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reliability designed, reliability delivered

Design for Manufacturability (DfM)

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James (Jim) McLeish, CRE

- **35 years of Vehicular, Military and Industrial Product Engineering Experience Practical, Hands on Practicing Engineer for Design & Launch of High QRD Products, Experience in Automotive QRD, Analysis/Development/Validation (A/D/V) DfR, PoF, Test Technology Development, Warranty Problem Solving, Root Cause/Failure Analysis**

  - Product Design, Development, Systems Engineering & Production (Chrysler & GM - 14 yrs)
    - ESA/EFC Digital Task Force (1st Microprocessor Based Engine Controller) - Chrysler Corp.
    - 3 Patents Automotive Electronic Control Systems - GM Adv. Product Engineer & GM E/E Engineering Center
    - System Engineering and Architecture Planning - GM Saturn Project
    - Engineering Manager - GM Military

  - Validation, Reliability, Quality Assurance, Warranty Problem Solving & Test Technology Development (GM - 16 yrs)
    - Technical Specialist/Team Leader in Quality & Warranty Problem Solving and Japanese Mizenboushi (Preventative Measures) Quality by Design Methods: GD3, DRBFM, DRBTR
    - Reliability Manager for GM Chevrolet-Pontiac-Canada Engineering
    - Manager GM Reliability Physics (Advance QRD, A/D/V & Test Technology Development)
    - Author or Co-author of 3 GM Reliability/Validation Test Standards

  - Michigan Office Manager & Senior Technical Staff (DfR Solutions - 5 yrs).
    - Principle Investigator for E/E Warranty/Failure Analysis and Root Cause Problem Solving
    - E/E Manufacturing Process Optimization, Yield Improvement
    - QRD Demonstration, Product Validation and Accelerated Testing
    - Design Reviews for Proactive Problem Prevention
    - Core Member SAE - Reliability Standards Workgroup
    - DoD Reliability Handbook Update Team & DoD Reliability Technology Roadmap Project

Design for Manufacturability

- Design Manufacturing) - (DFM) is the engineering ART of designing products that are easy to manufacture in order to facilitate "BUILD IT RIGHT, ON THE FIRST ATTEMPT".
- ART verses Science while science based, the art of DfR is in using the knowledge and experience of crafting/adapting DfM for Your Products and Processes.
  - Some industries have general guidelines but no universal solutions or cook books.
- Benefits of easy to build designs, produced in a capable process:
  - Faster to Market by Accelerating Product Launch Activities
  - Reduces need of Quality Control Inspectors & Tests
  - Improves Efficiency & Lowers Costs.
  - Improves Customer Satisfaction & Value.

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Design Engineering Influence on Lifecycle Costs

- Design/product engineering typically accounts for only 8-10% of a product budget.
  - But design decisions can determine up to 70-80% of manufacturing cost and have significant impact on Quality, Reliability, Durability (QRD) and serviceability.
  - Design decisions determine cost throughout the product lifecycle. Once these costs are locked in, they are very difficult and costly to change.
    - Root Cause Investigations.
    - Redesign Efforts
    - Engineering Change Orders (ECOs),
    - Tooling/ Process changes
    - Supplier / Process Re-Qualifications, and/or Re-Certification.

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Design Engineering Influence on Lifecycle Costs

- Design of Production Process decisions (material handling, process flow, assembly equipment) account for less than 20-30% of product costs.
- Total Lifecycle Cost, along with QRD and Customer Satisfaction can be better managed and optimized by developing products & their manufacturing processes simultaneously in cross functional or collaborative teams
  - The goal is to share information cross functionally between disciplines to make the design, development and production of the product faster and more streamlined.
  - Improves the ability of the design to be compatible with manufacturability and sourcing best practices.
  - To make the end product meet final customer expectations and needs.

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Benefits of Defect Preventions & Cost of Late Defect Correction

- The cost of finding and fixing defects increases by a factor of approximately 10x for each stage of assembly (Rule of Thumb).

- 0 defects = $0 Extra Costs.
- Defect Detection and Correction 10x Rule.

Assembly Level	Costs to Find & Fix
Incoming Parts	1x
Sub Assembly Level	10x
Final Assembly Level	100x
Dealer/Distributor Level	1000x
Final Customer Level	10,000x

- Efforts expended on defect prevention and to ensure early detection and correction of defects are resources well spent.

