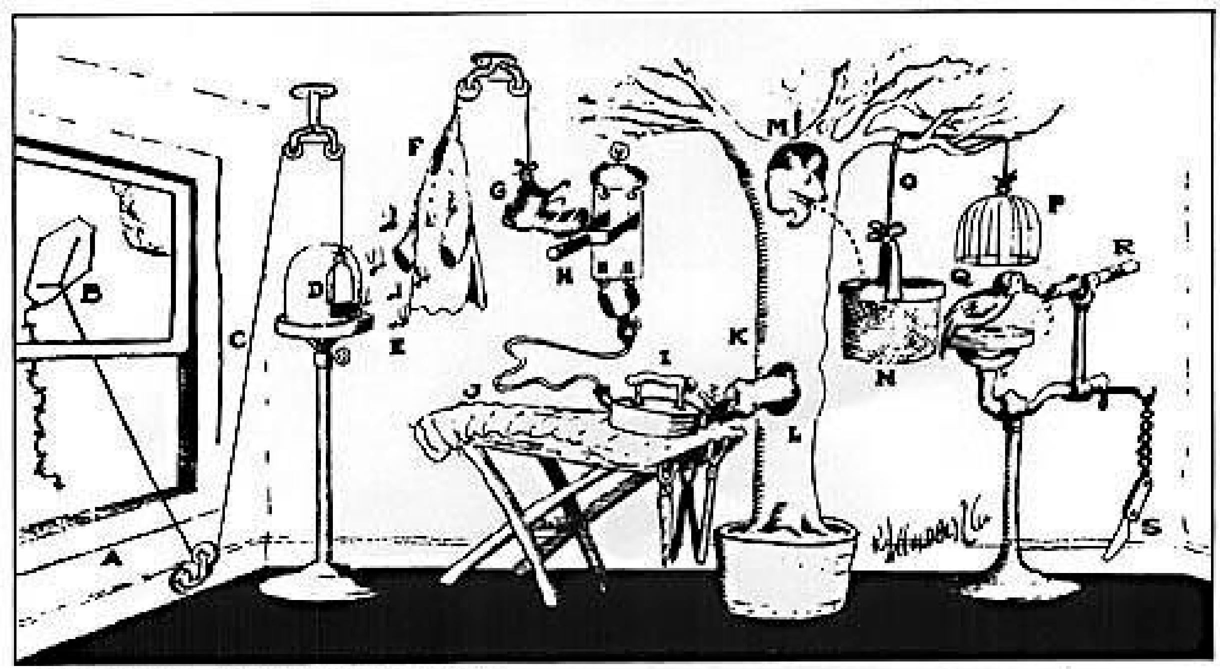


**Know the "Requirements / Market" Risks**

# Summary

- The Nature of Complexity
- Design Complexity
- Production Complexity
- Modernization Complexity



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