01. The Design Process

NASA ESMD Capstone Design

developed by

John K. Gershenson, Ph.D.

Professor of Mechanical Engineering

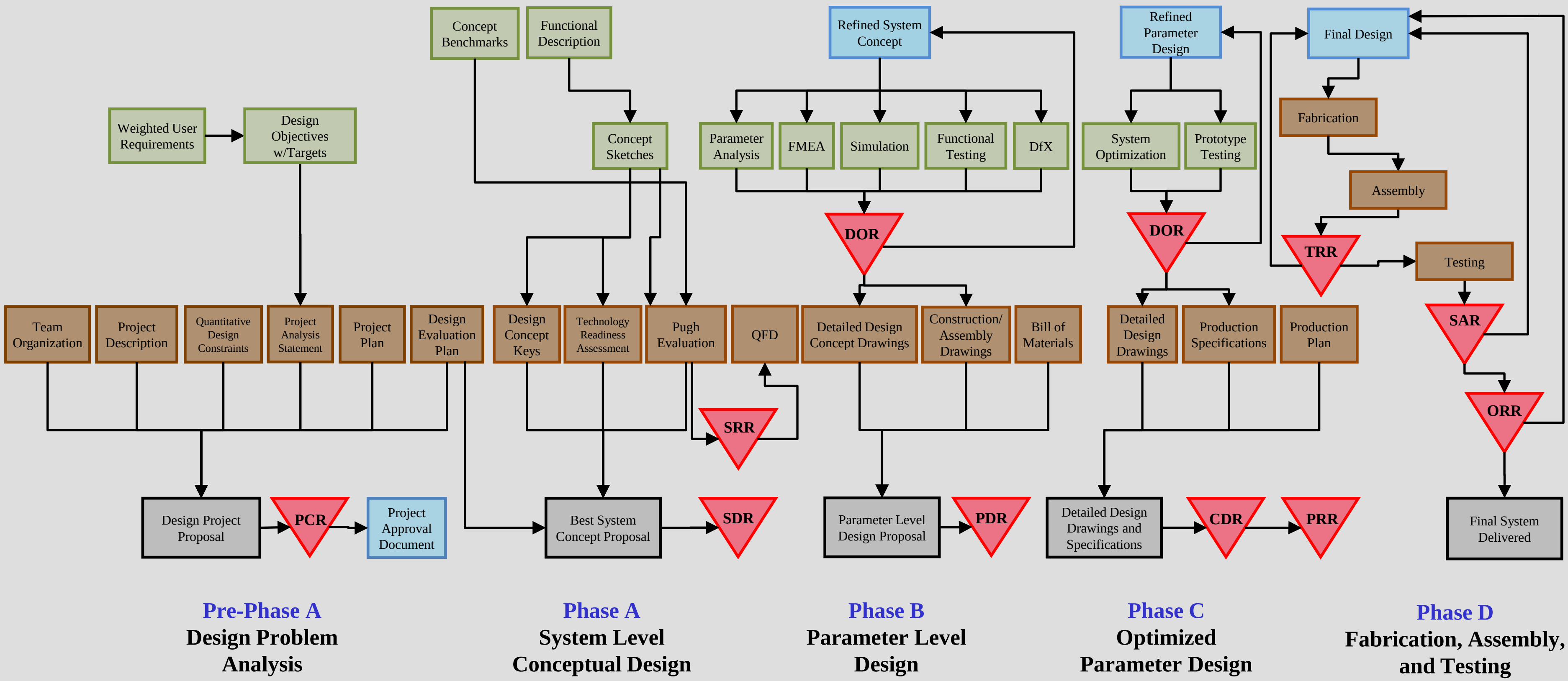
MICHIGAN TECHNOLOGICAL UNIVERSITY

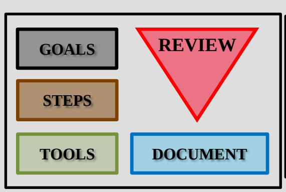
and

Director

thebenshimagroup

The Design Process





Review Points

PCR- Project Concept Review
SDR- System Design Review
PDR - Product Design Review
PRR- Production Readiness Review
SAR - System Acceptance Review
SRR- System Requirements Review
DOR- Design Objectives Review
CDR - Critical Design Review
TRR- Test Readiness Review
ORR - Operational Readiness Review

Why Use Such a Long, Structured Approach?

