

An introduction to the ~~Additive~~ Direct Digital Manufacturing (DDM) Value Chain

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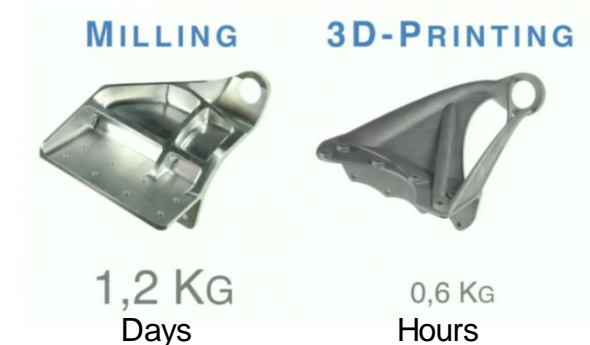
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Intro To ~~Additive~~ Direct Digital Manufacturing (DDM)

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Key Benefits of DDM Include:

- Reduced buy-to-fly ratios
- Reduced material cost
- Reduced part lead times
- No tooling needed
- Part consolidation (Unitization)
- Part weight reduction
- Improved thermal material properties
- Improved electrical material properties
- Replicating “out of production” parts



DDM Offers considerable value to current product value streams

Intro To ~~Additive~~ Direct Digital Manufacturing

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Additive Manufacturing = Rapid Manufacturing > Direct Digital Manufacturing (DDM)

- DDM is a value chain:
 - Employs advanced design methods and tools
 - Utilizes additive fabrication 3D printing technology
 - Exploits advanced inspection tools
- DDM is not a process revision
- DDM is a paradigm shift that fundamentally changes the manufacturing value chain and offers compelling business value
- The Society of Manufacturing Engineers (SME) has endorsed DDM

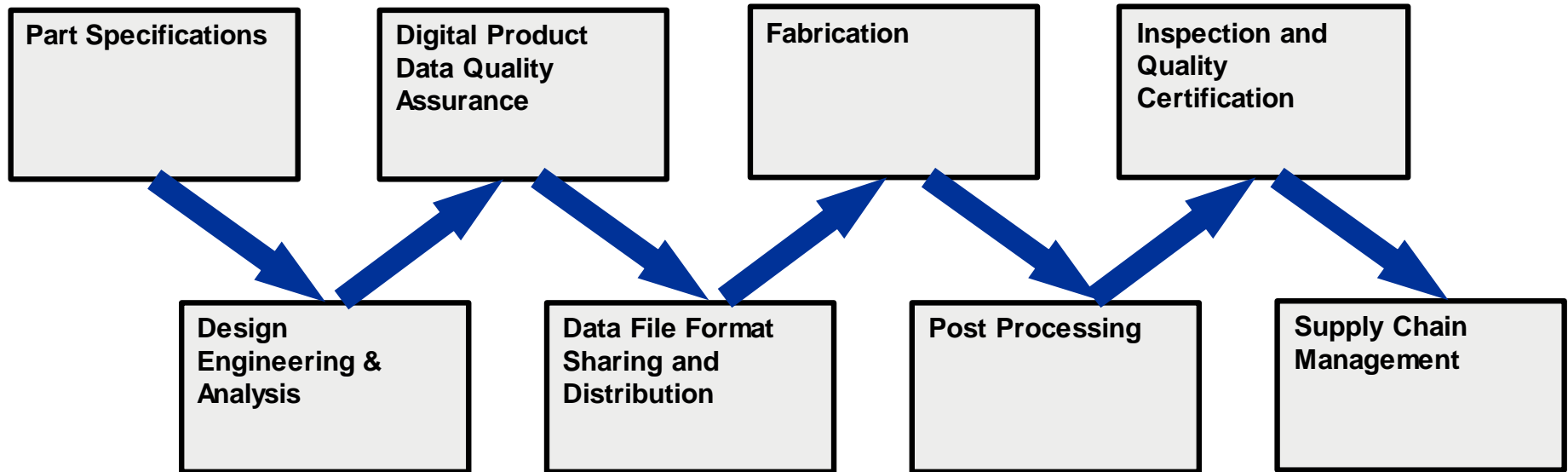
DDM is a data driven value chain

DDM is a revolution not an evolution

DDM Data Driven Value Chain

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Notional DDM Value Chain Stages