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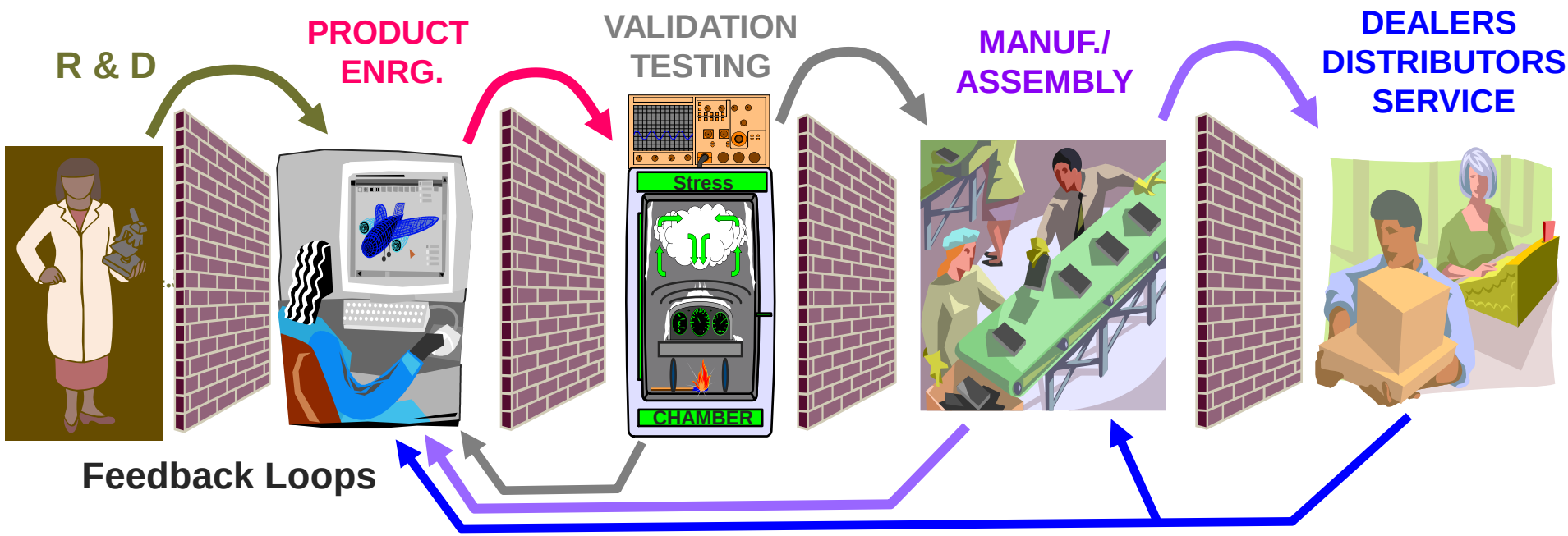
Old Style Product Development – "Sequential Over The Wall"



- Before DfM, it was "We designed it" ~ "You build it"!
- Design engineers worked independently, then transferred designs "over the wall" to the next department or external to the company (CM).
- Eventually manufacturing has to assemble the product.
  - Usually inherit a product not designed for their processes and too late to make changes.
  - Manufacturing forced struggle to meet yield, quality, cost or delivery targets.
  - Often required trial & error crisis management
  - Often resulted in launch delays, then quality and reliability issues.

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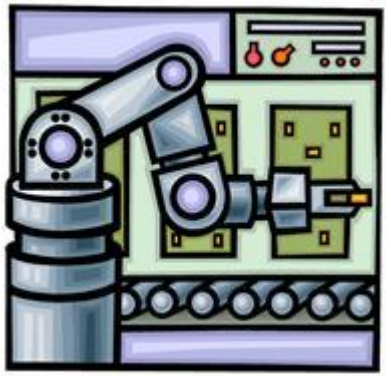
The ART of Design for Manufacturability

- Various forms of DfM practices exists in most industries.
  - Especially Strong practice in Automotive, Electronics, Appliances and Consumer Products
- Specific details highly dependent on Industry Products and Manufacturing Technology.
- Basic Requirements:
  - An understanding of best practices
  - Knowledge of what fails during your manufacturing processes
  - An understanding of the limitations of
    - Your processes
    - Your supply chain



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Key Design for Manufacturability Guidelines

- The foundation of a robust Design for Manufacturing system is a set of design guidelines and tasks to help the product team improve manufacturability, increase quality, reduce lifecycle cost and enhance long term reliability.

