Build4 Scale

U.S. Department of Energy

Beta Prototype and Test Plan

Module 4A Key Questions

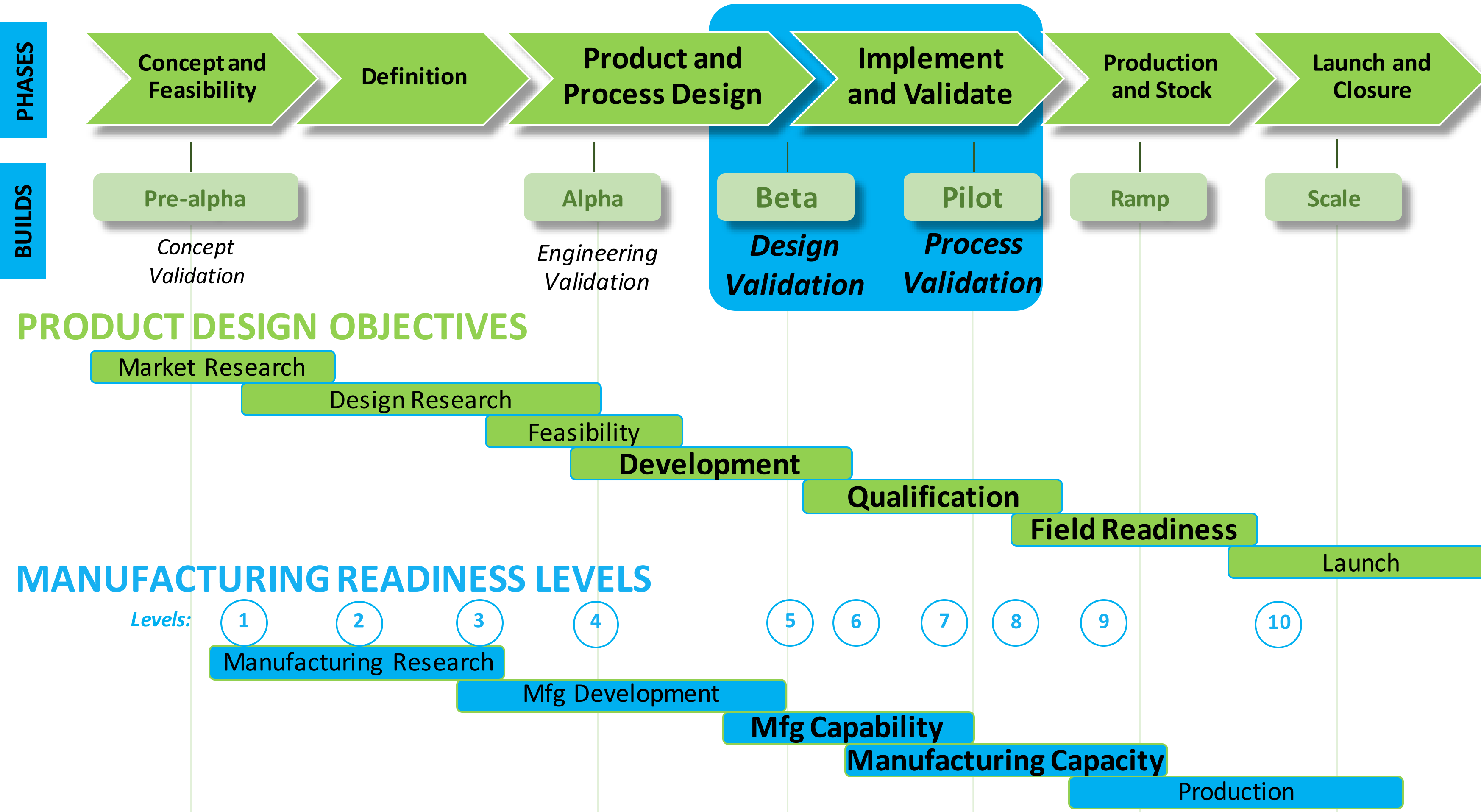
Motivation

Why is this module important?

- Many hardware innovators excel at creating technically-viable alpha prototypes, but lose customer and investor confidence by introducing several failed versions of beta prototypes before commercializing their product
- A basic understanding of how to reduce the number of variations of beta prototypes saves hardware innovators valuable time and money

Beta Prototype And Test Plan

Where does this fit into the development cycle?



Key Questions

Manufacturing Readiness Levels

(MRLs)

Material Solutions Analysis				Technology Development		Engineering and Manufacturing Development		Production and Deployment	Operations and Support
Basic manufacturing Implications Identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept developed	Capability to produce the technology in a laboratory environment	**Capability to produce a prototype components in a production relevant environment**	**Capability to produce a prototype system or subsystem in a production-relevant environment**	**Capability to produce systems, subsystems or components in a production-relevant environment**	Pilot line capability demonstrated. Ready to begin low-rate production	Low Rate Production demonstrated. Capability in place to begin Full Rate Production	Full Rate Production demonstrated and lean production practices in place
1	2	3	4	**5**	**6**	**7**	8	9	10

This module's content is relevant at these MRLs

Pre-alpha → **Alpha prototypes** → **Beta prototypes** → **Pilot prototypes**

Module Outline

- Learning objectives
- Difference between alpha and beta prototypes
- Design for failure mode and effects analysis (DFMEA) —What it is and how to use it to your benefit
- Manufacturing resources

Learning Objectives

- LO1. What are the key questions to consider when designing and testing a beta prototype?

What This Module Addresses

Key Questions

- What is the expectation of the customer, industry, or market for my product?
- What am I designing my product for (e.g., durability, serviceability)?
- What are the most common mistakes to avoid?
- How do I avoid the development of several prototype modifications?
- Where do I go for prototyping services?
- Who are the manufacturing experts that can help me through this process?

