Georgia Tech

September 25, 2019

DragonInnovation

Prototype to Production

Capstone Design

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/dragoninnovation

Learning Objectives

1. Understand the journey from a prototype to a saleable unit
2. Prototyping techniques
3. The Manufacturing Triangle: Cost, quality, and schedule

The Journey to Dragon

MIT

Walt Disney Imagineering

Hasbro

iRobot

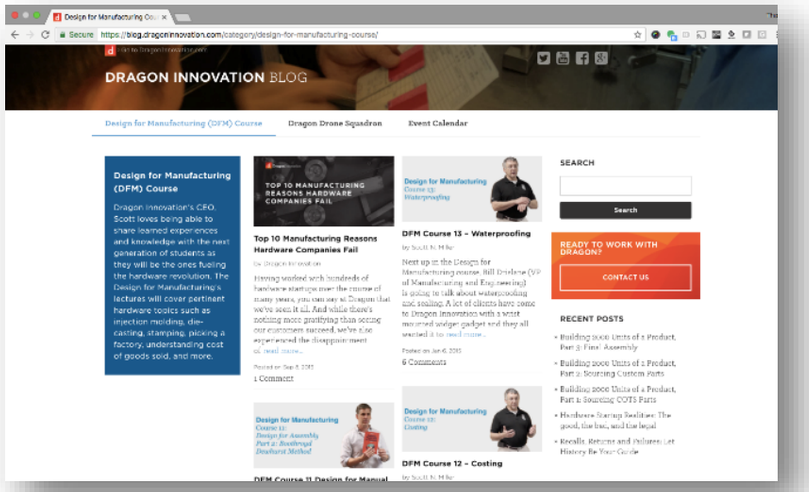
Dragon Innovation

AVNET
Reach Further™

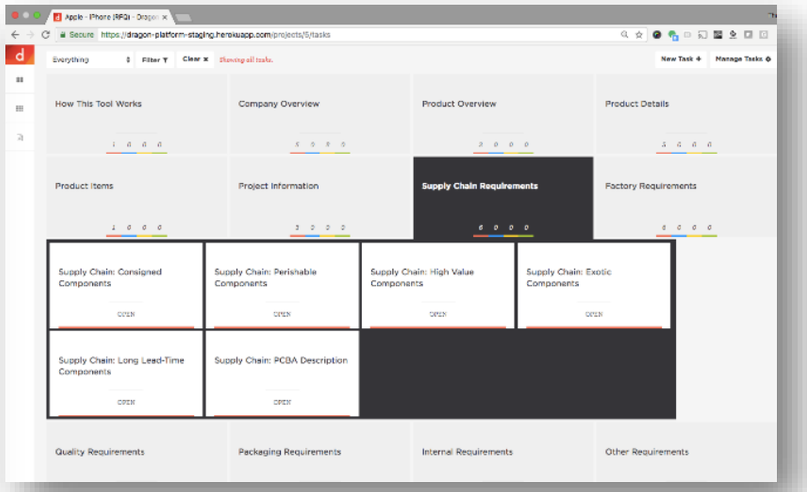
BOLT

Dragon's Approach

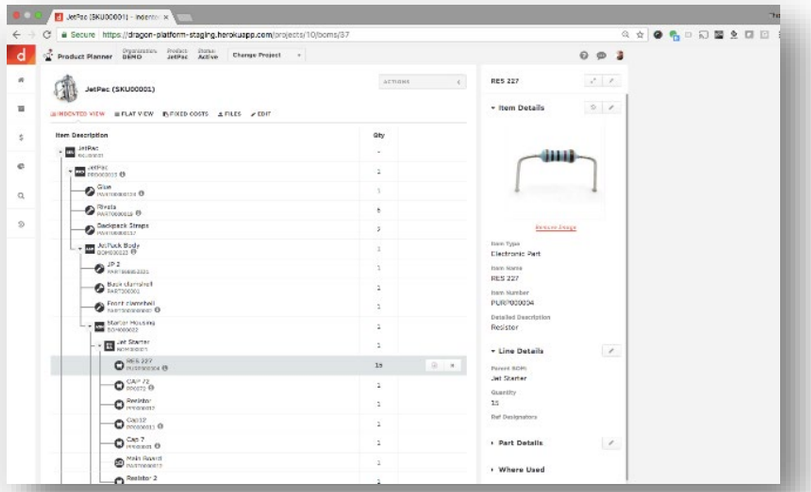
- Provide transparency and education on how the process works
- Reduce costs and increase efficiency via a manufacturing platform
- Simplify communications and bridge gaps
- Create high value connections throughout the ecosystem



DFM Videos on blog



Factory RFQ App



Factory Selector

Some of our Customers

“Dragon helped us take our crowdfunding success and translate it into shipping more than 100,000 Pebbles in just over a year.”

ERIC MIGICOVSKY
FOUNDER of PEBBLE

“Dragon’s depth of institutional knowledge about manufacturing accelerated our planning efforts.”

STEVE CHAMBERS
CEO of JIBO

“We've been working with Dragon from the moment we had a prototype and wanted to begin the manufacturing process”

JONATHAN FRANKEL
FOUNDER & CEO of NUCLEUS

MakerBot
Shark NINJA
muzik
ring
PillPack
vinli
JUICERO
scout
AKC
Andromium
sphero
JUNE
orbotix
PerkinElmer
CyPhy
canary
LIFX
formlabs
IDEO
Hobie
HAMMERHEAD
MOMENT
Wilson
THALMICLABS
kinsa
Petnet
CORAVIN

AND MANY MORE

Why is Manufacturing Hard?

