15. Prototype Testing

NASA ESMD Capstone Design

developed by

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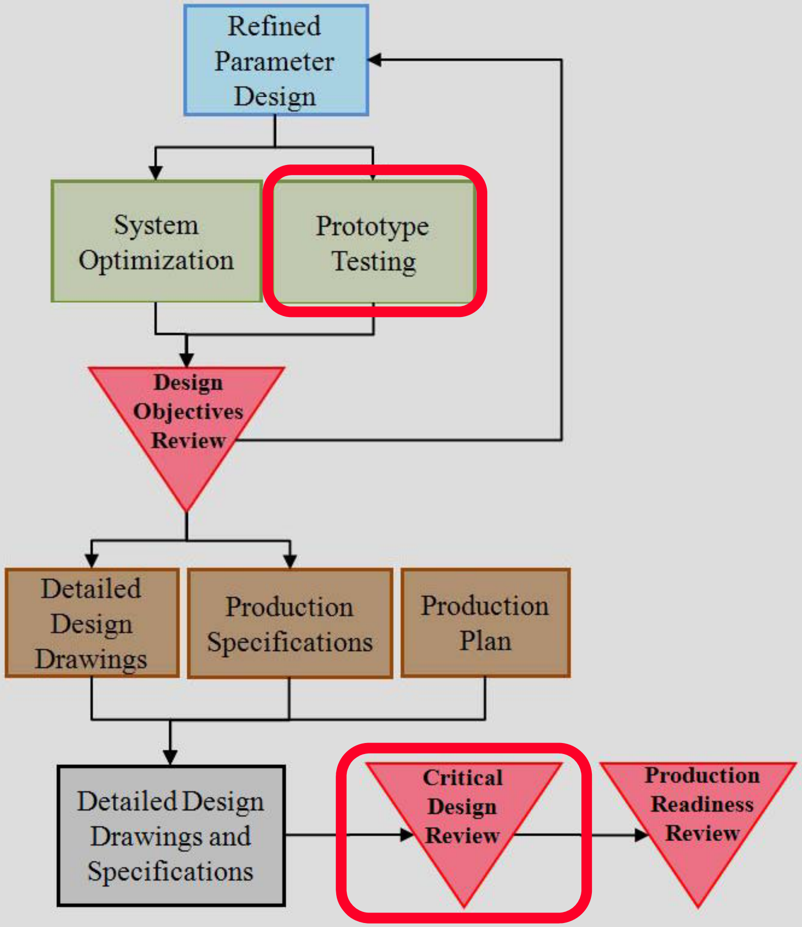
Where in the Process?



Phase C: Optimized Parameter Design

Project Tools Covered

- Prototyping
  - The process of building a working model of the system in order to test various aspects of design, illustrate concepts and elicit feedback.
- Critical Design Review
  - The purpose of this review is to demonstrate that the maturity of the design is appropriate to support proceeding with full scale fabrication, assembly, integration, and test, and that the technical effort is on track to meet performance requirements within the identified cost and schedule constraints.