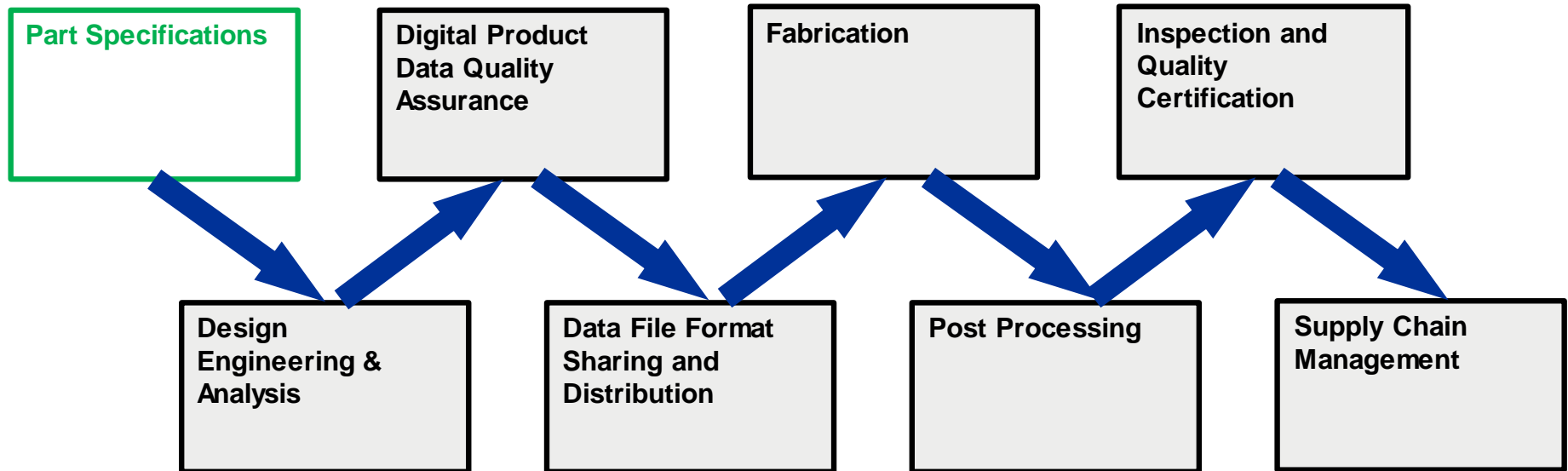


The DDM additive value chain is interdependent of its parts

DDM Data Driven Value Chain

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Notional DDM Value Chain Stages



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DDM Part Specifications

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What does the component need to do? (design for function)

Initial considerations prior to design:

- Allowables
- Dimensions
- Interfaces
- Loading
- Boundary Conditions
- Material Type
- Conductive/Non-Conductive
- Finish Type
- Environment

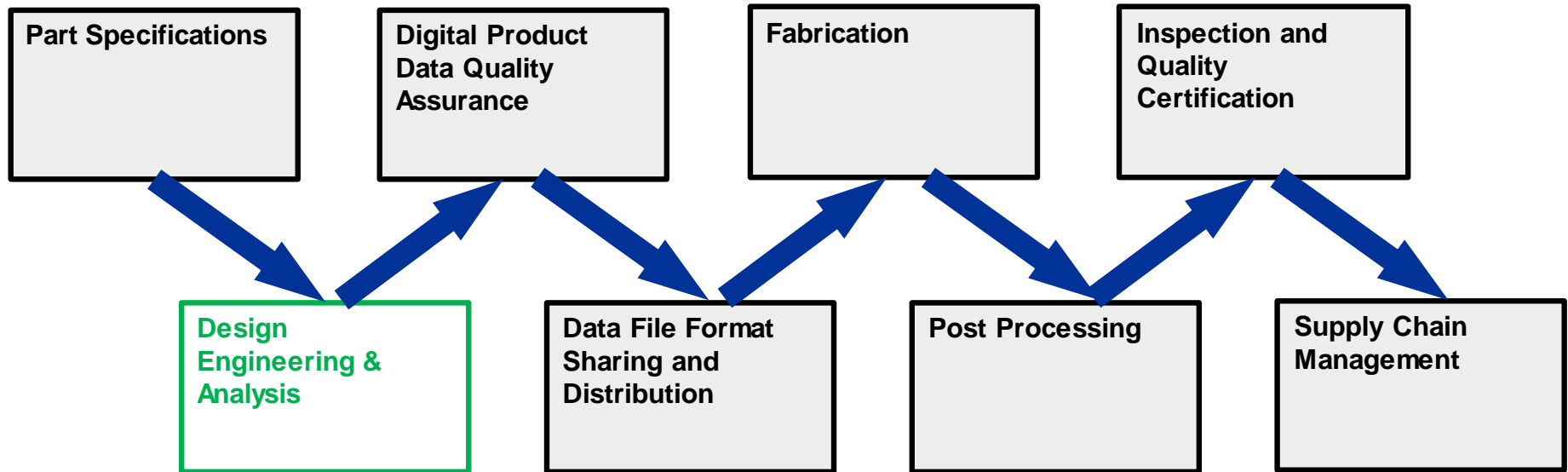
Print To Part!