Communication is a Big Deal

Bi-Directional Information Flow

Design Product

Send Data to CM

Build Tooling

Mold Parts

Assemble Product

Inspect & Ship

Manufacturing is Continually Evolving

- New Technologies
  New Locations
- New Tariffs

There are many “Unknown Unknows”

- COGS, tooling and manufacturing costs
- Lead times
- Permanence of Quality
- Iteration cycles
- DFMA
- Factory Selection and Management
- Team Scalability
- Schedule & Project Management
- Specialized skills (ME / EE / SW/ Q / SC / Logs)
- Retail Channel

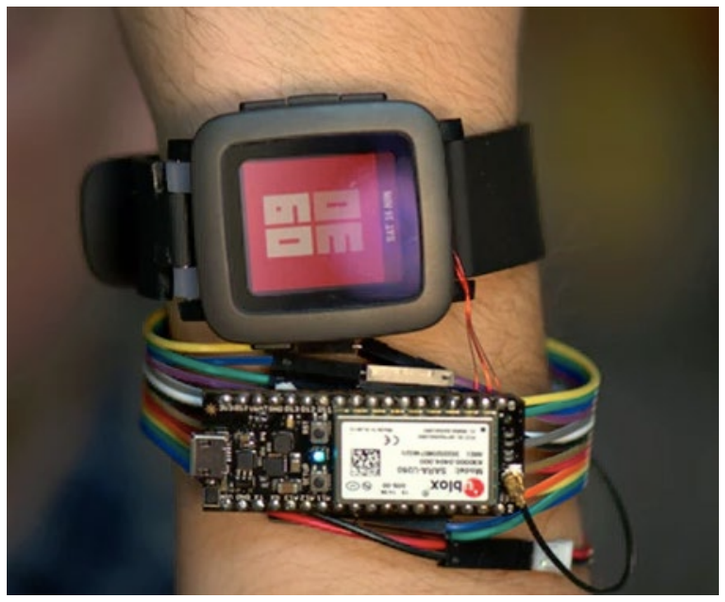
These early decisions can cast long shadows

What Do You Have To Do To Get….