Beta Prototype And Test Plan

Common mistakes and misconceptions

- Developing a product without considering how to design for its operating environment
- Launching a product without designing for potential failure modes
- Focusing on low cost and speed to market over careful design quality management and design for manufacturing
- Over-designing the product and failing to achieve margins predicted
- Falling into the trap of redesigning a product multiple times, which adds to product development costs that exhaust company funding and delays product introduction to market

To be successful your product must be unique, but your manufacturing process should not be!

Alpha Hardware Prototype

Basics

There are two types of alpha hardware prototypes:

- A "**looks-like prototype**" that provides insight to ergonomics and aesthetics
- A "**works-like prototype**" that demonstrates key functional elements
- Alpha hardware prototypes are often considered to be "lab experiments" that are not necessarily designed for the commercial requirements/environments
- They demonstrate what the product is capable of doing

Alpha Hardware Prototype

Basics (cont.)

- Alpha hardware prototypes use key features of the hardware product to allow people to interact with its functionality and proposed solution
- They are used to prove that core features of the product work in a development or testing environment under ideal conditions

Beta Hardware Prototype

Basics

- Beta hardware prototypes are a more polished version of the key features of the hardware product; they can be used directly by a customer
- They are built with the intent to prove that people want the solution by demonstrating it in the commercial requirements/environments
  - They are used to prove that core features work for a small set of cooperating beta customers under less-than-ideal conditions

Beta Hardware Prototype

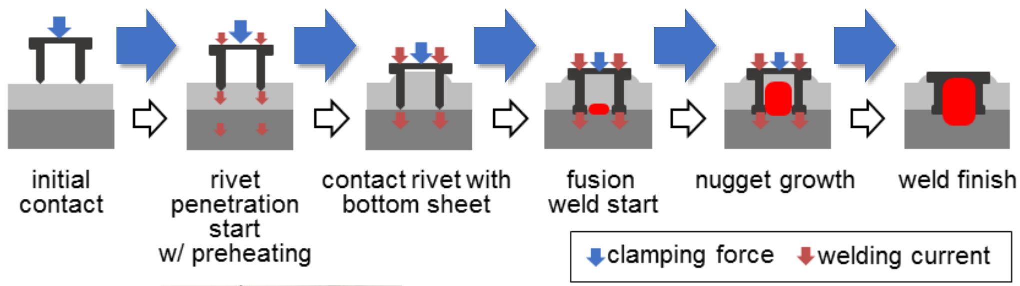
Basics (cont.)

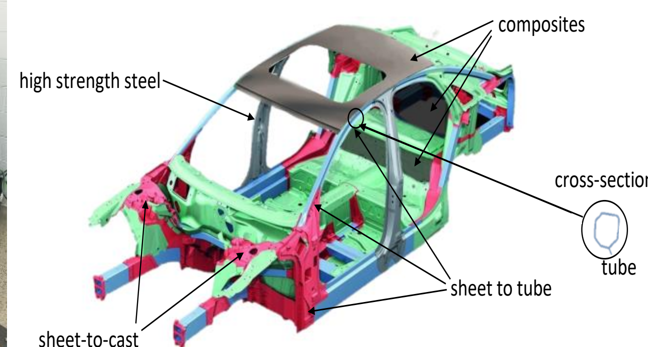
- Beta hardware prototypes are used to elicit customer feedback and gather additional data relating to usage and features needed to be able to support tweaking the product before product launch
  - —They can be run privately or through a handpicked set of customers and/or strategic partners
- They demonstrate the finished product, except for any important customer requirements that have not yet been discovered

Alpha to Beta Prototype

Case study 1 - Rivet weld joining

- **Company description**: The hybrid rivet weld technology combines the advantages of self-pierce riveting with resistance spot welding in joining of dissimilar materials (aluminum to steel)
- **Company type**:
  - —Product
  - —Material
  - ✓—Manufacturing Process
  - —Manufacturing Service
  - —Manufacturing Operations





Source: Optimal Process Technologies

Technology Readiness Level

Case study 1 - Rivet weld joining (cont.)

Year 1 progress →

Basic Tech Research	Feasibility Research	Tech Development		Tech Demonstration		System Commissioning	System Operation	
Basic principles observed and reported	Technology concept and/or application formulated	Proof of concept analyzed and experimented on	Component or system validation in lab environment	System validation, testing in operating environment	Prototype/ pilot system verification in operating environment	Full scale prototype verified in operating environment	Actual system complete and functioning in operating environment	Actual system tested and data collected over lifetime of system
1	2	3	4	5	6	7	8	9

Key Questions

Technology Readiness Level

Case study 1 - Rivet weld joining (cont.)

Year 1 progress → (from 4 to 6)

Year 2 progress → (from 6 to 8)

Basic Tech Research	Feasibility Research	Tech Development		Tech Demonstration		System Commissioning	System Operation	
Basic principles observed and reported	Technology concept and/or application formulated	Proof of concept analyzed and experimented on	Component or system validation in lab environment	System validation, testing in operating environment	Prototype/ pilot system verification in operating environment	Full scale prototype verified in operating environment	Actual system complete and functioning in operating environment	Actual system tested and data collected over lifetime of system
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Technology Readiness Level

Case study 1 - *Rivet weld joining (cont.)*

Year 1 progress → Year 2 progress →

Basic Tech Research	Feasibility Research	Tech Development		Tech Demonstration		System Commissioning	System Operation	
Basic principles observed and reported	Technology concept and/or application formulated	Proof of concept analyzed and experimented on	Component or system validation in lab environment	System validation, testing in operating environment	Prototype/ pilot system verification in operating environment	Full scale prototype verified in operating environment	Actual system complete and functioning in operating environment	Actual system tested and data collected over lifetime of system
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Year 3

Retreat

If if fails….