DDM design considerations begin with design for function

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Notional DDM Value Chain Stages



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DDM Design Engineering and Analysis

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Design For DDM Exploits the Fabrication Capabilities of 3D Printing

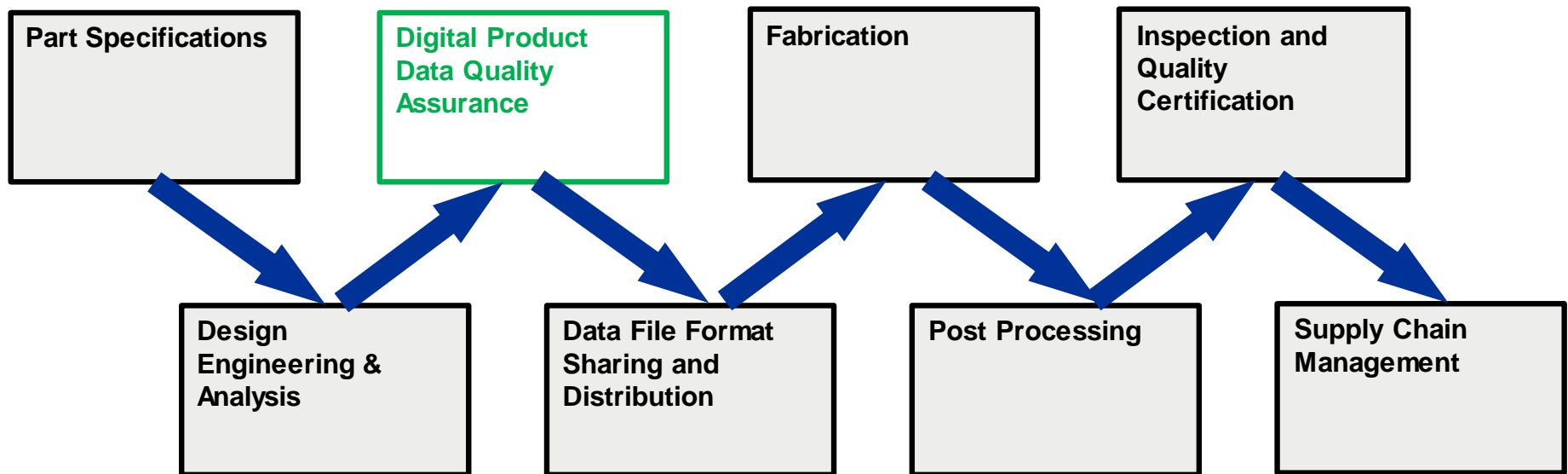
- **System Level Design**
 - **Consideration of other characteristics**
 - (i.e., mounting brackets, wire clips, supporting structure, attachment points for other items, etc.)
- **Structures in Nature (organic)**
 - Organic structures excellent examples of max strength min mass
 - Optimized designs from trial and error of loading conditions
- **Multi-Functional Design**
 - Combined functions into single component
 - Mount structure + heat exchanger
- **Component Consolidation (Unitization)**
 - Integration of multiple components to monolithic component
- **Internal Channels**
 - Fabrication of internal channels into component
- **Square Channels/Holes**
 - Hole geometry can be shaped in a way that optimizes the design

DDM unlocks design constraints based on producability

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Digital Product Data Quality Assurance

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Digital Product Data Quality is Essential To The DDM VS