FROM

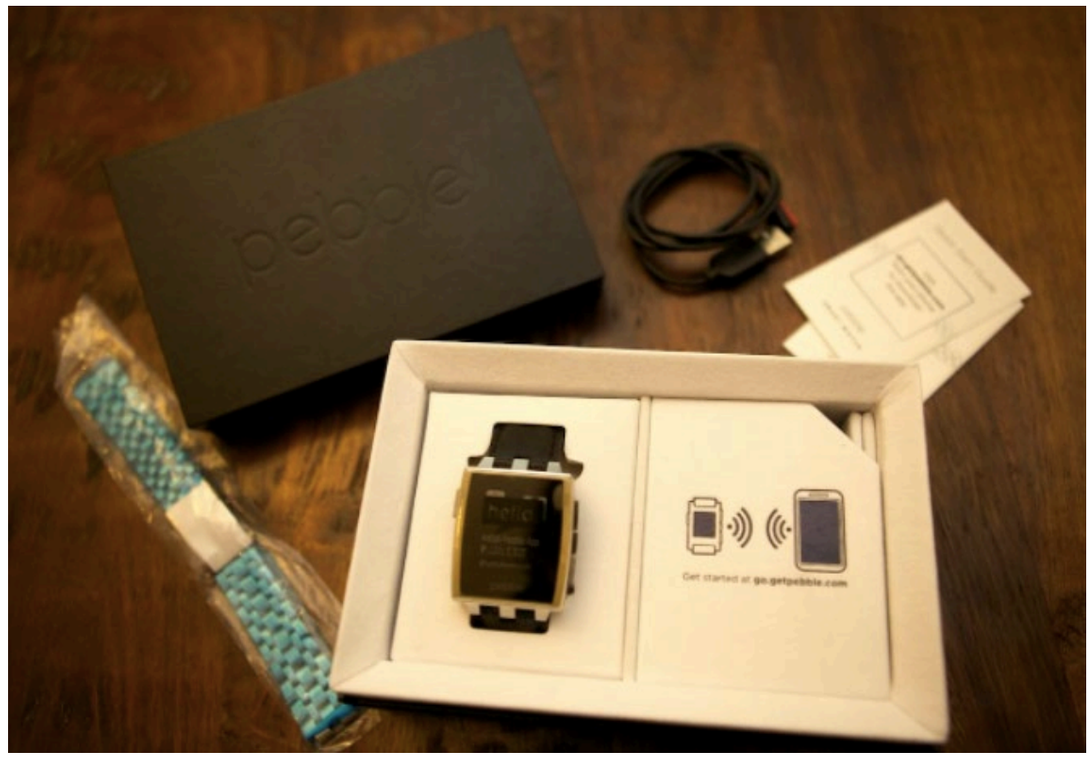
TO

Works-Like

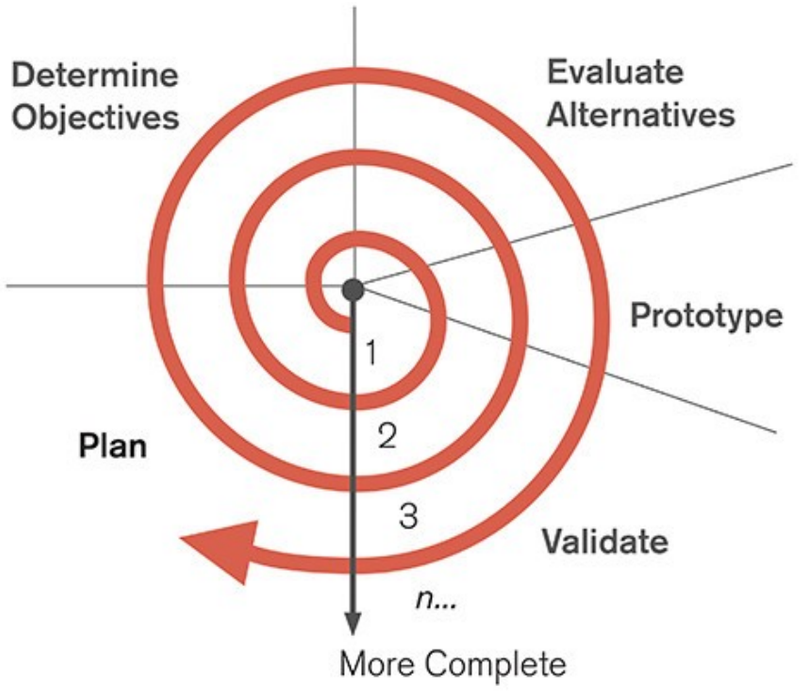


Looks-Like

Saleable product



New Product Introduction (NPI) Process

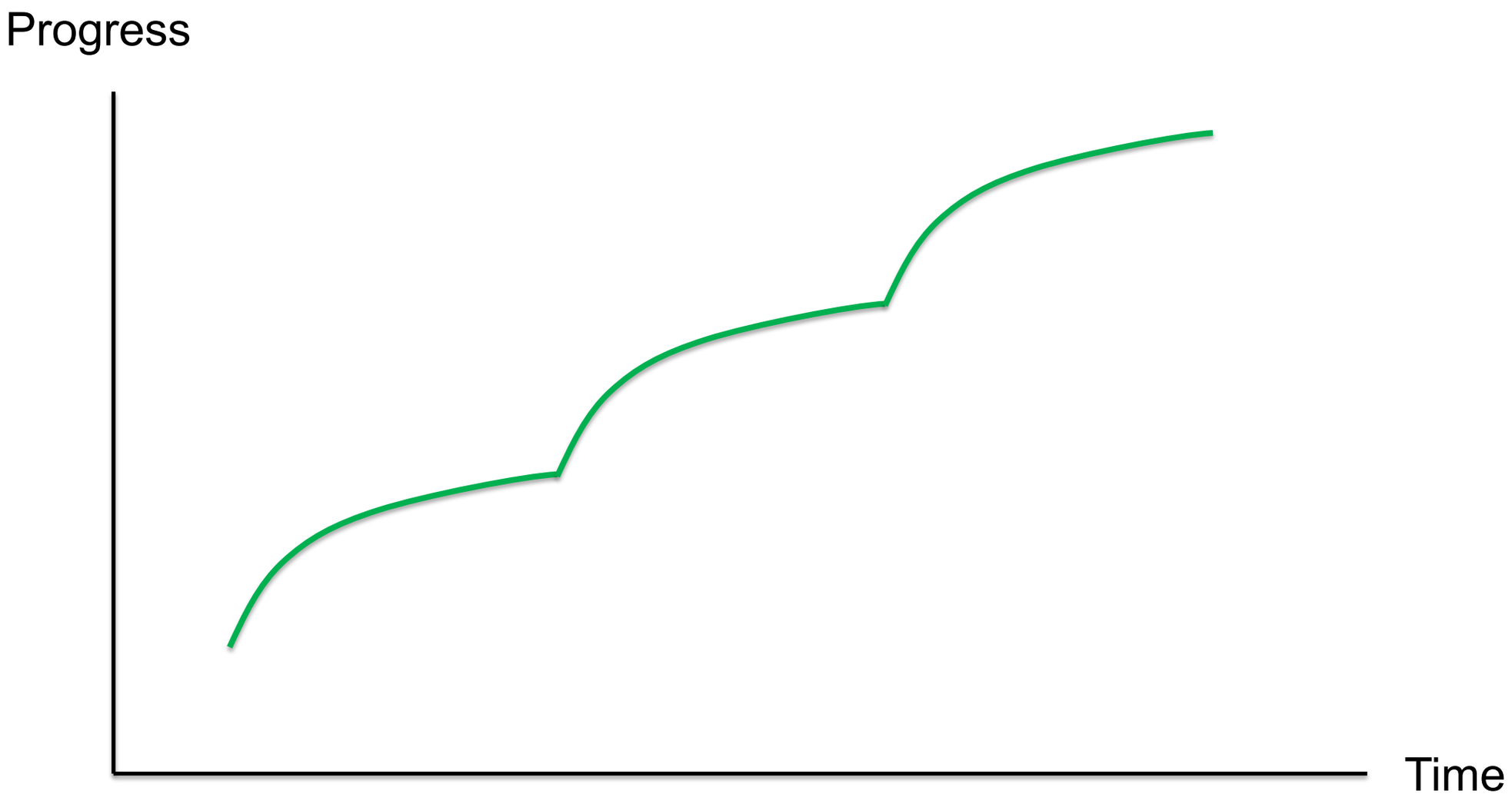


RF	DF	Toolin	FS	EP	FE	P	PS
Q	M	g		1	P	P	

Agile: Figure out what to build

Stage Gate: Know what to build

Sometimes you need to “Build it to Build it”