- When a test fails at a readiness level, there is a need to retreat backwards (often back two levels)

Example: If the full scale prototype fails to be Verified in Operating Environment (MRL7), you have to go back to MRL5 to test operating environments

Key Questions

Manufacturing Readiness Levels

Case study 1 - Rivet weld joining (cont.)

Material Solutions Analysis				Technology Development		Engineering and Manufacturing Development		Production and Deployment	Operations and Support
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Alpha to Beta Prototype

Case study 1 - Rivet weld joining (cont.)

Imagine this prototype is currently at manufacturing readiness MRL 4 and faces the following **DFM or scale up challenges**:

- ❑ Some, but not all, joining samples met customer quality specifications
- ❑ Process not repeatable and not proven on a variety of materials
- ❑ Too much customized tooling
- ❑ Poor understanding of cost trade offs of proposed process vs. existing production processes
- ❑ Equipment not optimized for mass production (automated material handling, robotics)
- ❑ No quality control measurement

What actions can be taken to address the challenges above?

Source: Optimal Process Technologies

Alpha to Beta Prototype

Case study 1 - Rivet weld joining (cont.)

Actions that can be taken to address the MRL 4 challenges on prior slide include:

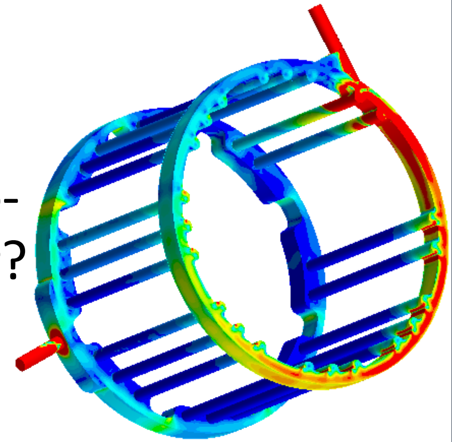
- **Design for quality**: adopted in-situ weld assurance testing to ensure quality
- **Design for customer requirements**: included demonstrations on a wide variety of mixed materials (Al, Mg, HSS)
- **Design for cost**: reduced customized tooling and aligned with existing production processes
- **Design for reliability**: used FEA/CFD modeling to optimize rivet shape and joining process
- **Design for takt time**: included automated rivet feeder, integrated with automation equipment

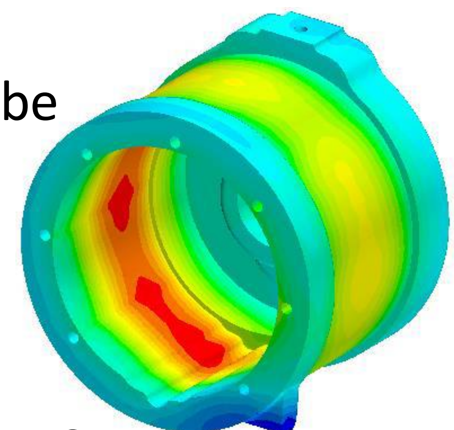
Source: Optimal Process Technologies

Key Questions

What does the customer, industry, or market expect of my product?

- How will the beta prototype be evaluated by the customer?
- What features/functions are must-haves, nice-to-haves, or are not that important to the customer?
- What are the typical expectations for product performance and durability?
- How must the product operate?
- How will the product's performance and quality be evaluated?
- What testing is required before my product will be considered for purchase by the customer?
- Can I simulate product in operation to predict performance before investing in physical prototype?





Source: Optimal Process Technologies

Key Questions

What am I designing my product for?

- Design for manufacturability
  - —Can I reduce BOM, material trade offs, cost reductions?
- Design for assembly and manufacturing process
  - —Can I reduce process steps, labor?
  - —Can I reduce capital equipment, tooling costs?
  - —Can I reduce scrap, improve yield?
- Design for durability, design for operating environment
  - —Have I considered noise/vibration/harshness testing, loading conditions, engineer for lifetime?

Key Questions

What am I designing my product for? (cont.)

- Design for maintenance serviceability
  - —Can I design in service cost reductions?
- Design for packaging
  - —Have I considered product protection, shipping logistics, transportation costs?
- Design for sustainability
  - —Can I reduce waste materials, scrap, allow for recyclability, use biodegradable materials?
- Design for customer usability
  - —Can I design to make it easy to use for my customer?

Key Questions

Other considerations

Lifecycle:

- ☐ How long does my product need to last?
- ☐ What does my product warranty need to cover?
- ☐ What is the expectation of the customer?

Customer usability:

- ☐ How will my product be handled by the customer?
- ☐ How will it be serviced if it requires maintenance and repair?

Logistics:

- ☐ How do I need to care for my product in inventory?
- ☐ What is the shelf life of my product?
- ☐ How will my product be transported?