- These guidelines need to be customized to your company's culture, products, technologies and based on a solid understanding of the intended production system – whether internal or external.

- "Generic Top 10" DfM guidelines and tasks that are applicable to many industries and processes.

DfM Guideline #1: Know Your History

- ***"Those who do not learn from history are doomed to repeat it."***
  - Learn from the past: Process yields, Returns, Corrective Actions Processes, Recalls, etc.
  - Develop and implement strategies to address and prevent recurrence of mistakes.
- Know and understand problems and issues with current & past products (Especially critical if carrying over existing technologies into new designs).
  - Manufacturability
  - Delivery
  - Quality
  - Repairability & Serviceability,
  - Regulatory issues
  - Recalls

- Best approach is to have an effective system for capturing and disseminating this historical knowledge throughout the organization.
- Absolute minimum should be focused brain storming sessions (post-mortems) to collect lessons learned/best practices from all areas of the organization.

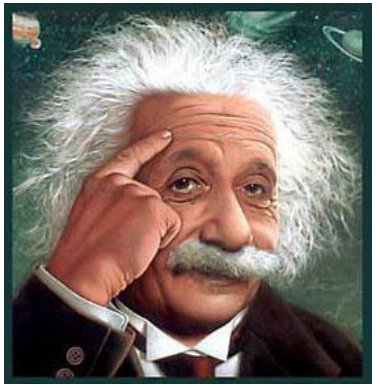
DfM Guideline #2: Standardize Design Methods

- Standardize design, procurement, processes, assembly, and equipment throughout your organization
  - Reduces overall cycle time.
  - Simplifies training and tasks.
  - Reduces repeated mistakes
  - Improves opportunity for bulk discounts.
  - Improves opportunity for automation and operation standardization.

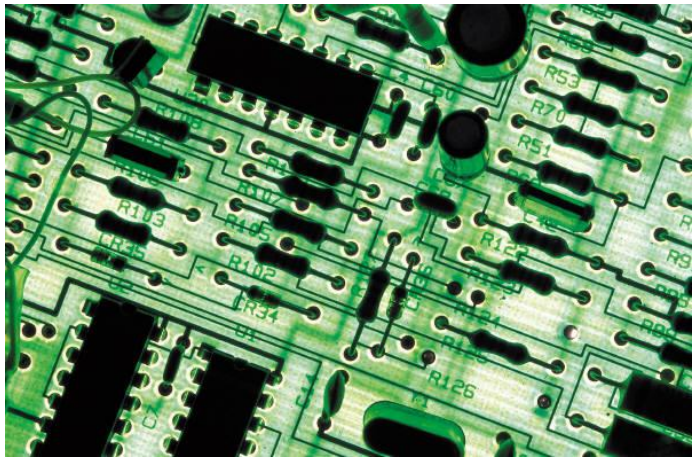
- Don't Redesign the Wheel
  - Never custom design something that you can buy off the shelf.
- Limit exotic or unique components.
  - Higher prices due to low volumes and less supplier competition.
  - Lower quality for exotic components.
  - More opportunity for supply chain disruptions.

DfM Guidelines #3: Simplify the Design by Parts Reduction

Everything should be made as simple as possible, but not one bit simpler.
- Albert Einstein



- Parts reduction is one of the best ways to *reduce the cost of fabricating and assembling a product and increase quality and reliability.*
  - Reduces parts costs.
  - Reduces direct labor costs.
  - Reduces process equipment.
  - Reduces number or workstations.
  - Fewer opportunities for defective parts.
  - Fewer opportunities for assembly errors.



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DfM Guideline #3: Simplify the Design by Parts Reduction

- Parts reduction is also one of the best ways to reduce structural costs.
  - *Fewer parts rippling through the entire organization reduces the work load for every department at every level.*
  - *Fewer items to be processed by:*
    - Product Development
      - Engineering, Purchasing, Development/Test Labs.
    - Manufacturing Support
      - Inventory Warehousing, Material Handling, Service Parts.
      - Quality Management.
    - Manufacturing facilities
      - Facility Size, Equipment, Processing/Assembly Time & Labor
    - Provides more opportunities for process automation.