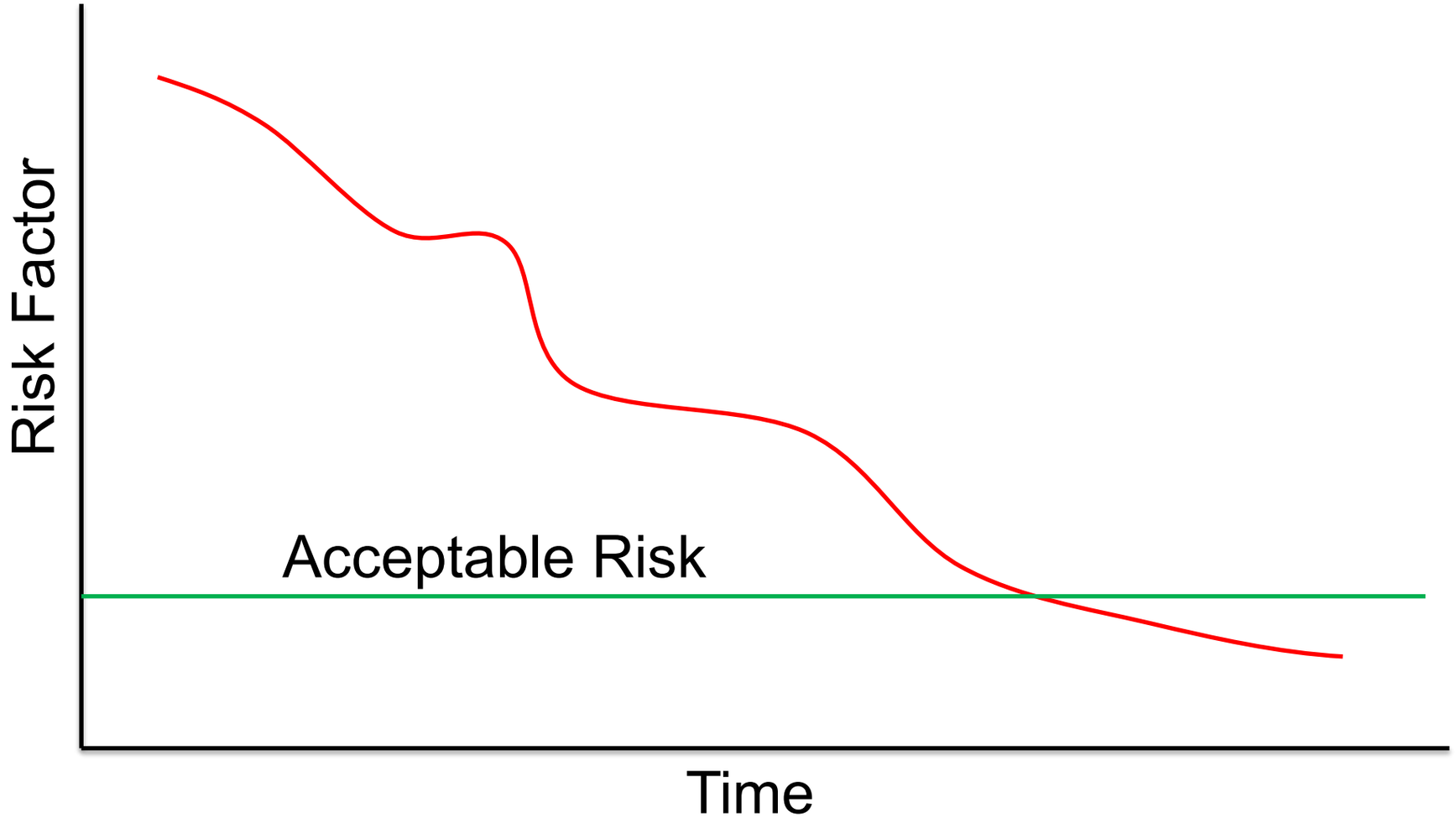


But don’t be lazy – use engineering vs. guess work when appropriate.

List, Prioritize & Track Risk

Risk	Likelihood	Severity	Risk Factor
Item 1	5	5	25
Item 2	2	8	16
Item 3	1	5	5

Total: 46



Create a Realistic Schedule

IDEA → A B

PROTO → C D E F G H I J K L M N O P Q

CROWDFUND → R S T U V

MANUFACTURE → W X Y

DELIVER → Z

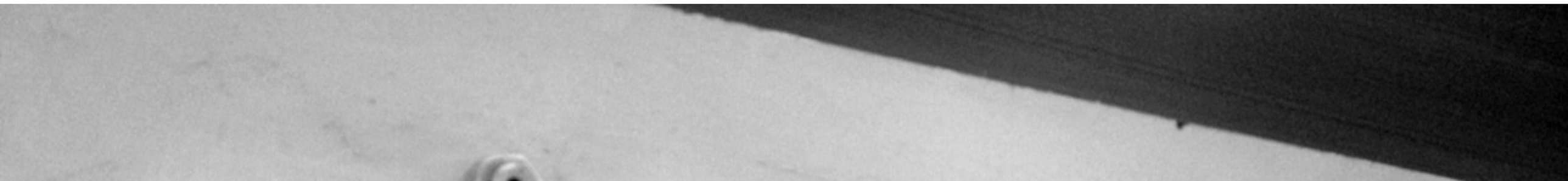
IDEA → A B

PROTO → C D E F

CROWDFUND → G H I J

MANUFACTURE → K L M N O P Q R S T U V W

DELIVER → X Y Z



How the Process Works from 1 to 1M

If you're not Apple

New HW starts here

Apple starts here

	1	10	100	1K	10K	100K	1M	10M
Mech	Hand	3D	CNC Rubber Mold	ProtoLab CNC	Tool(1)		Tool(N)	
EE/SW	Arduino/PI			Pre-Certified Module	Chip w/ Cert		ASIC	
Prod	Local Shop		Need to find & Vet & Match	Domestic CM	PRC-CM	Existing Relationship	Owned Factory	OEM
COGS	Optimized for speed & Ease of development						Optimized for cost & stability	
Quality Plan	Primitive or Absent						Mature	
Schedule	Blind Spots						Mature	
Tools/BOM	Excel						Enterprise	