- It avoids embarrassment when a better solution is found far into the project
- The disciplined approach leads to more creative solutions and time saved in the long run

(Lumsdaine *et al*., 2006)

Why Use Such a Long, Structured Approach?

- It saves costs
  - Changing concepts on paper is inexpensive
  - Changes during prototyping are more costly
  - Changes at production ramp-up are very expensive
  - Changes due to warranty claims and recalls are extremely expensive and can affect market share and the reputation of the company

(Lumsdaine *et al*., 2006)

Project Life-Cycle Phases

	Phase	Purpose	Typical Output
Formulation	Pre-Phase A Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, identify potential technology needs.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups
Formulation	Phase A Concept and Technology Development	To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, and needed system structure technology developments.	System concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition
Formulation	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents, and prototypes
Implementation	Phase C Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
Implementation	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the products to create the system, meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
Implementation	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
Implementation	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

(NASA Systems Engineering Handbook, SP 2007)

Objective

- A system is designed, built, and operated so that it accomplishes its purpose safely in the most cost-effective way possible considering performance, cost, schedule, and risk

(NASA Systems Engineering Handbook, SP 2007)

What is Cost-effectiveness?

- Cost
  - The cost of a system is the value of the resources needed to design, build, operate, and dispose of it
  - Because resources come in many forms- work performed by personnel and contractors; materials; energy; and the use of facilities and equipment such as wind tunnels, factories, offices, and computers - it is convenient to express these values in common terms by using monetary units (such as dollars of a specified year)

(NASA Systems Engineering Handbook, SP 2007)

What is Cost-effectiveness?

- Effectiveness
  - The effectiveness of a system is a quantitative measure of the degree to which the system's purpose is achieved
  - Effectiveness measures are usually very dependent upon system performance
    - For example, launch vehicle effectiveness depends on the probability of successfully injecting a payload onto a usable trajectory
    - The associated system performance attributes include the mass that can be put into a specified nominal orbit, the trade between injected mass and launch velocity, and launch availability

(NASA Systems Engineering Handbook, SP 2007)

What is Cost-effectiveness?

- Cost-effectiveness
  - The cost-effectiveness of a system combines both the cost and the effectiveness of the system in the context of its objectives
  - While it may be necessary to measure either or both of those in terms of several numbers, it is sometimes possible to combine the components into a meaningful, single-valued *objective function* for use in design optimization
  - Even without knowing how to trade effectiveness for cost, designs that have lower cost and higher effectiveness are always preferred