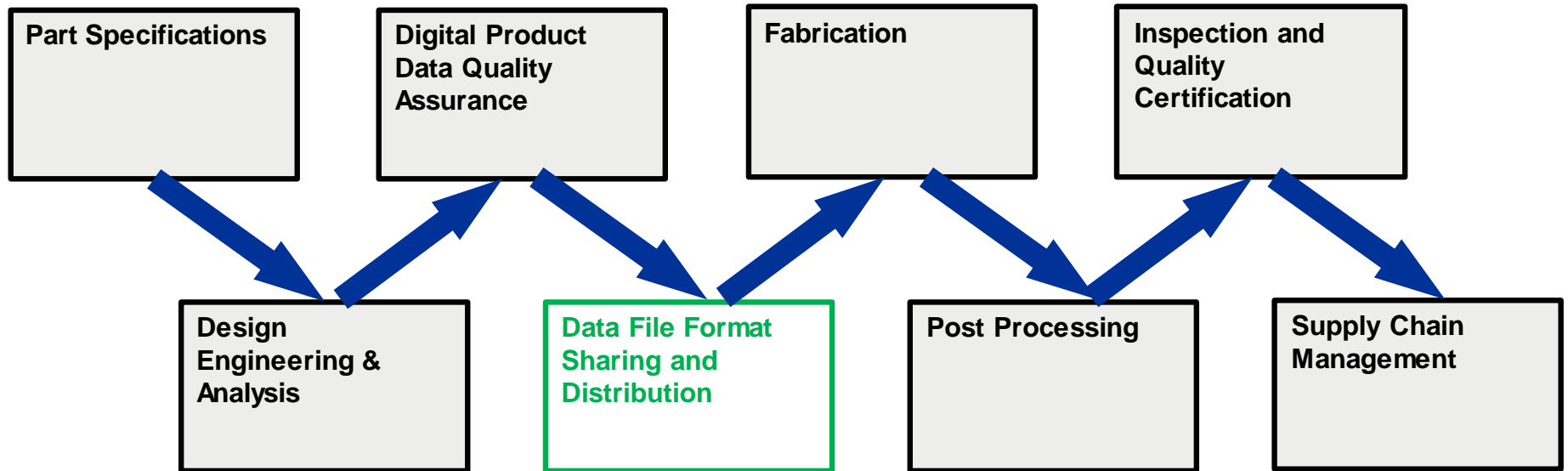
- CAD Model Geometry Must Use 3D Closed Solids
- Component Assemblies Must Be Merged To Solid
- CAD Validation & Verification Check
 - Manifold Geometry
 - Topology
- File Format Conversion Verification and Validation
 - Conversion errors
- Machine Code Verification and Validation
 - Sliced Data
 - G-Code
- ISO Standards Compliant Data Specifications
 - STL – ASCII File
 - AMF - XML
 - 3MF - XML

DDM requires robust data specification compliance

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DDM Data File Format Sharing and Distribution

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DDM Product Authority Must Be Managed As High Value Capital Assets

- **STL – Legacy File Spec. for 3D printing (tessellated)**
 - Adopted in the eighties
 - Inadequate for continued use
- **AMF – Contemporary ISO/ASTM File Spec.**
 - XML structure
 - Uses advanced optimized tessellation (curved triangles)
 - Supports advanced attributes and metadata with DRM
- **3MF**
 - Industry consortium
 - Cloud deployable
 - Advanced print descriptions
 - Supports DRM
- **Digital Rights Management**
 - Loss of authority data = IP escape
 - Strictly controlled distribution is key