Roomba Prototypes
Even Simple Things are Harder than they Appear

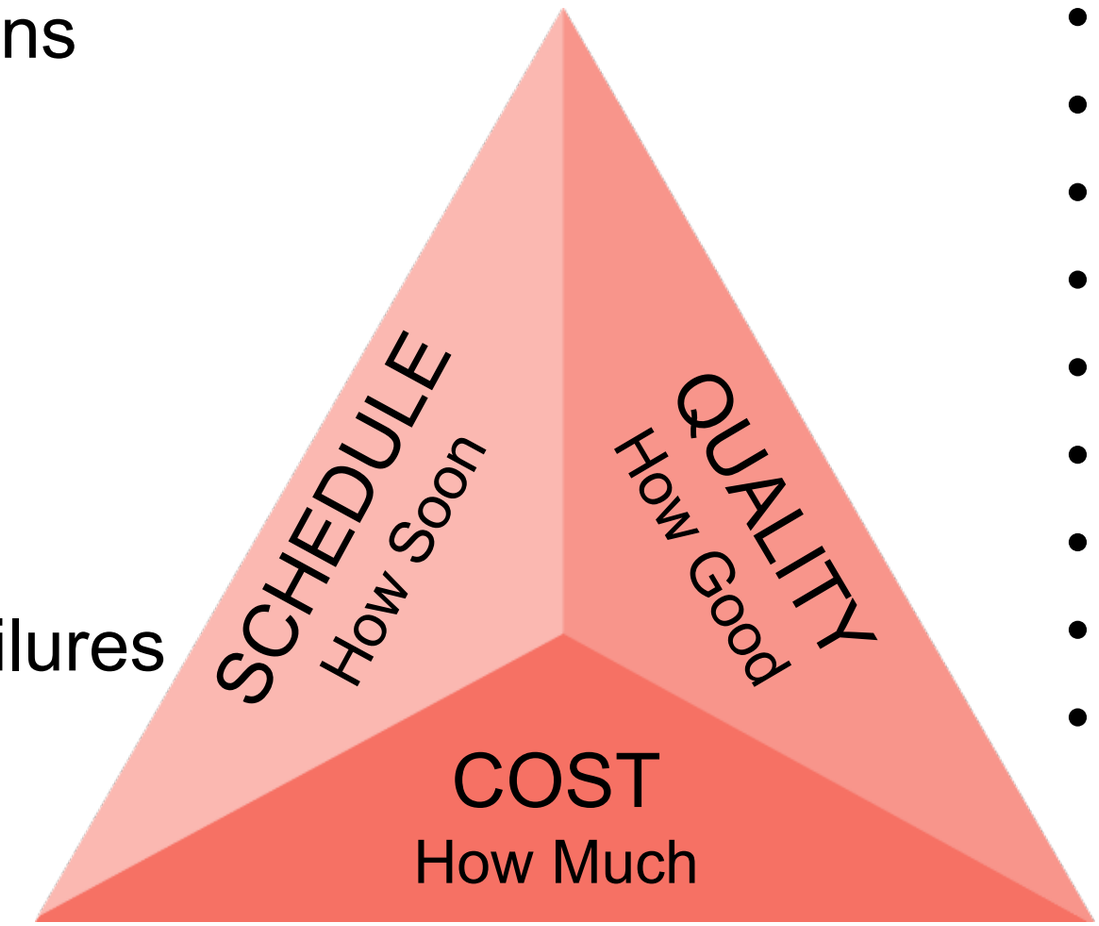
- Birth Story
- Sheet Metal
- Basic Dimensions
- Constraints
- Cleaning Head
- Vacuum
- Handle
- Side Brush

ADDITIONAL SLIDES NOT COVERED IN LECTURE

The Manufacturing Triangle

There are always tradeoffs

- Design iterations
- Technology development
- Tooling
- Certification
- Testing
- Clinical trails
- Late design failures



- Validate & Verify
- Risk reduction
- Design for reliability
- Yields
- Safety
- Complaint rate
- Warranty returns
- Scrap rate
- Cost of maintenance

- Cost of Mfg
- Materials
- Tooling
- Support
- Sale price

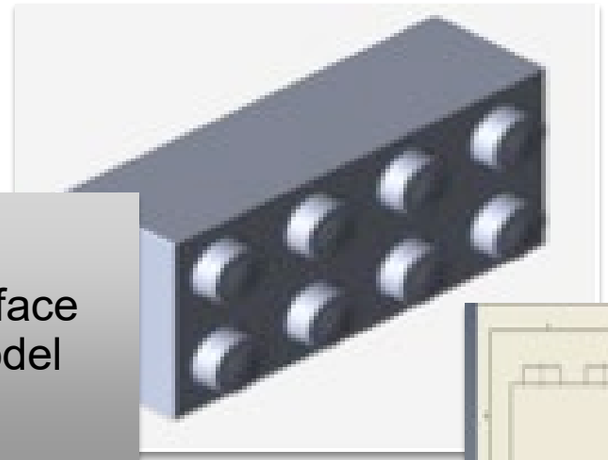
- NRE
- Testing
- Yields
- Cycle time
- Profit

Preparing for Manufacturing

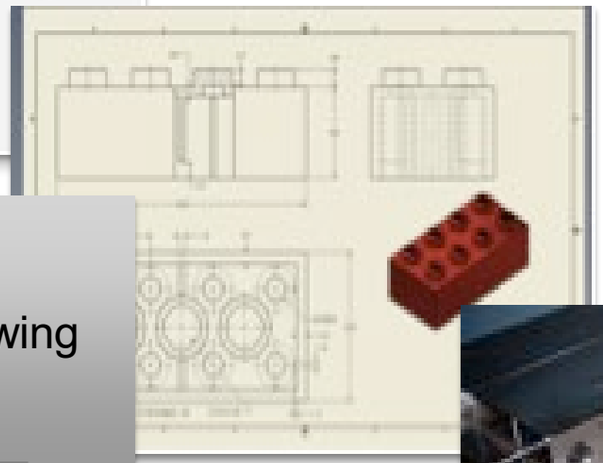
Your beautifully designed product can't be built	**Design for Mfg.**	• Design for assembly • Design for manufacturing • Design for testing	• Design for variation • Design for maintenance • Design for cost
Activities will take longer and you will need more iterations than you expect	**Schedule**	• Late changes • Quality failure • Certification delay • Mfg capacity	• Lead-Times • Part delay • Multiple DVTs
Your product won't look, feel or work like you want	**Quality Planning**	• Functional testing • Life testing • Certification • Durability testing • Transportation	• Safety • Board level tests • Shipment audits • V&V • FDA
You will spend way more than you budget before you get revenue	**Cash flow analysis**	• Forecasting • Tradeoff of MOQ and capital costs • Terms • Risk buys	• Long lead items • Spares and replacements • Cash flow • Payment terms