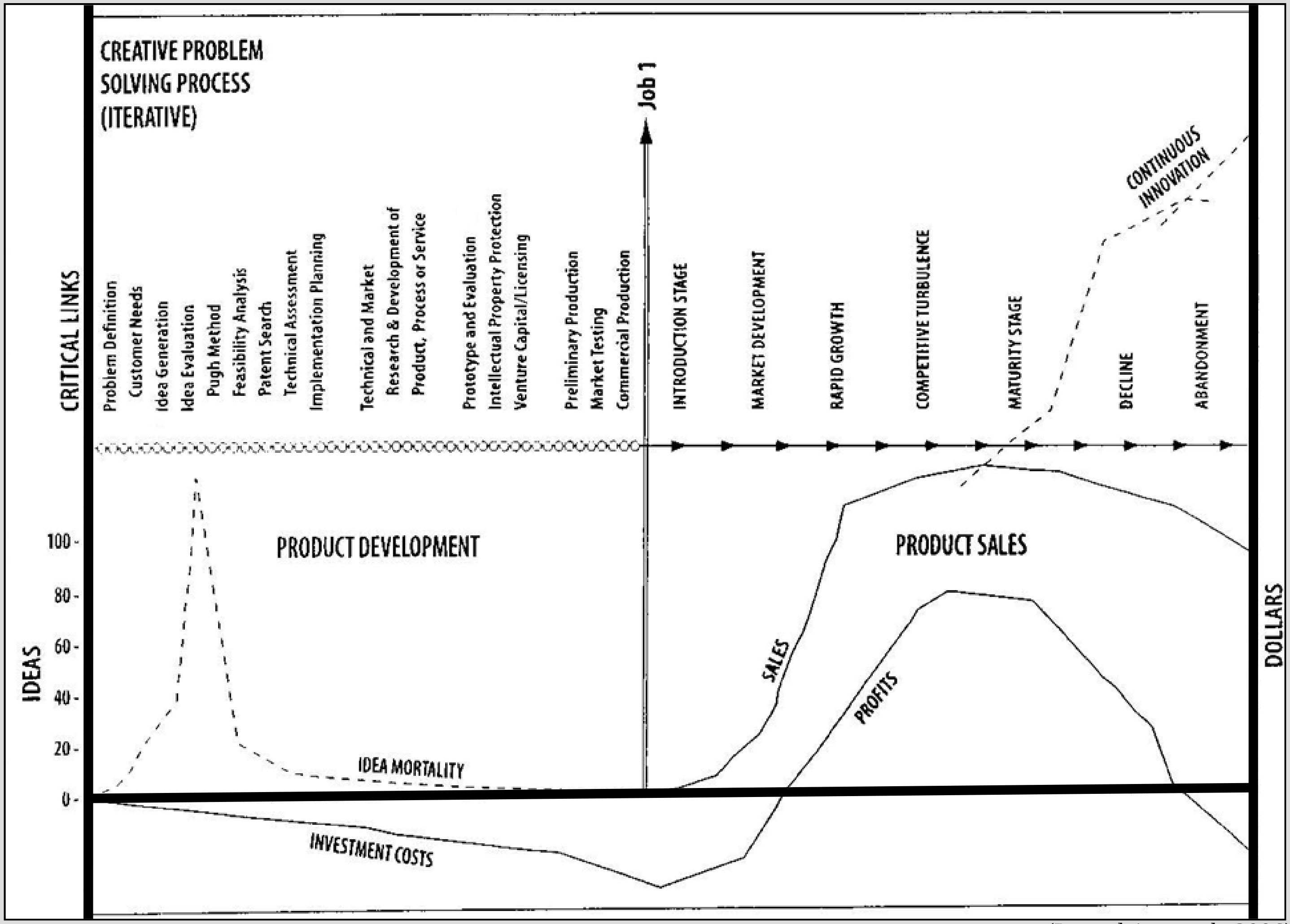
Definition of Prototype

- A prototype is an original or experimental model upon which copies are based

Purpose of Engineering Prototypes

- Prototypes are built primarily to evaluate performance relative to technical design specification
- Prototypes confirm the “best” concept coming out of the Pugh evaluation process
- Prototypes are used to discover the reliability and failure modes and to guide design teams in making improvements
- Prototypes must replicate the behavior of the products in practice in the operating range

Where does Prototyping fit in the Product Development Process?



(Lumsdaine *et al.*, 2006)

Benefits of Prototyping

- Demonstrates at an early stage whether the design works as required and how well it actually meets customer needs
- Can improve communication within product development team, to key customers and partners and to third parties such as regulators and financiers
- Physical prototyping can detect unanticipated phenomena from the environment of use, man-machine interfaces, and interaction of technologies
- Prototyping can (and should) be a design tool, not just a validation and verification tool

Prototypes

- Prototype systems can be effective in enabling efficient producibility even when building only a single system
- Prototypes are built early in the life cycle and they are made as close to the product item in form, fit, and function as is feasible at that stage of development
- The prototype is used to "wring out" the design solution so that the experience gained from the prototype can be fed into design changes that will improve the manufacture, integration, and maintainability

(NASA Systems Engineering Handbook, SP 2007)

Types of Prototypes

- Proof of concept
  - Provides a physical or computer simulated embodiment of the product, system, subsystem, or component
  - Usually a bench test or gross simulation model which allows early and rapid comparison of alternatives as measured by primarily by key performance attributes and secondarily by look and feel

(Ullrich, 1995)

Types of Prototypes

- Alpha prototypes
  - Represent "production intent" but do not attempt to replicate an actual production article
  - While identical materials and configuration are used, the alpha prototype is not fabricated in the actual processes to be used in production
  - These are design discovery and risk reduction tools

(Ullrich, 1995)

Types of Prototypes

- Beta Prototypes
  - Built with parts supplied by the proposed production processes, verifying the performance and reliability of the actual product from real facilities and processes
  - Extensive use testing and assessment is performed both by customers and the development team
  - It is both a quality assurance and commercial risk reduction tool