Product Launch

Common mistakes and misconceptions

- Product process costs are not predictable
- Limited participation or coordination from a team perspective
- Launch is more reactive than proactive
- Takes too long to launch the product
- Not achieving the predicted margins
- Overlooking lowest cost options for production and assembly
- Too dependent on lower cost overseas partners for quality management
- Over-promising and under-delivering

Product Design

Common mistakes and misconceptions

- Product is engineered well, but cannot be produced
- Product is poorly engineered because advanced simulation tools were not used (FEA/CAE)
- Product is over-engineered
- Product must be completely redesigned
- Failure to rethink product design to drive out cost
- Product cost overruns (i.e., tooling and capitol equipment costs)

Product Process

Common mistakes and misconceptions

- Process cannot "run at rate" as expected
- Failure to plan for every part
- Poor part quality
- Failure to reduce operations costs and waste
- Failure to improve, measure, or track quality
- Failure to properly manage inventory of inbound BOM or outbound finished-product stock
- Encountering capacity constraints
- Requiring more space or new building to accommodate new sales
- Over-investing in operations and running at low capacity rates

Developing Beta Prototypes

Cast study 2 – Start-up electric vehicle company

Mistakes made:

- Introduced the product sixteen months later than original timeline
- Sole-sourced suppliers and ran into parts shortages when suppliers couldn't deliver
- Took short cuts on quality inspection of battery packs
- Final cost of vehicle was $20,000/car more than the original target price
- Did not design product for durability and experienced multiple failures in the field

Developing Beta Prototypes

Cast study 2 – Start-up electric vehicle company (cont.)

Impact:

- Company margins were negative on first vehicle launch
- Angered pre-order deposit customers by not delivering vehicle by date advertised
- Warranty cost skyrocketed when batteries failed and side-impact crashes led to legal settlements
- Exhausted investor funds and filed for bankruptcy

Developing Beta Prototypes

Cast study 2 – Start-up electric vehicle company (cont.)

Best practices:

- Mitigated the cost risk by developing a disciplined approach to cost targeting for the entire vehicle BOM
- Controlled product options and variations
- Mitigated supply-chain risks by securing multiple sources of suppliers for each part
- Mitigated quality risk by implementing DFM and cost upfront with internal teams and external supply partners

Developing Beta Prototypes

Cast study 2 – Start-up electric vehicle company (cont.)

Best impact:

- Company margins were positive on first vehicle launch
- Pre-order deposit customers had their vehicles delivered on time
- Limited failures experienced in the field, which controlled warranty and recall costs
- Received follow-on investor funds to launch new vehicle platforms

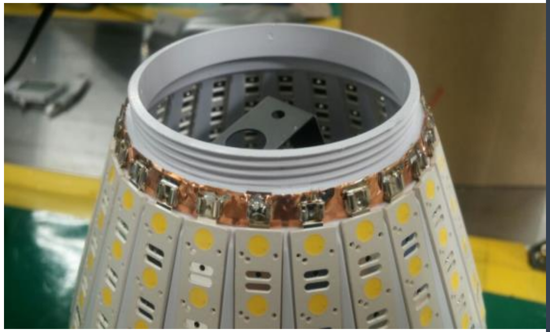
Developing Beta Prototypes

Case study 3 – LED lamp

What is the expectation of the customer, industry, or market for my product?

- Working off of B1-A, market feedback was conducted with assistance from industrial design firm prior to prototype iteration, interviewing stakeholders (field crews, distributors, utility executives). The product expectation is an industrial grade LED lamp, designed for use in outdoor street lighting conditions. The warranty requirements for municipal customers often are 10 years, meaning durability and reliability are key deciding factors. There are also minimum output and efficiency requirements, which are quite high given the state of current LED technology. This means the product must use high quality components while keeping costs low.

Product: B1-a and B1-b



Key Questions

Developing Beta Prototypes

Case study 3 – LED lamp (cont.)

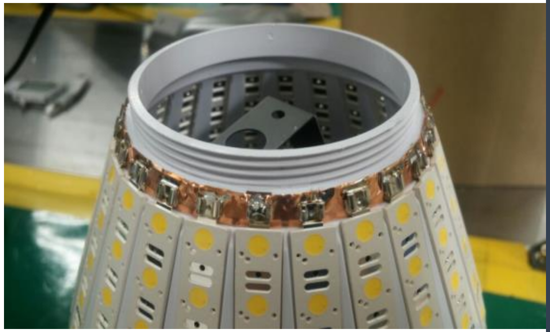
What am I designing my product for? (in order of priority)

- Performance (light quality measured in lumens delivered)
- Energy efficiency (measured in lumen output per watt for the total delivered system)
- Reliability (reliability to exceed 10 year warranty requirement)
- Price

What are the common mistakes to avoid?

- Spending too much time in the weeds trying to minimize the cost of every component in the BOM. Identify the core components that drive BOM and focus on optimizing those. For this case study, the LED packaging was most important.

Product: B1-a and B1-b



Key Questions

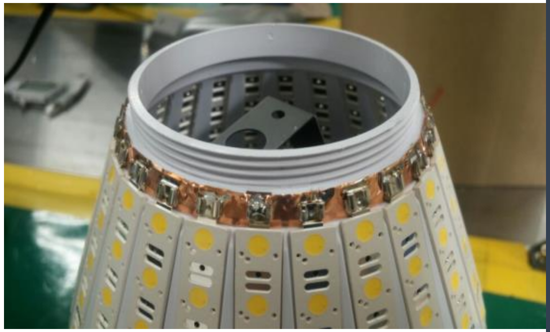
Developing Beta Prototypes

Case study 3 – LED lamp (cont.)

How do I avoid the development of several prototype modifications?

- Make extensive use of computer simulations to validate heat transfer performance of various design iterations prior to going to physical prototype
- Implement design for manufacturing sooner in the engineering and design process. This is where the industrial design firm added a lot of value, as innovators are often unable to see the manufacturing implication landmines early on (chassis designs that would optimize for extrusion vs. stamping processes).

Product: B1-a and B1-b



Developing Beta Prototypes

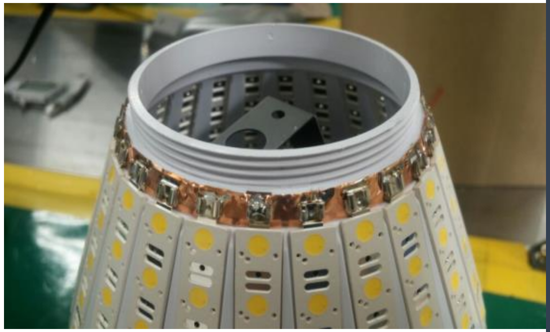
Case study 3 – LED lamp (cont.)