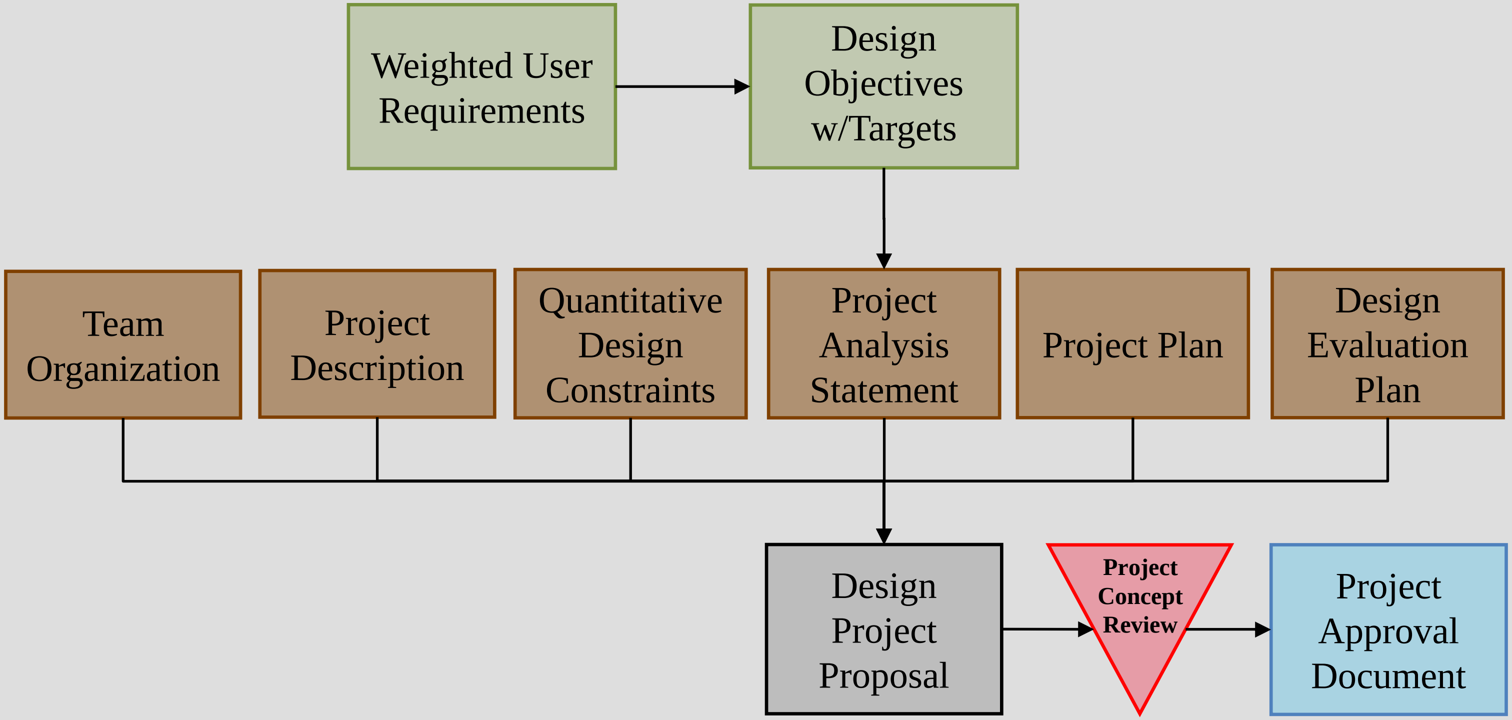
(NASA Systems Engineering Handbook, SP 2007)

The Dilemma

- At each cost-effective solution
  - To reduce cost at constant risk, performance must be reduced
  - To reduce risk at constant cost, performance must be reduced
  - To reduce cost at constant performance, higher risks must be accepted
  - To reduce risk at constant performance, higher costs must be accepted

(NASA Systems Engineering Handbook, SP 2007)