DfM Guidelines #3: Simplify the Design by Part Reduction

- Modular design
  - Use complete modules and subassemblies, instead of designing, fabricating and assembling everything yourself, simplifies every level of your activities.
  - Modules can be manufactured and tested before final assembly.
  - Modules facilitate the use of standard components to minimize product variations.
  - Modules add flexibility to product update in the redesign process

DfM Guidelines #3: Simplify the Design by Part Reduction

- Parts Commonality via Multi-Use/Multi-Functional Parts
  - Develop an approved or preferred parts lists or a standardized BOM (Bill of Materials) to encourage different products lines to share common parts.
    - Designer CAD/CAE systems can be configured to access preferred designs and parts catalogs.
  - Whenever possible use one-piece structures from injection molding, extrusions, castings and powder metals or similar fabrication techniques instead of bolt/glue together multi part assemblies.
  - Establish part families of similar parts based on proven materials, architecture and technologies that are scaled for size or functionality
  - Use Multi-functional parts that perform more that one function, example:
    - An electric conductor that also serves as a structural member,
    - A cover or base plate that also serves as a heat sink
    - Incorporate guiding, aligning, or self-fixturing features into housing and structures.

DfM Guideline #4: Design for Lean Processes

Fundamental Principle of Lean

Anything that does not add value to the product is ***waste*** *and must be reduced or eliminated*

DfM Guideline #4: Design for Lean Processes

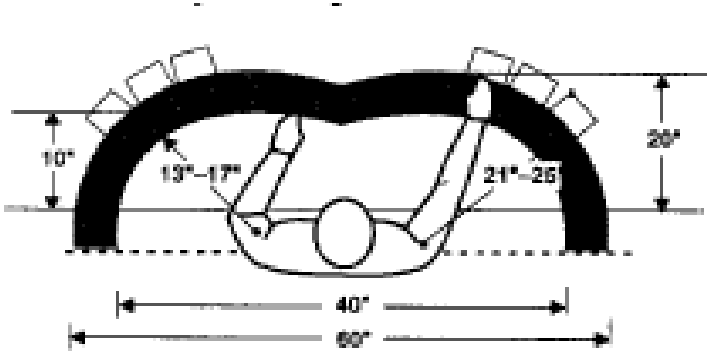
- Lean supply, fabrication and assembly processes are essential design considerations.
  - Simple lean fabrication/processing/assembly is more likely to be done quickly and correctly
    - Right part at the right station at the right time
  - Reduced throughput time equals faster time to market and lower costs (reduced labor hours and faster turns).
  - Designs that are easy to assemble manually will be more easily automated.
  - Assembly that is automated will be more uniform, more reliable, and of higher quality.

DfM Guideline #4: Design for Lean Processes

- Develop and use standard guidelines appropriate for the process being performed. Common hole sizes, lines, and spacings.
  - Standard circuit board soldering temperature profiles
  - Standard handling, avoid High Moisture Sensitivity Level (MSL) > 3 components
  - For assembly - design for human factors – the "Visual" Factory
    - Allow for visual, audio & tactile feedback to ensure correct assembly.
      - Makes it obvious to follow the correct process flow.
      - Bottlenecks and problems are more easily identified
    - Provide adequate access clearances for tools and hands.
    - Design in self aligning and self guiding features such as tapered parts, guide pins or groves.
    - Design work to use standard tools and settings: crimpers, splicers, cutters, solder iron tips, drill bit sizes, torque settings, wire sizes
      - Minimizes tool clutter and decision making on what to use

DfM Guideline #4: Design for Lean Processes

- Ergonomics is the science of equipment and station design to maximize productivity by reducing operator fatigue and discomfort.
- Know and apply lean principles to design manual operations for the capabilities of the operators.
  - Design the work station area to minimize the distance to access and move incoming parts.
  - Design tasks and work areas to maximize the efficiency and quality of operators work.
  - Overuse injuries like Carpal Tunnel Syndrome, occur among people who work in fixed positions, perform rapid repetitive tasks, or use forceful movements.
  - Avoid heavy parts that will fatigue operators, risk worker injury, or slow down assembly.
  - Provide appropriate material handling aids and tools.