DDM file sharing and distribution exposes IP

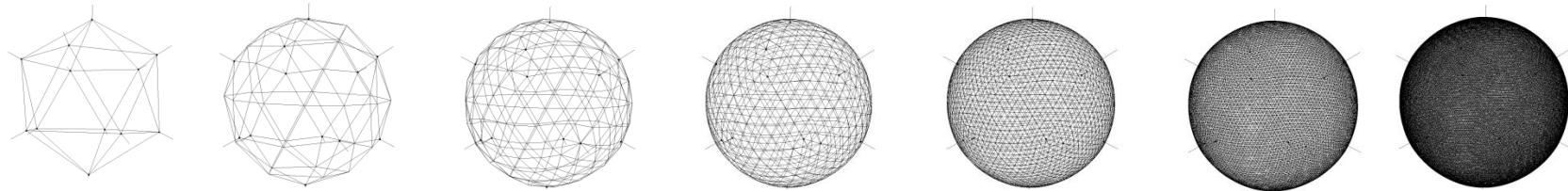
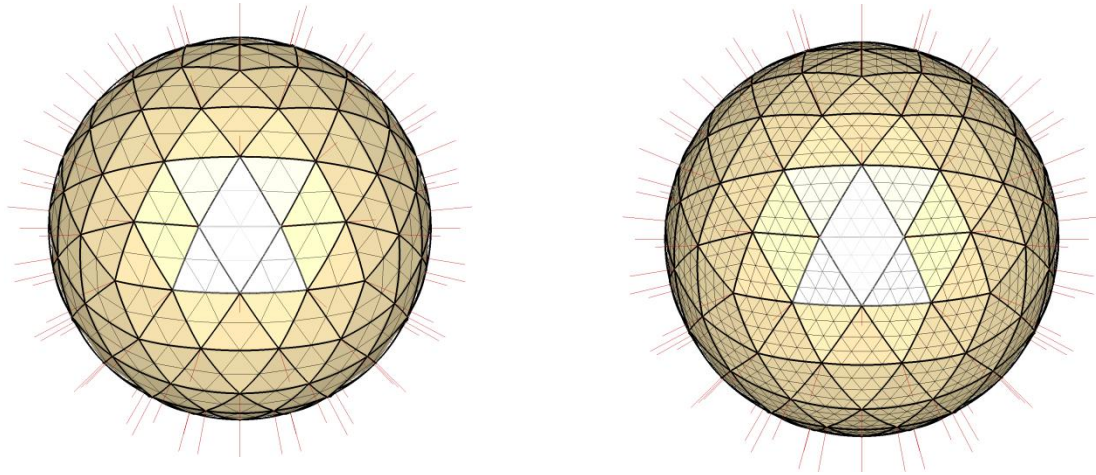
DDM File Sharing

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AMF Sub-D Surface Geometry

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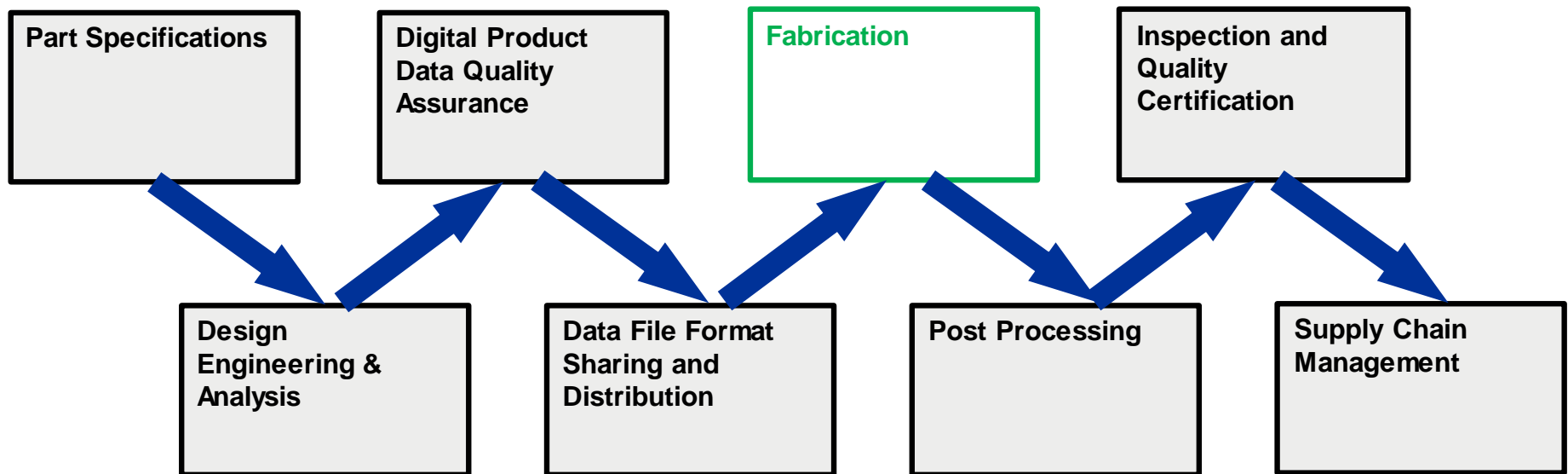