Pre-Phase A: Design Problem Analysis



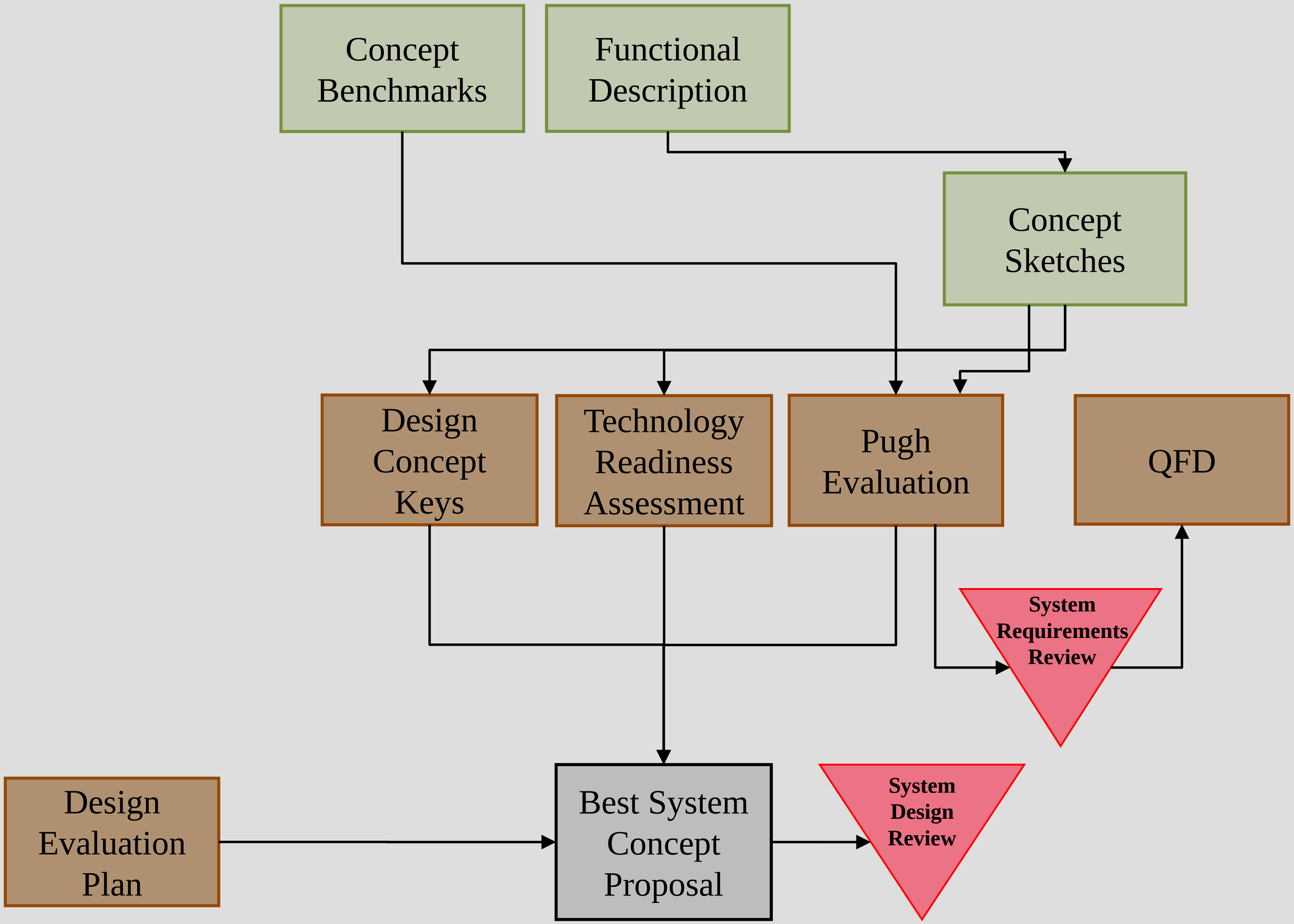
Pre-Phase A: Design Problem Analysis

- Goals
  - Design Project Proposal
- Steps
  - Team Organization
  - Quantitative Design Constraints
  - Project Analysis Statement
  - Project Planning
  - Design Evaluation Plan

Pre-Phase A: Design Problem Analysis

- Tools
  - Weighted User Requirements
  - Design Objectives with Targets
- Reviews
  - Project Concept Review