- The industrial design firm had the in-house capabilities to create most of the component parts that were needed to make the proof of concept prototype (3-D printing, CNC machining capabilities, etc.)

Where do I go for prototyping services?

- DFM consulting firms (such as Dragon Innovation)
- Industrial design firms
- Independent consultants

Product: B1-a and B1-b



Key Questions

How do I avoid the development of several prototype modifications?

- ☐ How do I design now to avoid mistakes in the future?
- ☐ Have I considered all potential failure modes?
- ☐ What are the potential effects of those failures?
- ☐ What are the likely causes or reasons for those failures?
- ☐ What is the likelihood of occurrence and severity of each failure mode?

Recommendation: Hardware companies and innovators should institute **Design for Failure Mode and Effects Analysis* (DFMEA)** as a part of their Beta Prototype Plans (see next page)

* Adapted from "*Quality Training Portal: 19 Steps to Conduct a DFMEA*"
www.qualitytrainingportal.com/resources/fmea/fmea_10step_dfmea.htm

Failure Mode And Effects Analysis

Design for failure mode and effects analysis

- Design for failure mode and effects analysis (DFMEA) is a highly structured, systematic product-design methodology for pre-evaluating potential product
- DFMEA is often the first step of a product- or process-reliability study; it involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects
- For each component or process, the failure modes and their resulting effects on the rest of the system are recorded in a specific DFMEA worksheet

Conduct A DFMEA

Step-by-step

1. Review the design: Use a blueprint or schematic of the design/product to identify each component and interface
2. Brainstorm potential failure modes: Review existing documentation and data for clues
3. List the potential effects of failure: There may be more than one for each failure
4. Assign severity rankings: Based on the severity of the consequences of failure
5. Assign occurrence rankings: Based on how frequently the cause of the failure is likely to occur

Conduct A DFMEA

Step-by-step (cont.)

6. Assign detection ranking: Based on the chances the failure will be detected prior to the customer finding it
7. Calculate the risk priority number (RPN): Severity x Occurrence x Detection
8. Develop the action plan: Define who will do what by when
9. Take action: Implement the improvements identified by your DFMEA team
10. Calculate the resulting RPN: Re-evaluate each of the potential failures once improvements have been made and determine their impact on the RPNs

Conduct A DFMEA

Step 1 - Review the design

- Ensure that all team members are familiar with the product and its design
- Identify each of the main components of the design and determine the function or functions of those components and interfaces between them
- Study all components defined in the scope of the DFMEA
- Use a print or schematic for the review
- Add reference numbers to each component and interface
- Try out a prototype or sample
- Invite a subject matter expert to answer questions
- Document the function(s) of each component and interface

Conduct A DFMEA

Step 2 - Brainstorm potential failure modes

- Review documentation for clues about potential failure modes before undertaking brainstorming sessions
- Use customer complaints, warranty reports, and reports that identify things that have gone wrong (i.e., hold tag reports, scrap, damage, and rework) as inputs
- Consider what may happen to the product under difficult usage conditions and how the product might fail when it interacts with other products

Conduct A DFMEA

Step 2 - Brainstorm potential failure modes (cont.)

- Consider potential failure modes for each component and interface
- A potential failure mode represents any manner in which the product component could fail to perform its intended function or functions
- Many components will have more than one failure mode. Do not leave out a potential failure mode just because it does not happen often. Document each one.

Don’t take shortcuts here; this is the time to be thorough

Conduct A DFMEA

Step 3 – List potential effects of failure

- An effect of failure is defined as the impact of a failure on a system should it occur
- The effect is related directly to the ability of that specific component to perform its intended function
- Some failures will effect customers, others effect the environment, the product-production process, and the product itself

Conduct A DFMEA

Step 4 – Assign severity rankings

- The severity ranking scale is critical to the success of DFMEAs because it establishes the basis for determining the risk of one failure mode relative to that of another
  - Severity ranking is based on a relative (not an absolute) scale ranging from 1–10 (10 means the effect has a dangerously high severity, leading to a hazard without warning; 1 means the severity is extremely low)
  - Example forms can be found in the FMEA Resource Center: http://www.qualitytrainingportal.com/resources/fmea/index.htm (left column, under Forms and Check Lists); FMEA's severity ranking scale: https://qualitytrainingportal.com/resources/fmea-resource-center/?section=generic-severity-rating-scale
- The DFMEA ranking scale should be used consistently throughout an organization; this enables comparison of the RPNs of different DFMEAS to one another

Conduct A DFMEA

Step 4 – Assign severity rankings (cont.)

- The best way to customize a ranking scale is to start with a generic scale and modify it to be more meaningful to your organization
- By adding organization-specific examples to the ranking definitions, DFMEA teams will have an easier time using the scales; using examples saves time and improves the consistency of rankings from team to team
- As you add specific examples, consider adding several columns with each column focused on a topic. One topic could provide descriptions of severity levels for customer satisfaction failures and another for environmental, health, and safety issues. Remember, though, that each row should reflect the same relative impact or severity on the organization or customer.

Conduct A DFMEA

Step 5 – Assign occurrence rankings

- The potential cause must be known in order to determine the occurrence ranking because, just as the severity ranking is driven by the effect, the occurrence ranking is a function of the cause
- The occurrence ranking is based on the likelihood, or frequency, that the cause (or mechanism) of failure will occur
- If the cause is known, it is easier to identify how frequently a specific mode of failure will occur
- The occurrence ranking scale, like the severity ranking scale, is a relative scale ranging from 1–10

Conduct A DFMEA

Step 5 – Assign occurrence rankings (cont.)