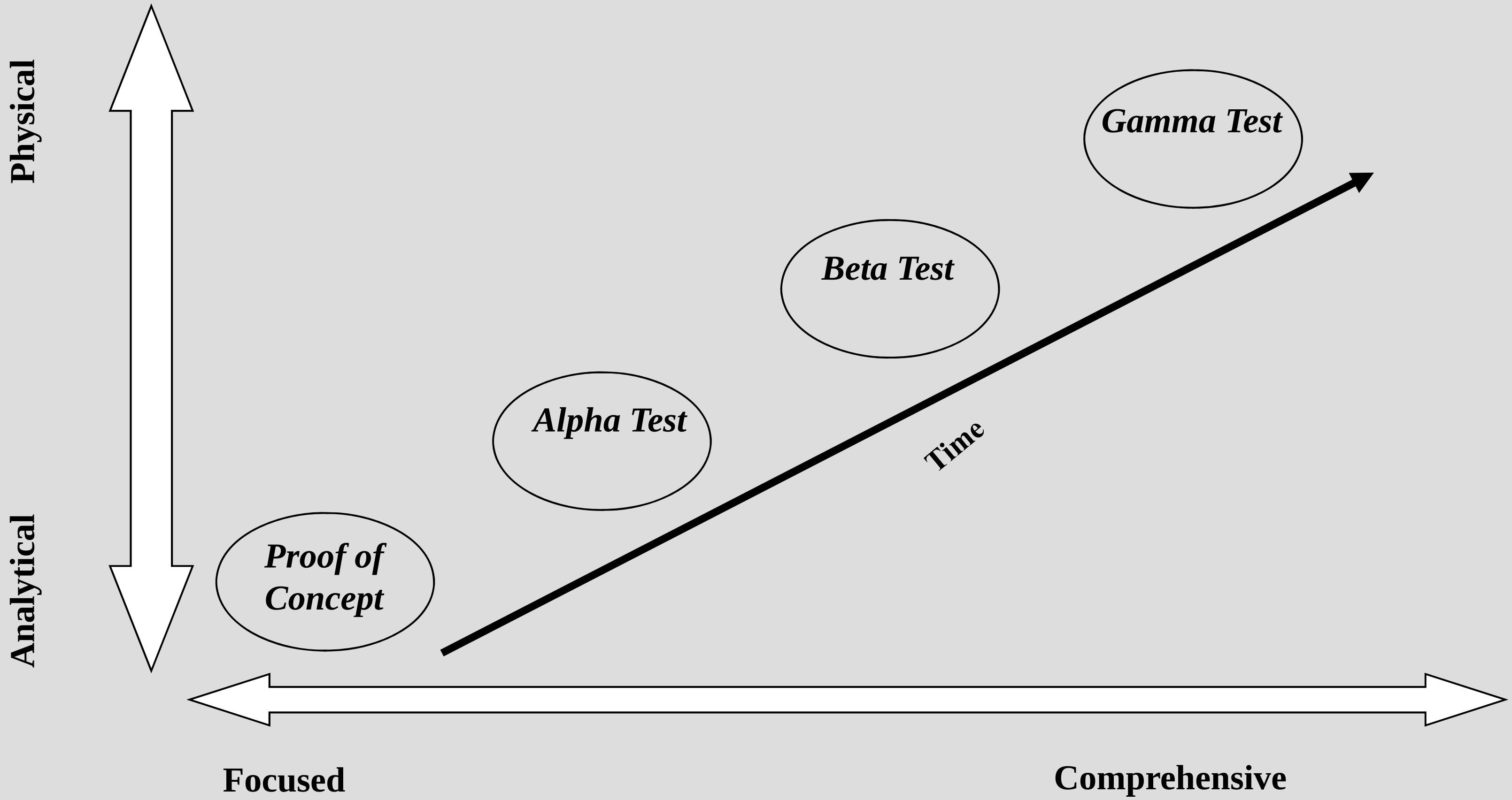
(Ullrich, 1995)

Types of Prototypes

- Gamma Prototypes
  - Form of test marketing that proves that a product and related services fully meets market needs before full introduction
  - Extends beta testing to include the consumable items and services needed to support the product
  - Conducted in customer’s actual environment of use

(Ullrich, 1995)

Prototyping Dimensions, Scope, and Approach



(Ullrich, 1995)

Prototype as a Marketing Tool

- Have an artist's concept drawing - to "sell" your concept
- Prepare detailed engineering drawings to explain the details of your invention and how it works
- To protect your concept, you need patent drawings - in a special format required by the U.S. Patent and Trademarks Office
- It is nearly impossible to find a licensee unless you have a working prototype!
- The biggest " deal killer" in business is to have a prototype that is not exactly like your proposed product

What is a Test Plan?

- Needed at prototype stage too
- This is a brief report detailing the purpose, objectives, procedure, test specimen, and expected results for tests of product components, prototypes, and production models

Test Plan Format

- Describe purpose of tests
  - The product prototype model, production number, or other identifier of test object
  - Any desired certification or sanction which is desired from successful tests
  - Specific limitations on the scope of the tests (*e.g.*, overall concept only, packaging durability only, susceptibility to voltage surges only, *etc.*)
  - Which design decisions do you seek to validate?