Phase A: System Level Conceptual Design



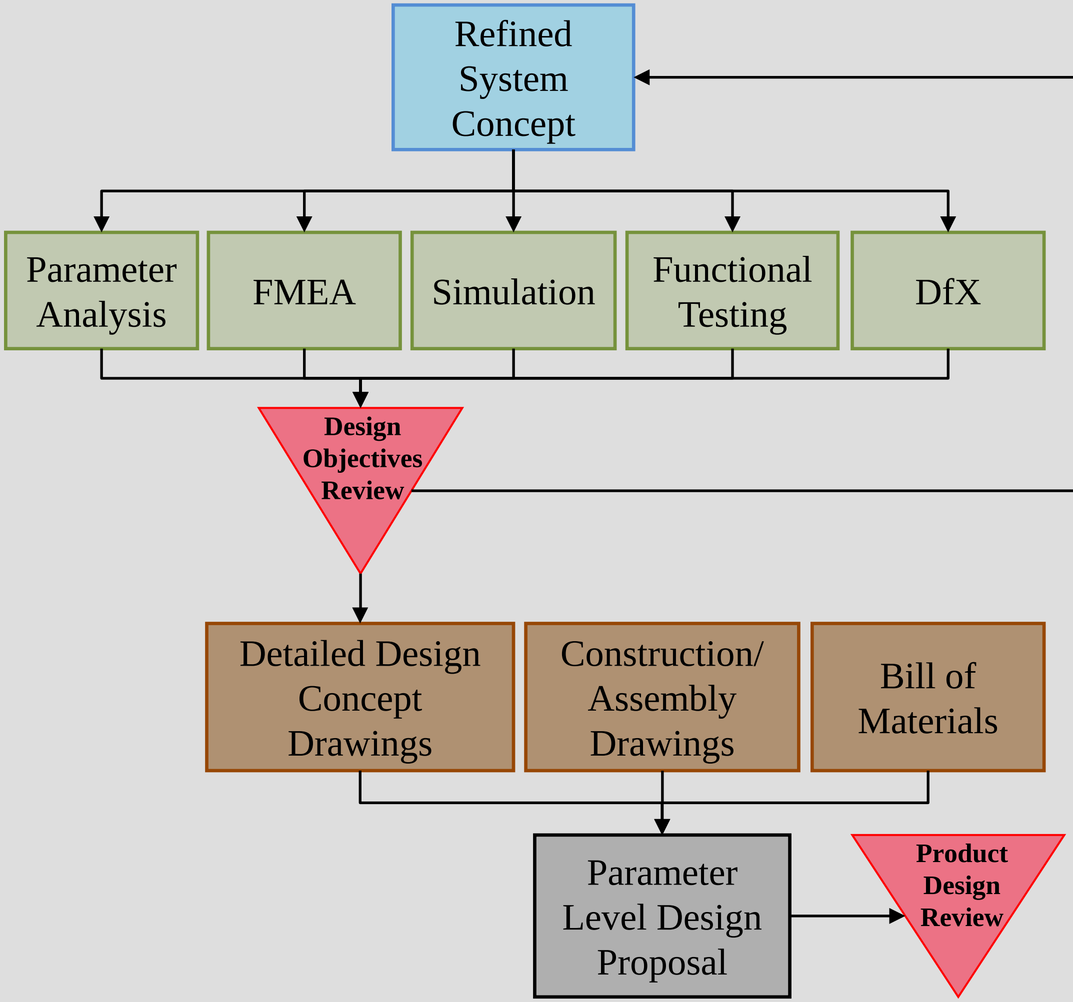
Phase A: System Level Conceptual Design

- Goal
  - Best System Concept Proposal
- Steps
  - Design Evaluation Plan (from Pre-Phase A)
  - Design Concept Keys
  - Pugh Evaluation
  - Technology Readiness Assessment
  - QFD

Phase A: System Level Conceptual Design

- Tools
  - Concept Sketches
  - Concept Benchmark
  - Functional Description
- Reviews
  - System Requirements Review
  - System Design Review