- An occurrence ranking of 10 means the failure mode occurrence is very high; it happens all of the time (conversely, a 1 means the probability of occurrence is remote)
- See FMEA's Forms and Checklists webpage for an occurrence ranking scale example
- Your organization may need to develop a customized occurrence ranking scale to apply to different levels or complexities of design; it is difficult to use the same scale for a modular design, a complex design, and a custom design
- Some organizations develop three different occurrence ranking scales (time-based, event-based, and piece-based) and select the one that applies to the design or product

Conduct A DFMEA

Step 6 – Assign detection rankings

- To assign detection rankings, consider the design or product-related controls already in place for each failure mode and then assign a detection ranking to each control
- Think of the detection ranking as an evaluation of the ability of the design controls to prevent or detect the mechanism of failure

Conduct A DFMEA

Step 6 – Assign detection rankings (cont.)

- Detection controls identify the cause of failure, the mechanism of failure, or the failure mode itself after the failure has occurred, but before the product is released from the design stage
  - A detection ranking of 1 means the chance of detecting a failure is almost certain, whereas a 10 means the detection of a failure or mechanism of failure is absolutely uncertain
  - To provide DFMEA teams with meaningful examples of design controls, consider adding examples tied to the detection ranking scale for design-related topics such as design rules, design for assembly and design for manufacturability (DFA/DFM) issues, and simulation and verification testing
  - See FMEA's Forms and Checklists webpage for examples of custom DFMEA ranking scales

Conduct A DFMEA

Step 6 – Assign detection rankings (cont.)

- Prevention controls are always preferable to detection controls
  - Prevention controls come in different forms and levels of effectiveness
  - Prevention controls prevent the cause or mechanism of failure (or the failure mode itself) from occurring; they generally impact the frequency of occurrence

Conduct A DFMEA

Step 7 – Calculate the risk priority number (RPN)

- The RPN provides a relative risk ranking; the higher the RPN, the greater the potential risk
  - —Since each of the three relative ranking scales ranges from 1–10, the RPN will always be between 1 and 1,000; the RPN is an excellent tool for prioritizing focused improvement efforts
- The RPN is calculated by multiplying the three rankings together: the severity ranking, the occurrence ranking, and the detection ranking; calculate the RPN for each failure mode and effect

  Note: The current AIAG FMEA Manual suggests only calculating the RPN for the highest effect ranking for each failure mode. We do not agree with this suggestion. We believe that if this suggestion is followed, it will be too easy to miss the need for further improvement on a specific failure mode.

Conduct A DFMEA

Step 8 – Develop the action plan

- Taking action means reducing the RPN
- The RPN can be reduced by lowering severity, occurrence, or detection individually or in combination with one another
- A reduction in the severity ranking for a DFMEA is often the most difficult to attain—it usually requires a design change
- Reduction in the occurrence ranking is accomplished by removing or controlling potential causes or mechanisms of failure
- A reduction in the detection ranking is accomplished by adding or improving prevention or detection controls
- What is considered an acceptable RPN? The answer depends on the organization.

Example: An organization may decide that any RPN above a maximum target of 200 presents an unacceptable risk and must be reduced. If so, an action plan (who will do what, by when) is needed.

Conduct A DFMEA

Step 8 – Develop the action plan (cont.)

DFMEA tools to reduce the relative risk of failure modes requiring action:

- Design of experiments (DOE)
  - Powerful statistical improvement techniques that can identify the most critical variables in a design and the optimal settings for those variables
- Mistake-proofing
  - Techniques that can make it impossible for a mistake to occur, reducing the occurrence ranking to 1
  - Particularly important when the severity ranking is 10

Conduct A DFMEA

Step 8 – Develop the action plan (cont.)

DFMEA tools to reduce the relative risk of failure modes requiring action (cont.):

- Design for assembly and design for manufacturability (DFA/DFM)
  - Techniques that help simplify assembly and manufacturing by modularizing product sub-assemblies, reducing components, and standardizing components
- Simulations
  - Simulation approaches include pre-production prototypes, computer models, accelerated life tests, and value-engineering analyses

Conduct A DFMEA

Step 9 – Take action

- The action plan outlines the steps needed to implement the solution, including who will perform them and when they will be completed
- A simple solution only requires a simple action plan, while a complex solution requires more thorough planning and documentation; most action plans identified during a DFMEA will fall under the simple “who, what, and when” category
- Responsibilities and target completion dates for specific actions to be taken are identified
- An action plan may trigger a large-scale project. If that happens, conventional project management tools (including PERT Charts and Gantt Charts) will be required to keep the action plan on track.

Conduct A DFMEA

Step 10 – Recalculate the resulting RPN

- By calculating the resulting RPN, this step in a DFMEA confirms that the action plan has produced the desired results
- To recalculate the RPN, reassess the severity, occurrence, and detection rankings for the failure modes after the action plan has been completed