CAD to acceptable part more than just one step

Surface model



Drawing



Tooling

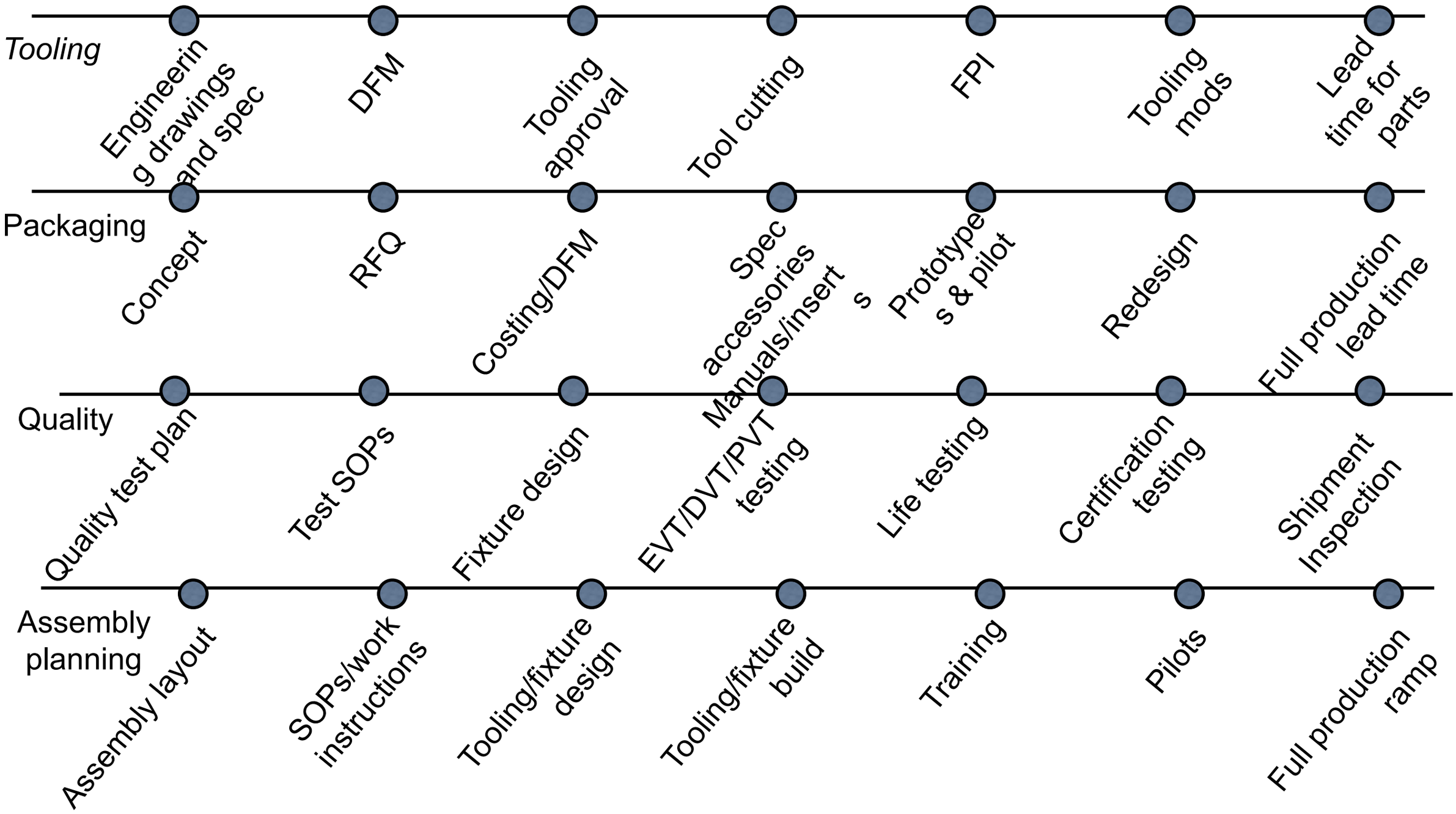
Process Design

Part

Measure

Your product is defined by more than just the CAD

Now what...



Other activities: Forecasting, cost modeling, supplier management, PCBA transition, engineering

SALE PRICE

Distribution Costs	Retail markup, factoring, 3PL logistics, etc..
Company gross profit	Apple ~50% Laptops ~25%
Warranty	5% of sales
Customs/Shipping	$0.3 to $2.00

COGS

Markup/Profit	9% - 25% of total
Labor	10% of total
Scrap	1.5-3% of Material
Packaging	$0.50-$5
Accessories	$0.50-$5