Phase B: Parameter Level Design



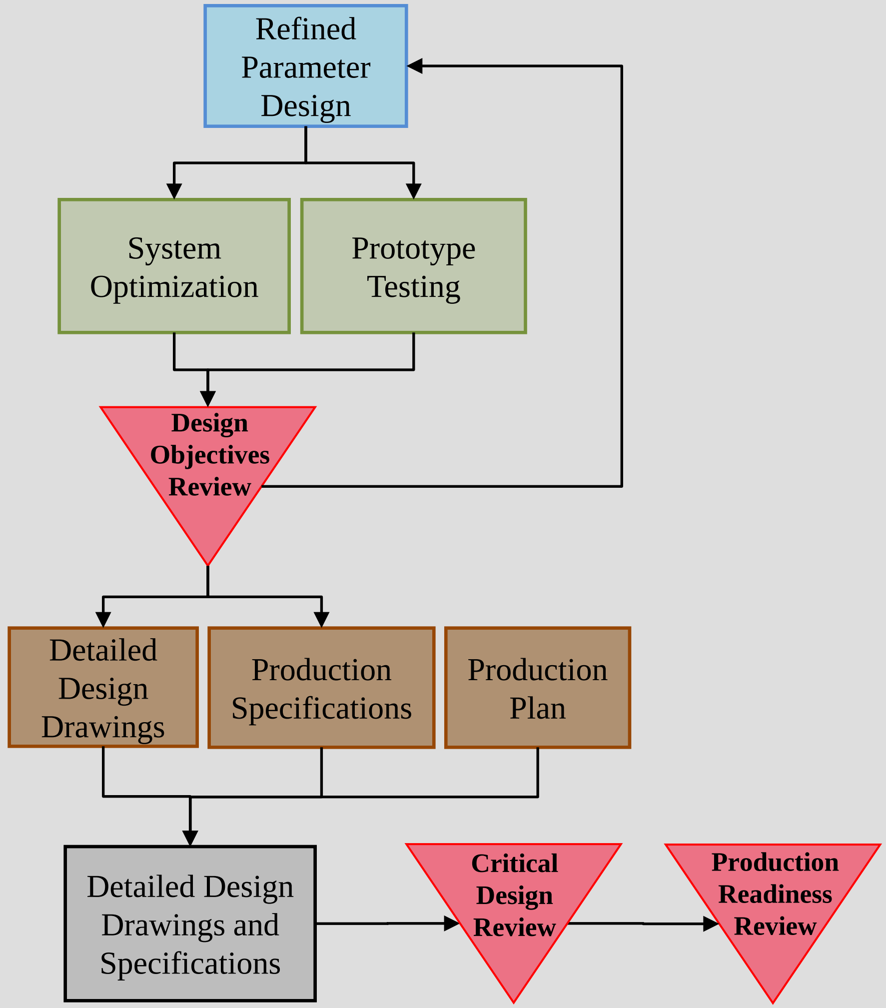
Phase B: Parameter Level Design

- Goal
  - Parameter Level Design Proposal
- Steps
  - Detailed Design Concept Drawings
  - Bill of Materials
  - Construction/Assembly Drawings

Phase B: Parameter Level Design

- Tools
  - Parameter Analysis
  - FMEA
  - Simulation
  - Functional Testing
  - DfX
- Reviews
  - Design Objectives Review
  - Product Design Review