DFMEA

Case study 4 – Automotive body structures

- Joining dissimilar materials processes to produce lighter weight cars

Functional Requirement / Design Parameter	Potential Failure Mode(s)	Potential Effect(s) of Failure Mode	SEV	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Design / Process Controls	DET	RPN
Rivet quality (design, shape, materials)	Faulty rivet due to dimensional inconsistency and material variation	No-weld or unsatisfactory weld joint created, spatter occurance	10	Manufacturing failure of rivet being out of spec in length, diameter, burs, wrong or poor material	5	Rivet quality inspection (varification prior to "weld")	5	250
Rivet quality (design, shape, materials)	Poor rivet design, too sensitive to welding application conditions	No-weld or unsatisfactory weld joint created, spatter occurance, excessive/localized melting	10	Rivet design not validated	3	Ensure robust rivet design through CAE CFD analysis simulate rivet loading conditions for each material joining application	2	60
Rivet quality (design, shape, materials)	Rusted or contaminated rivets	No-weld or unsatisfactory weld joint created, spatter occurance	8	Poor storage and packaging conditions of rivets	3	Coating rivets or controlled environment for storage, packaging, shipping	3	72
Rivet quality (design, shape, materials)	Rivet shape is not optimized for ideal joint	No-weld or unsatisfactory weld joint created, spatter occurance	8	Rivet wall thickness or rivet head taper causes excesive local melting	3	Optimization of rivet shape through CAE analysis	2	48
Rivet feeding	Out of position of rivet	No-weld	10	180 out of position	5	Sensor / vision detection?	5	250
Rivet feeding	Rivet jamming	No-weld	10	slightly out of position causing a jam	5	Sensor / vision detection / error-proofing	5	250
Rivet feeding	Orientation of rivet to floor is angled creating poor positioning	No-weld or unsatisfactory weld joint created	8	mis-feed / jammed mechanism	3	use tape feed instead of bowl feeder	3	72
Weld control	Experiencing a "narrow weld lobe"	unsatisfactory weld joint created	6	Not optimizing weld current, force, joining time	3	Optimization of weld parameters for robustness	3	54
Weld control	Sensor errors or failures (if adpative feedback control applied)	unsatisfactory weld joint created	8	Electromagnetic interference (EMI), vibration, spatter, sensor power disruption	3	Self-system sensor diagnosis, sensor redundancy, sensor shielding/protection	3	72
Weld control	Low current density due to shunting	unsatisfactory weld joint created	6	Weld electrode wear or contamination, transformer errors/failure	3	Weld eletrodes maintenance (e.g., tip dressing, automated tip replacement), transformer monitoring/diagnosis	3	54
Weld control	Failure for weld current to pre-heat rivet	unsatisfactory weld joint created	6	Weld electrode wear or contamination, transformer errors/failure, rivet design or material does allow for satisfactory thermal conductivity	3	Weld eletrodes maintenance (e.g., tip dressing, automated tip replacement), transformer monitoring/diagnosis, optimize rivet design and material via thermal transfer analysis	3	54
Weld control	Excessive or partial melting	unsatisfactory weld joint created	6	Current sensor failure, power supply failure	3	Self-system sensor diagnosis, sensor redundancy	2	36

Severity: Scale 1 - 10, where 1=predicted <3 defects/million, 10=>500K defects/million

Detectability: scale 1-10, where 1=always detected by current plan, 10=unable to detect

Occurrence: Scale 1-10 where 1=predicted <3 defects/million, 10=500>500K defects/million

Beta Prototype Quality Plan

Exercise – DFMEA worksheet

Functional Requirement / Design Parameter	Potential Failure Mode(s)	Potential Effect(s) of Failure Mode	SEV	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Design / Process Controls	DET	RPN

Severity:
Scale 1 - 10, where 1=predicted <3 defects/million, 10=>500K defects/million

Detectability: scale 1-10, where 1=always detected by current plan, 10=unable to detect

Occurrence:
Scale 1-10 where 1=predicted <3 defects/million, 10=500>500K defects/million

Resources

DFMEA/PFMEA

- Quality Training Portal: 10 steps to conduct a DFMEA
  http://www.qualitytrainingportal.com/resources/fmea/fmea_10step_dfmea.htm
- Chart It Now: DFMEA template
  http://www.chartitnow.com/DFMEA-Template.html
- QIMacros: FMEA template in Excel
  https://www.qimacros.com/lean-six-sigma-articles/fmea-template/
- Systems2win: FMEA template
  http://www.systems2win.com/solutions/FMEA.htm
- DMAIC Tools: PFMEA (definitions and explanations)
  https://www.dmaictools.com/dmaic-analyze/pfmea

Manufacturing Resources

Shared asset facilities/prototyping services

- TechShop: Shared manufacturing space http://www.techshop.ws/
- Makerspace: Shared manufacturing space http://makerspace.sp.edu.sg/
- Quick Parts: 3D printing service http://www.3dsystems.com/quickparts
- R&D Technologies: 3D printing service rnd-tech.com
- Protolabs: 3D printing, CNC machining, injection molding service www.protolabs.com
- Maketime: CNC machining service www.maketime.io
- Rapid Manufacturing/Vaupell: Prototype sheet metal, machined parts, cabling service https://rapidmanufacturing.com/
- Circuit Hub: On demand PCB manufacturing service https://circuithub.com/

Manufacturing Resources

How do I find manufacturing experts?

Identify regional supplier matchmaking and connection programs. Examples include:

- Greentown Labs Manufacturing Initiative, a Boston-area clean-technology hardware incubator partnership with Massachusetts Manufacturing Extension Partnership (MassMEP) http://www.greentownlabs.com/wp-content/uploads/2015/02/020515-Manufacturing-Initiative-PDF1.pdf
- InnoState, a Michigan entrepreneur-manufacturer matchmaking program organized by MEP Michigan Manufacturing Technology Center (MMTC) http://innostatemi.com/
- Pure Michigan Business Connect, a matchmaking portal with listing of events http://www.michiganbusiness.org/grow/pure-michigan-business-connect/

Finding Manufacturing Expertise

Recommendations

- Get to know your local manufacturing extension partnership (MEP)
- Secure a manufacturing expert as an advisor, even if it means providing some equity
- Take advantage of retired and semi-retired manufacturing experts who are often eager to share their experience and knowledge with innovators and startups

***Not** soliciting help from manufacturing experts is a common mistake!*

Manufacturing Resources

DFX Training Resources

- Society of Manufacturing Engineers (SME) Tooling U: Extensive on-line manufacturing training http://www.tooling.com/
- SME Manufacturing Insights® Videos http://www.sme.org/mi/
- SME Fundamental Manufacturing Processes (FMP): 44 videos on major manufacturing processes http://www.sme.org/fmp/
- SME DFMA Training http://www.toolingu.com/ilt/915101/Design-for-Manufacturability-and-Assembly-DFMDFA
- Advice Manufacturing Processes: Short videos on a range of common manufacturing industry processes http://www.advice-manufacturing.com/Manufacturing-Processes.html

Manufacturing Resources

DFX Training Resources (cont.)