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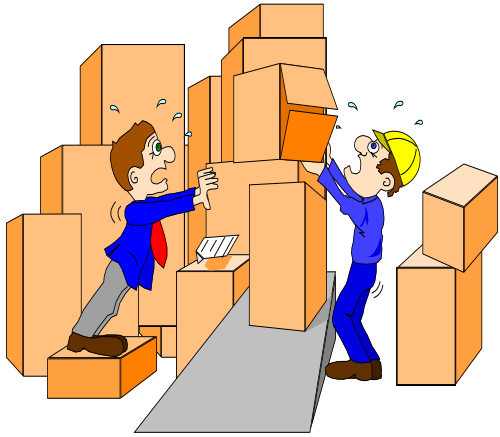
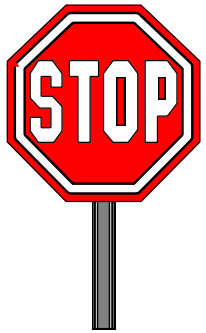
DfM Guideline #5: Eliminate Waste



- Seven Types of Waste
  1. *Overproduction*
     - Build more than required, before required.
  2. *Waiting*
     - Stop build to look for parts, tools, material, information
  3. *Transportation/Moving*
     - Moving material, parts, tooling
     - Transferring product between locations, into/out of racks
  4. *Process Inefficiencies*
     - Unnecessary operations, too many inspections, not building to customer spec
  5. *Inventories/Storage*
     - Excess raw material, excess WIP
  6. *Unnecessary Motions*
     - Walking, climbing, bending, searching, identifying
  7. *Defective products*
     - Low Yields, mistakes leading to large reworks, sorting, inspection



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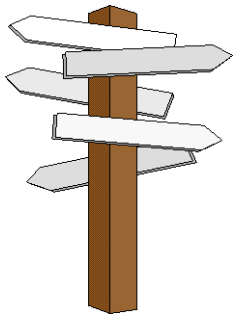
DfM Guideline #6: Design for Parts Handling

- Proper and Logical Sequence of Assembly Tasks
- Adjacent Assembly stations
- Avoid extra handling, storage and transfers of work in process
- Continuous Flow lines try to avoid batch builds.
- Minimize handling to correctly position, orient, and place parts and avoid multiple or complex assembly orientations.
- Try to avoid excessive twisting, rotating, repositioning.



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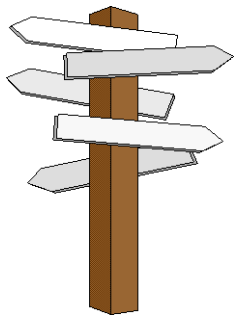
DfM Guideline #6: Design for Parts Handling

- Use non-symmetrical parts where possible. When symmetrical parts are needed, use keying features to ensure proper orientation. Make orienting and mating parts as visually obvious as possible.
  - Use parts oriented in magazines, bands, tape, reels or strips when possible or use parts designed to consistently orient themselves when fed into a process
  - Reduce and avoid parts that can be easily damaged, bent, or broken.
  - Design parts with surfaces that can be easily grasped, placed or fixtured.
  - Reduce the need for temporary fastening and complex fixtures.
  - Begin assembly with a large base component with a low center of gravity to add other parts to.
  - Use gravity, assembly should proceed vertically with other parts added on top
    - *Exception: avoid upward orientation of debris /contamination sensitive features, prevent dust or moisture from falling into electrical, hydraulic, pneumatic connector or lines*
  - Use appropriate easy access, safe packaging for parts but try to minimize the creation of waste.



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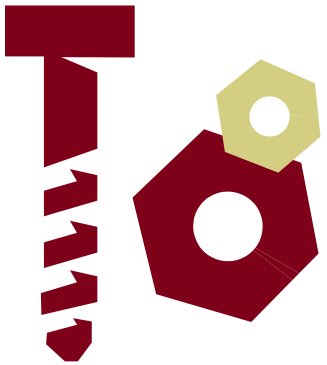
DfM Guideline #7: Design for Joining & Fastening

- Design for efficient joining and fastening.
  - Fasteners increase the cost of manufacturing, handling and feeding operations.
    - Screws, bolts, nuts and washers are time-consuming to assemble & difficult to automate.
    - Increased potential for defects (missing and improper assembly).
  - Avoid threaded fasteners when possible, consider alternative,
    - Consider the use of snap-fit.
    - Evaluate adhesive bonding techniques.
  - Where fasteners must be used, minimize variety
    - Use guidelines and standardize fasteners to minimize the number, size, and variation.
    - Self-tapping and chamfered screws are preferred.
    - Use captive fasteners when possible.