Sub-Division N

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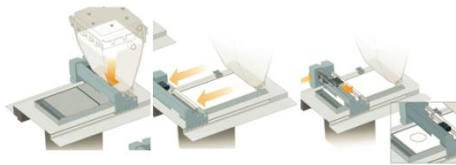


The DDM additive value chain is interdependent of its parts

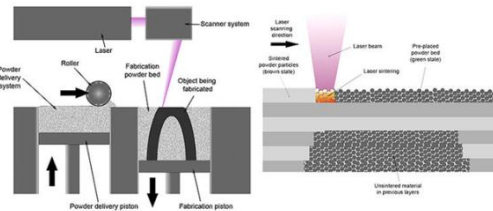
DDM Fabrication Process (3D Printing)

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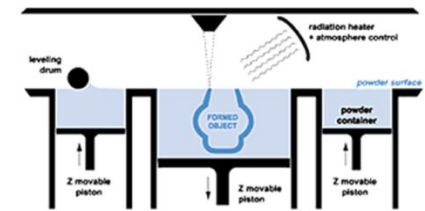
3-Dimensional Printing
(powder based, polymers and ceramics)



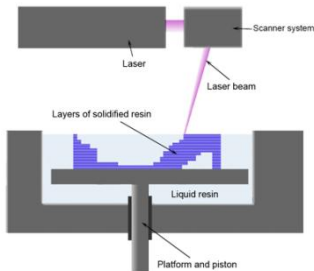
Selective Laser Sintering
(powder based, thermoplastics and composites)



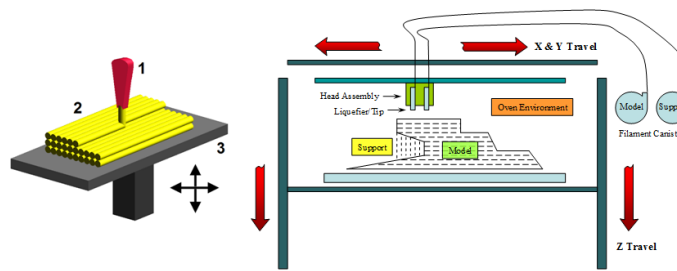
Direct Metal Laser Sintering
(powder based, steels and titanium)



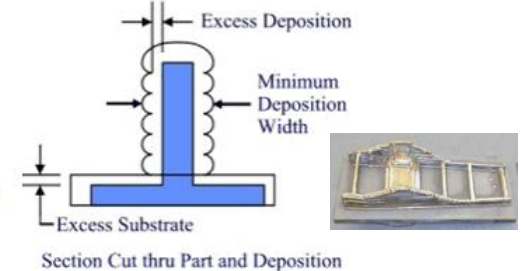
Stereolithography
(resin based, photosensitive polymers)



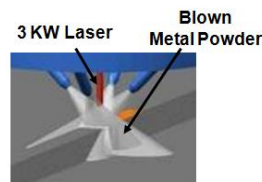
Fused Deposition Modeling
(filament based, amorphous thermoplastics)



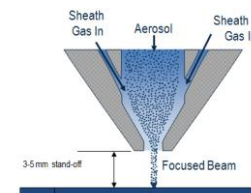
Laser Additive Manufacturing
(filament based, steels and titanium)



Laser Freeform Manufacturing
(powder based, steels, invar and titanium)