- The Manufacturing Institute: Manufacturing skills certification programs http://www.themanufacturinginstitute.org/Skills-Certification/Certifications/NAM-Endorsed-Certifications.aspx
- AME Alliance: 8-week manufacturing certification courses http://amealliance.org/8-week-certificates
- Alison Institute: Online manufacturing training classes https://alison.com/learn/manufacturing
- DfR Solutions: Design for manufacturing training programs www.dfrsolutions.com
- Electronics Manufacturing Training http://www.ipc.org
- Manufacturing Skills Training Programs http://scientific-management.com/skills-training-programs

Manufacturing Resources

DFX Training Resources (cont.)

- Munro & Associates: Lean design manufacturing optimization training http://leandesign.com/lean-design/
- Munro & Associates: Design profit manufacturing costing software http://www.designprofit.com/
- Ricardo: Product development, engineering and manufacturing training, and consulting http://www.ricardo.com/en-GB/What-we-do/knowledge/Training/
- Society of Automotive Engineers (SAE): DFM, DFA training http://training.sae.org/seminars/92047/
- Tec-Ease, Inc.: Design for assembly and GD&T training http://www.tec-ease.com/design-assembly.php
- Engineers Edge: DFMA training http://engineersedge.com/training_engineering/design-for-manufacturing-training.htm

Manufacturing Resources

DFX Training Resources (cont.)

- OMNEX: DFMA training http://www.omnex.com/training/rd_Series/design_manufacturing_assembly.aspx
- SSA: DFMA training http://www.ssa-solutions.com/training-program/design-for-manufacturing-assembly.php
- Manufacturing Quality Training ASQ www.asq.org
- Automotive Industry Action Group's (AIAG's) Advanced Product Quality Planning (APQP) (available via courses or on-line) http://www.aiag.org/store/training/details?CourseCode=ELCTO
- TU Delft/UNEP: Design for sustainability http://www.d4s-sbs.org/
- Surface Mount Technology Association (SMTA): Online manufacturing training courses www.smta.org

Manufacturing Resources

DFX Training Resources (cont.)

- Six Sigma U: Design for six sigma training http://www.6sigma.us/design-for-six-sigma-dfss.php
- NPD Solutions: Design for maintenance and serviceability workshops http://www.npd-solutions.com/featuredworkshops/dfsws
- Dragon Innovations: BOM development tools https://www.dragoninnovation.com/dragon-standard-bom
- Greentown Labs and MassMEP: Best practices for training startups to work with manufacturers http://greentownlabs.com
- Invent@NMU: Hardware entrepreneur accelerator program focused on acceleration to market through DFX principals http://www.nmu.edu/invent/home

Manufacturing Resources

DFX Training Resources (cont.)

- Connecting Green Technology Entrepreneurs: Building connections for green technology entrepreneurs https://www.infodev.org/infodev-files/connecting-green-technology-entrepreneurs-full.pdf
- E2 by Shoptech: All-in-one manufacturing software (quoting, accounting, production, inventory, etc.) www.shoptech.com
- Basic CAD tools: Autodesk's Fusion 360 http://www.autodesk.com/products/fusion-360
- Basic CAD tools: SolidWorks www.solidworks.com
- Geometric Global: Design for manufacturing software http://info.geometricglobal.com/design-for-manufacturing-software
- Design-IV: DFM/DFA software http://www.design-iv.com/

Manufacturing Resources

Other

Manufacturing Training Network Resources

- U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) http://energy.gov/eere/office-energy-efficiency-renewable-energy
- U.S. Department of Energy's Advanced Manufacturing Office (AMO) http://energy.gov/eere/amo/advanced-manufacturing-office
- National Network of Manufacturing Institutes (NNMIs) http://manufacturing.gov/nnmi/institutes.html

Manufacturing Resources

Other (cont.)

Where to look for additional resources online:

- University and U.S. national laboratory manufacturing websites and training programs
- Existing design for manufacturability training resources (e.g., SME)
- Manufacturing Extension Partnerships (MEPs) programs http://www.nist.gov/mep/
- Hardware-based incubators and accelerators
- Entrepreneurial mentorship and expert-in-residence (EiR) programs
- Entrepreneurial contract manufacturing matchmaking programs

References

- Dragon Innovation Blog, September 8, 2016: Top 10 Manufacturing Reasons Hardware Companies Fail http://blog.dragoninnovation.com/2016/09/08/1414/
- MForesight Report Manufacturing 101: An Education and Training Curriculum for Hardware Entrepreneurs (downloadable PDF file) http://mforesight.org/download/5107/
- MMTC Production Preparation Process (3P) https://www.the-center.org/Our-Services/Operational-Excellence/Lean/Production-Preparation-Process-(3P)
- Wikipedia: Failure mode and effects analysis https://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis
- Quality Training Portal: 19 steps to conduct a DFMEA www.qualitytrainingportal.com/resources/fmea/fmea_10step_dfmea.htm