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DfM Guidelines #8: Use Error Proofing Techniques

- **Mistakes will happen, What can go wrong will go wrong.**
  - Anticipate and Eliminate opportunities for error

- **Use error proofing techniques in product design and assembly**
  - Make the correct assembly process visually obvious, well-defined and clear cut, remove confusion and interpretation.
  - Have written instructions in 1 location only – no competing documents
  - Minimize wording in instructions, use pictures, icons, photos instead
  - Key unique parts so that they can be inserted only in the correct location.
    - Use notches, asymmetrical holes and stops to mistake-proof the assembly process.
  - Design verifiability into the product and its components.
    - Sight, Sound or Field - use visual, audio or tactile feedback
    - Use color coding
    - Electronic products can be designed to contain self-test diagnostics
  - Avoid or simplify adjustments or modifications

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DfM Guidelines #8: Use Error Proofing Techniques

- **Wiring, Hose & Air lines.**
- **Protect the Fragile Easily Damaged Items.**
  - Emphasize routing paths.
  - Avoid share corners and turn.
  - Watch our for Pinch points.
  - Avoid rub and chafing opportunities
  - Use structures that protect these flexible, fragile items
    - Shrouds
    - Conduits
    - Extra tape wrap

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DfM Guideline #9: Design for Process Capabilities

- Make use of specific production DFM guidelines or know the process capabilities of the production equipment you expect to use.
  - Avoid unnecessarily tight tolerances and tolerances that are beyond the inherent capability of the manufacturing processes or operators in a continuous production situation. Tighter is not always better!
  - Perform tolerance stack up analyses on multiple, connected processes and parts.
  - Determine when new production process capabilities are needed and allow sufficient time to develop/optimize new processes, determine optimal process parameters and establish controlled processes.

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DfM Guideline #10: Design for Test, Repair, & Serviceability

- Defects will occur. Design for ease of test and repair will make these processes more efficient, cost effective, and reliable.
  - Use recommended component spacing to allow for safe repair or replacement
  - Design in diagnostics, self tests, meaningful error messages interfaces.
  - ESD Considerations - provide warning labels and appropriate workstations protective features where needed.
  - Standardize approaches and methods.
    - Minimize parts variety, minimize tools/special tools needed
  - Minimize disassembly steps to access replaceable/repairable Items.
    - Consider unfastening and refastening, disassembly and reassembly issues.
    - Use self-fastening and self-jigging Features when possible.
    - Consider impact of adhesives, coating, and potting
  - Wiring/Hose Interconnection – consider disconnect and reconnect capabilities.
- Failed products are often returned to the manufacturer for service and failure analysis. Where possible, use the production test equipment/setup for returns analysis.

A Basic DfM Checklist for Circuit Boards

- Baseline
  - Your design matches their capabilities (75% 'sweet spot')
  - Design is transferable
- Bare Board
  - Trace width and spacings
  - Laminate material
  - Symmetry of stackup
  - Complexity of via connections
  - Incorporation of new materials (embedded passives)
  - Single-sided vs. double-sided
- System
  - Blind connections
  - Z dimension limitations
- Assembly
  - Elimination of hand soldering or wave soldering when possible
  - Proximity of components to flex points
  - Component spacing
  - Size of components and complexity of packaging
  - Orientation of components to wave solder
  - Shadowing during wave solder
  - Appropriate dimensions and spacings for PTHs and bond pads
  - Attachment methods
  - Moisture sensitivity level (MSL)
  - Cleanliness

Summary & Recap

- DfM is a proven, cost-effective strategic methodology.
- Early, effective cross functional involvement:
  - Reduces overall product development time (less changes, spins, problem solving)
  - Results in a smoother production launch
  - Speeds time to market
  - Reduces overall costs
    - Designed right the first time
    - Optimizes # of parts
    - Optimizes # of process steps and use of correct, efficient steps
    - Reduces labor costs to repair and resolve issues
    - Improves overall production efficiency
    - Build right the first time = less rework, scrap, and warranty costs
  - Improves quality and reliability results in:
    - Higher customer satisfaction
    - Reduced warranty costs

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