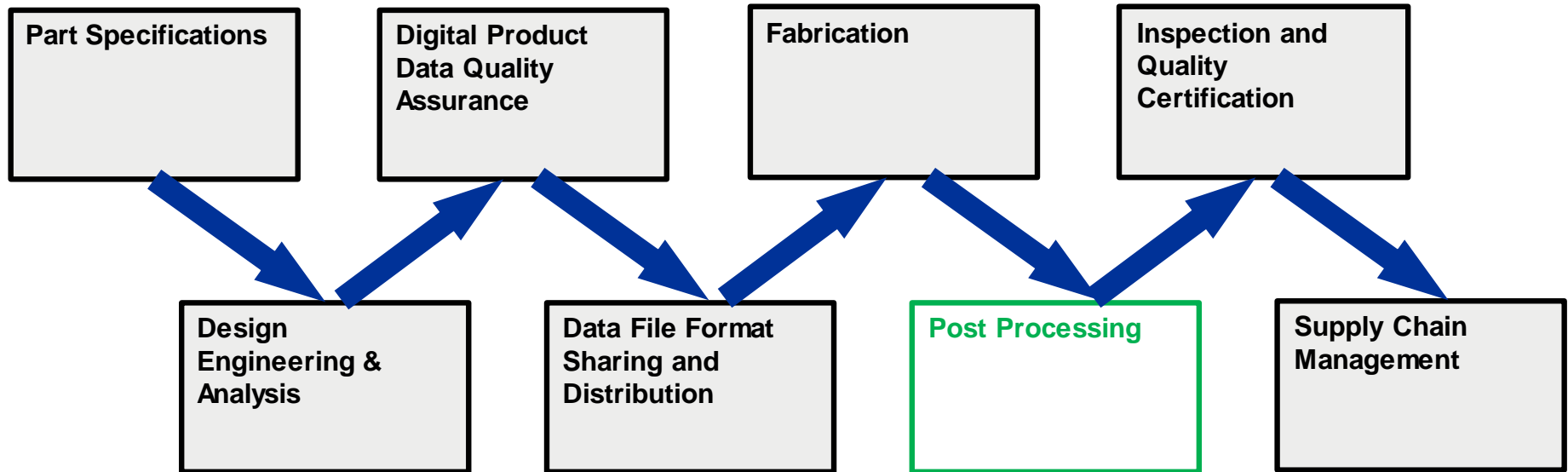
Direct Write Electronics
(deposition of conductive materials)



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DDM Fab Post Processing

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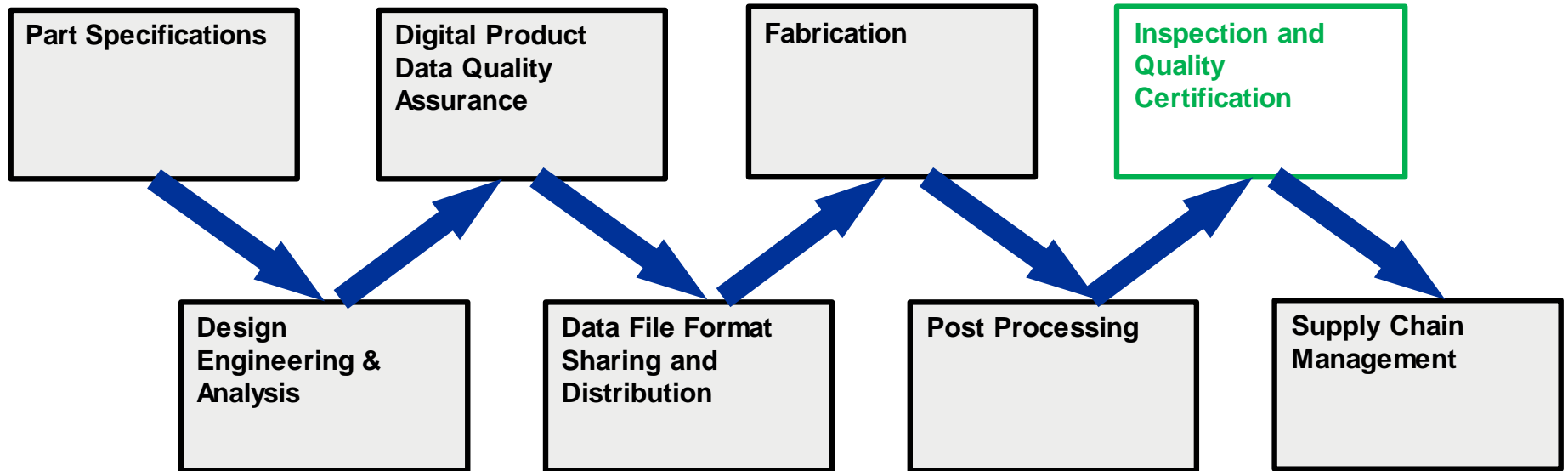
- **De-burring**
- **Support Structure Removal**
- **HIP**
 - Hot Isostatic Pressing
- **Annealing**
 - Controlled heat
- **Stress Relief**
 - Controlled cooling
- **Surface Finishing**
 - Machining, tumbling, shot peening, sanding, sand blasting, etc
- **Coatings**
 - Painting, fillers, epoxy or urethane sealants, and metallic plating