Test Plan Format

- Specify the test objectives
  - What needs to be measured during the test?
  - Specify the particular equipment required by model number. Include specifications for all specialized data collection equipment.

Test Plan Format

- Example
  - Heat pump output and electrical power input in heating mode (both within 0.1kilowatts) as a function of outdoor temperature ranging from -20° C to 60° C (in increments of 5° C or less, measured to within 0.2° C)

Test Plan Format

- Specify the Test Procedure
  - Specify step-by step instructions for carrying out the tests or refer to a standard testing protocol published by an engineering society such as IEEE, ASME, ASCE, ASTM, or ASHRAE
  - Which variables need control or monitoring?
  - Specify the exact sequence in which the test will be run or how tests will be ordered (random selection, determined by test performance, or other methods)
    - Any required environmental conditions should be noted (such as temperature, humidity, pressure, *etc*.)

Test Plan Format

- Summarize Expected Results
  - What outcomes are you expecting from the tests?
  - This projection is necessary to plan data collection equipment ranges, set up data sheets or computer data bases, and anticipate safety needs (particularly for tests to destruction)
  - If you do not know roughly what will happen, data collection and analysis may be in jeopardy

Test Plan Format

- Specify format of output
  - Specify whether handwritten data sheets, computer spreadsheets, computer generated plots, or other prescribed formats will be required

Analysis and Conclusion

- After the data (raw data can be left for the appendix of the final report but should be in it somewhere no matter how large), the analysis should be included
- Method of analysis must be described in test plan with pass/fail criteria
- Carry out analysis as prescribed showing at least the analyzed data in the body of the report
- The pass/fail criteria should be applied and a brief conclusion made
  - If the conclusion is fail – what will be done?

The Critical Design Review (CDR)

- What?

  The final review before resources are committed to fabrication

(NASA Systems Engineering Handbook, SP 2007)

The Critical Design Review (CDR)

- When?

  Held near the completion of an engineering model or the end of the breadboard development stage

- Why?

  Conducted to demonstrate that the detailed design is complete and ready to proceed with coding, fabrication, assembly, and integration efforts

(NASA Systems Engineering Handbook, SP 2007)

The Critical Design Review (CDR)

- Results
  - The build-to baseline, production and verification plans are approved
  - Authorizes coding of deliverable software, and system qualification testing and integration

(NASA Systems Engineering Handbook, SP 2007)

The Critical Design Review (CDR)

Critical Design Review

Entrance Criteria	Success Criteria
1. Successful completion of the PDR and responses made to all PDR RFAs and RIDs, or a timely closure plan exists for those remaining open. 2. A preliminary CDR agenda, success criteria, and charge to the board have been agreed to by the technical team, project manager, and review chair prior to the CDR. 3. CDR technical work products listed below for both hardware and software system elements have been made available to the cognizant participants prior to the review: a. updated baselined documents, as required; b. product build-to specifications for each hardware and software configuration item, along with supporting tradeoff analyses and data; c. fabrication, assembly, integration, and test plans and procedures; d. technical data package (e.g., integrated schematics, spares provisioning list, interface control documents, engineering analyses, and specifications); e. operational limits and constraints; f. technical resource utilization estimates and margins; g. acceptance criteria; h. command and telemetry list; i. verification plan (including requirements and specifications); j. validation plan; k. launch site operations plan; l. checkout and activation plan; m. disposal plan (including decommissioning or termination); n. updated technology development maturity assessment plan; o. updated risk assessment and mitigation; p. update reliability analyses and assessments; q. updated cost and schedule data; r. updated logistics documentation; s. software design document(s) (including interface design documents); t. updated LLIL; u. subsystem-level and preliminary operations safety analyses; v. system and subsystem certification plans and requirements (as needed); and w. system safety analysis with associated verifications.	1. The detailed design is expected to meet the requirements with adequate margins at an acceptable level of risk. 2. Interface control documents are appropriately matured to proceed with fabrication, assembly, integration, and test, and plans are in place to manage any open items. 3. High confidence exists in the product baseline, and adequate documentation exists or will exist in a timely manner to allow proceeding with fabrication, assembly, integration, and test. 4. The product verification and product validation requirements and plans are complete. 5. The testing approach is comprehensive, and the planning for system assembly, integration, test, and launch site and mission operations is sufficient to progress into the next phase. 6. Adequate technical and programmatic margins and resources exist to complete the development within budget, schedule, and risk constraints. 7. Risks to mission success are understood and credibly assessed, and plans and resources exist to effectively manage them. 8. SMA (e.g., safety, reliability, maintainability, quality, and EEE parts) have been adequately addressed in system and operational designs, and any applicable SMA plan products (e.g., PRA, system safety analysis, and failure modes and effects analysis) have been approved.

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