Phase C: Optimized Parameter Design



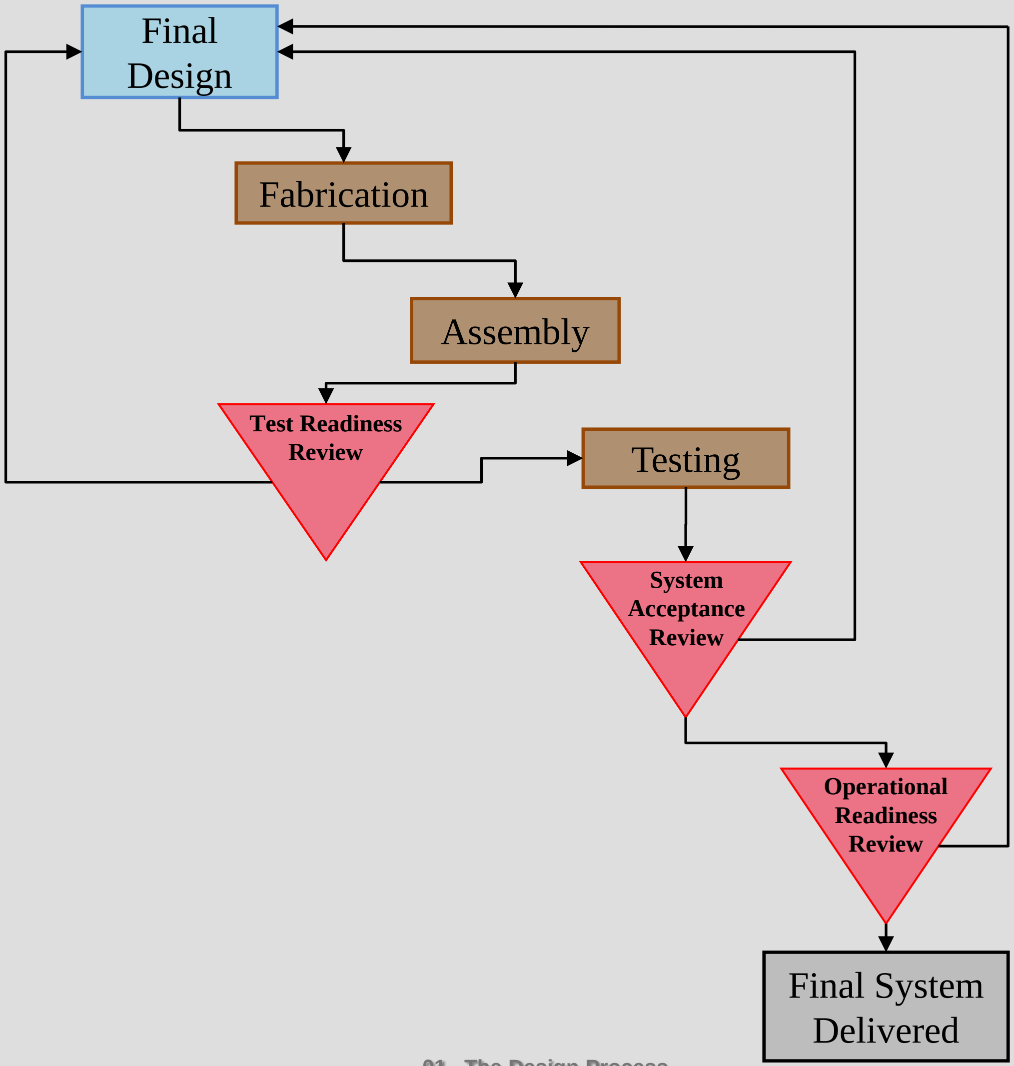
Phase C: Optimized Parameter Design

- Goal
  - Detailed Design Drawings and Specifications
- Steps
  - Detailed Design Drawings
  - Production Specifications
  - Production Plan

Phase C: Optimized Parameter Design

- Tools
  - System Optimization and Tradeoffs
  - Prototype Testing
- Reviews
  - Design Objectives Reviews
  - Critical Design Review
  - Production Readiness Review

Phase D: Fabrication, Assembly, and Testing



Phase D: Fabrication, Assembly, and Testing

- Goal
  - Final System Delivered
- Steps
  - Fabrication
  - Assembly
  - Testing

Phase D: Fabrication, Assembly, and Testing

- Reviews
  - – Test Readiness Review
  - – System Acceptance Review
  - – Operational Readiness Review

Systems Engineering

- Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system
- A “system” is a construct or collection of different elements that together produce results not obtainable by the elements alone

Objective

- “The objective of systems engineering is to see to it that the system is designed, built, and operated so that it accomplishes its purpose in the most cost-effective way possible, considering performance, cost, schedule and risk.”
  – NASA Systems Engineering Handbook SP-6105