DDM does requires post processing touch labor

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Quality Inspection & Certification

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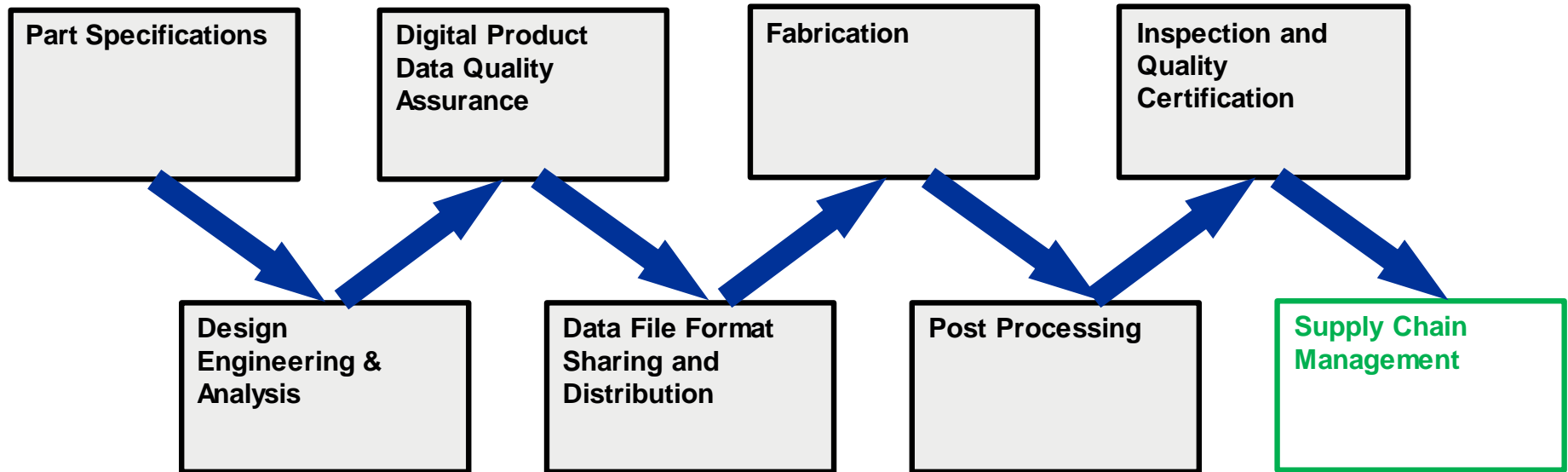
- **Optical Inspection**
 - 2D white light photogrammetry
 - Time of flight laser scanner
- **Radiologic Inspection**
 - X-Ray
 - MRI
 - Neutron Backscatter
- **CT Inspection**
 - Internal channels and voids
- **Other Inspection methods (Quality Record)**
 - Build process slice recording
 - Computer Imaging
 - Thermal Imaging

DDM will challenge the limits of inspection capabilities

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DDM Supply Chain

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The DDM Supply Chain Disrupts Traditional Sourcing Models

- **In-House**
 - **Factories**
 - Large footprint – environmental, safety, material storage, energy
 - Scheduled maintenance – servicing, repairing, calibrating
 - High quality production parts – Quality and certification inspection
 - **Laboratories**
 - Short run parts
 - Prototypes – form, fit, function
 - Manufacturing aids – safety, tools, covers, etc.
 - **Desktop**
 - On-demand printing
 - Tactile iterative component design
 - **Printer Farms**
- **External Suppliers**
 - **Specialized Fabricators**
 - Metals
 - Polymers
 - Large Size Printing
 - **Large Scale Printer Farms**
 - Cloud Based Dispatching

DDM supply chain optimized for automation and efficiency

Serialization & Anti Counterfeiting

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Lost IP results in lost revenue, counterfeit parts and safety risks.

Serializing Parts:

- Etched
- Coating
- Paint
- Embedded
- Micro Markers
- Nano-Doping
- Trace Element Nuclear

Digital Rights Management

- Higher fidelity of authority part information is shared
- Security of 3rd Party Suppliers Unknown

DDM IP protection is key to success

Conclusion

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Direct Digital Manufacturing value stream planning must be done holistically with all functions being interdependent to each other. Equal and balanced development of the DDM constituent functions offers maximum value to production. When mature, the DDM value stream will supplant most other manufacturing norms.