Materials

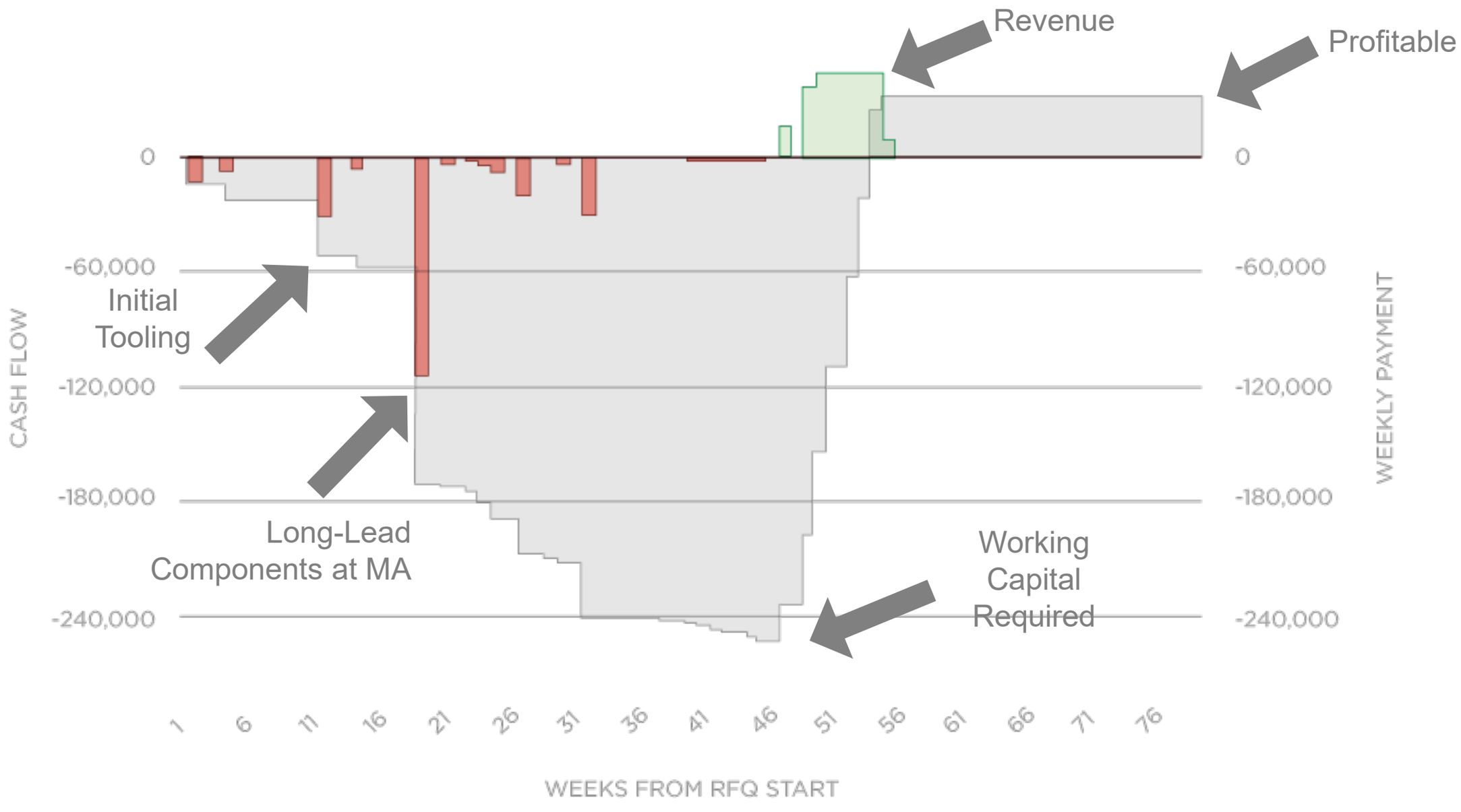
- Purchased OTS parts
- Custom parts
- PCBA and comp.
- Processing costs
- Raw material

NON RECURRING COSTS (NRC)

- Production line fixtures and test fixture
- Certifications
- Testing/testing equipment
- Pilot runs/samples
- Tooling
- Engineering

Working capital is critical

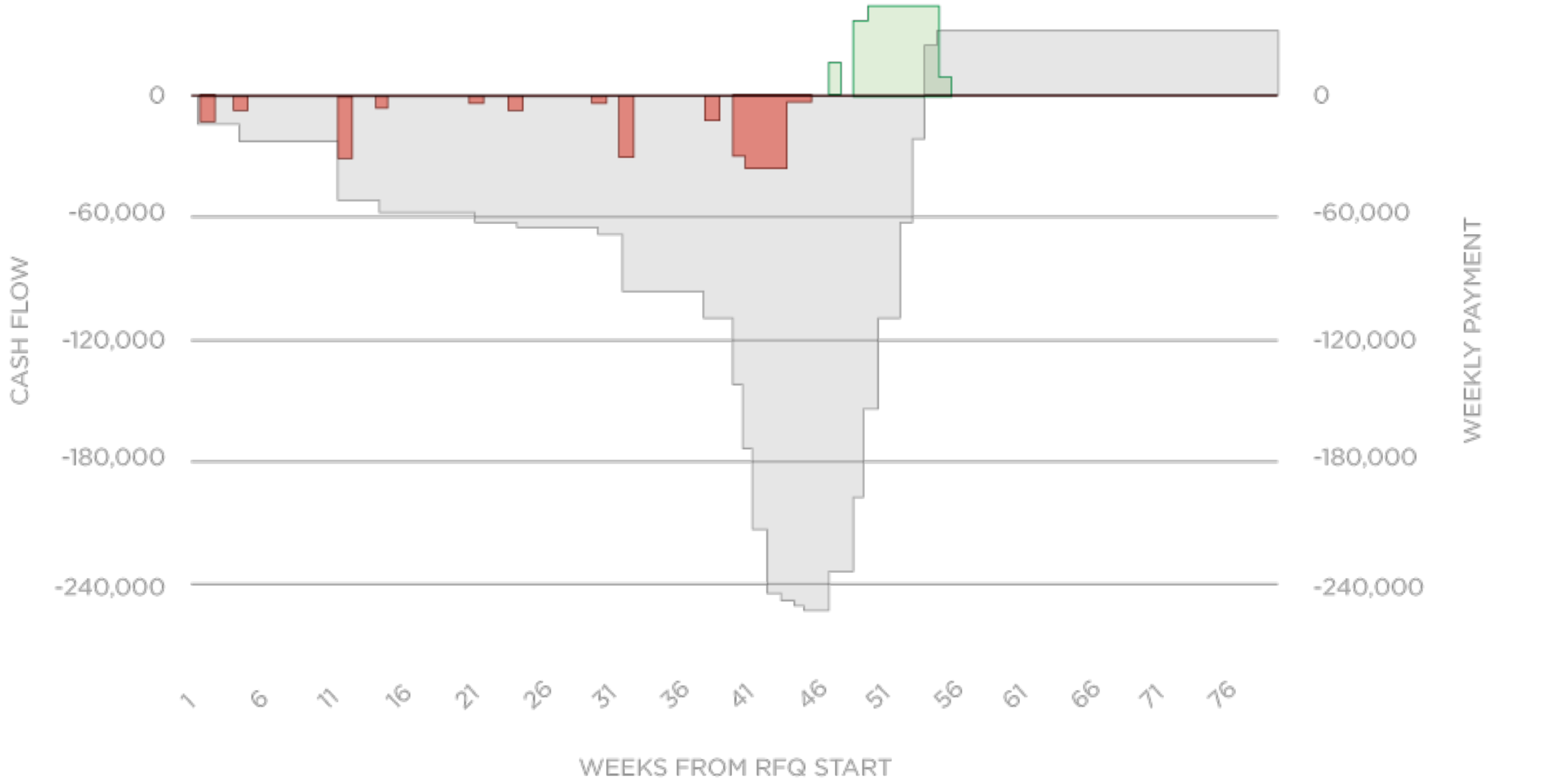
COMPONENT TERMS	CM TERMS	CUSTOMER TERMS	SHIPPING
100% at MAR	XF (Net 0)	Net 30 from Delivery	Sea (5 Weeks)