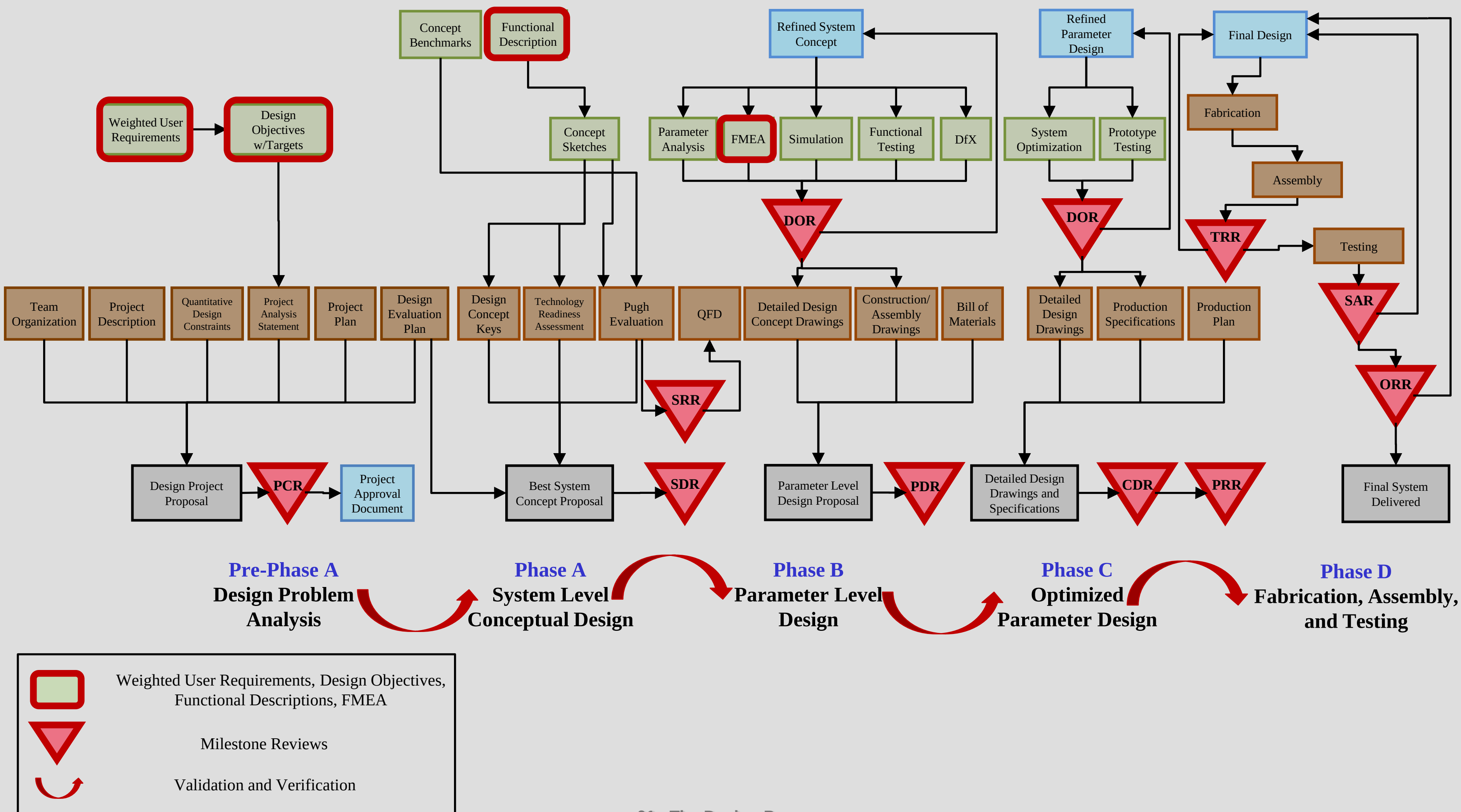
System Engineering Functions

- Major functions that lay the ground work for a robust approach to the design, creation, and operation of system

Key SE Functions

- Design Objectives and Constraints
- Weighted User Requirements
- Functional Descriptions
- Validation and Verification
- Interfaces and ICDs
- Milestone Reviews
- Risk Management

Key SE Functions in the Design Process



Design Objectives and Constraints

- *When?*
  - Pre-Phase A: Design Problem Analysis
- *What?*
  - Clearly define and document the design goals to make sure that the team is working towards a common goal
  - Capture quantitative constraints that can be used to validate product design

Weighted User Requirements

- *When?*
  - Pre-Phase A: Design Problem Analysis
- *What?*
  - Establish the various requirements like functional, performance, interface, environmental, *etc*.
  - Document these requirements in a formal manner
  - Refine these requirements by conducting trade studies

Functional Descriptions

- *When?*
  - Phase A: System Level Conceptual Design
- *What?*
  - Goal is to develop an architecture and design that meets the requirements
  - Block diagrams are key mechanism for documenting and communicating the functional analysis and architecture to the team

Validation and Verification

- *When?*
  - Takes place over the systems engineering lifecycle to show that systems of interest meet the objectives

Validation

- Assure design meets the *objectives*
  - For example, validate the ICDs to weighted user requirements and functional descriptions and architecture

Verification

- Verify the design against the *requirements*
  - Use as an important risk reduction measure
  - Carry out functional tests and simulations as in Phase B
  - Using a Critical Design Review (CDR) in Phase C, assign the requirements a verification method

Verification

- Verify the design against the *requirements*
  - Verify the requirements in Phase C and D using the Production Readiness Review (PRR) and Operational Readiness Review (ORR) respectively
  - Review of the verification results is particularly effective in identifying and correcting problems

Interfaces and ICDs

- *When?*
  - Before Phase C
  - Establish before Product Design Review (PDR) to allow detailed design to proceed with minimal risk of changes
- *What?*
  - Describe and document where and how various system elements need to connect or communicate with each other

Milestone Reviews

- *When?*
  - Between and during all phases
- *What?*
  - Validate the quality and completeness of a system engineering phase or portion thereof
  - Facilitate knowledge sharing and identification and resolution of challenges and issues

Risk Management

- When?
  - Apply various tools at appropriate phases
- What?
  - Perform FMEA at parameter level design during Phase B
  - Report results of FMEA at critical milestone reviews
  - Use other tools like FTA, reliability analyses, *etc*.

01. The Design Process

NASA ESMD Capstone Design

developed by

John K. Gershenson, Ph.D.

Professor of Mechanical Engineering

MICHIGAN TECHNOLOGICAL UNIVERSITY

and

Director

thebenshimagroup

NASA