WORKING CAPITAL: $250k

Improve Component Payment Terms

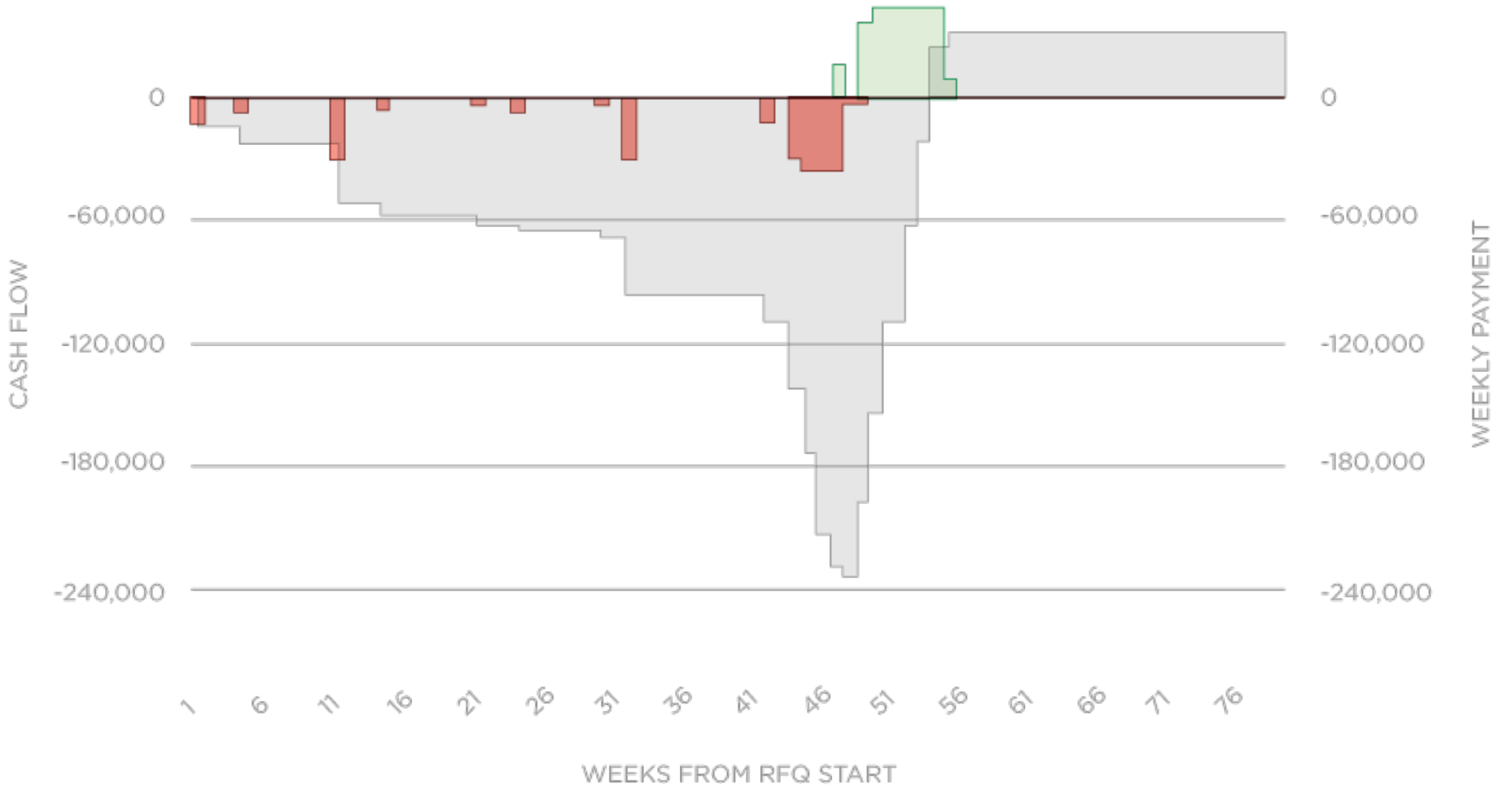
COMPONENT TERMS	CM TERMS	CUSTOMER TERMS	SHIPPING
0% at MAR	XF (Net 0)	Net 30 from Delivery	Sea (5 Weeks)



WORKING CAPITAL: $250k

Improve Factory Payment Terms

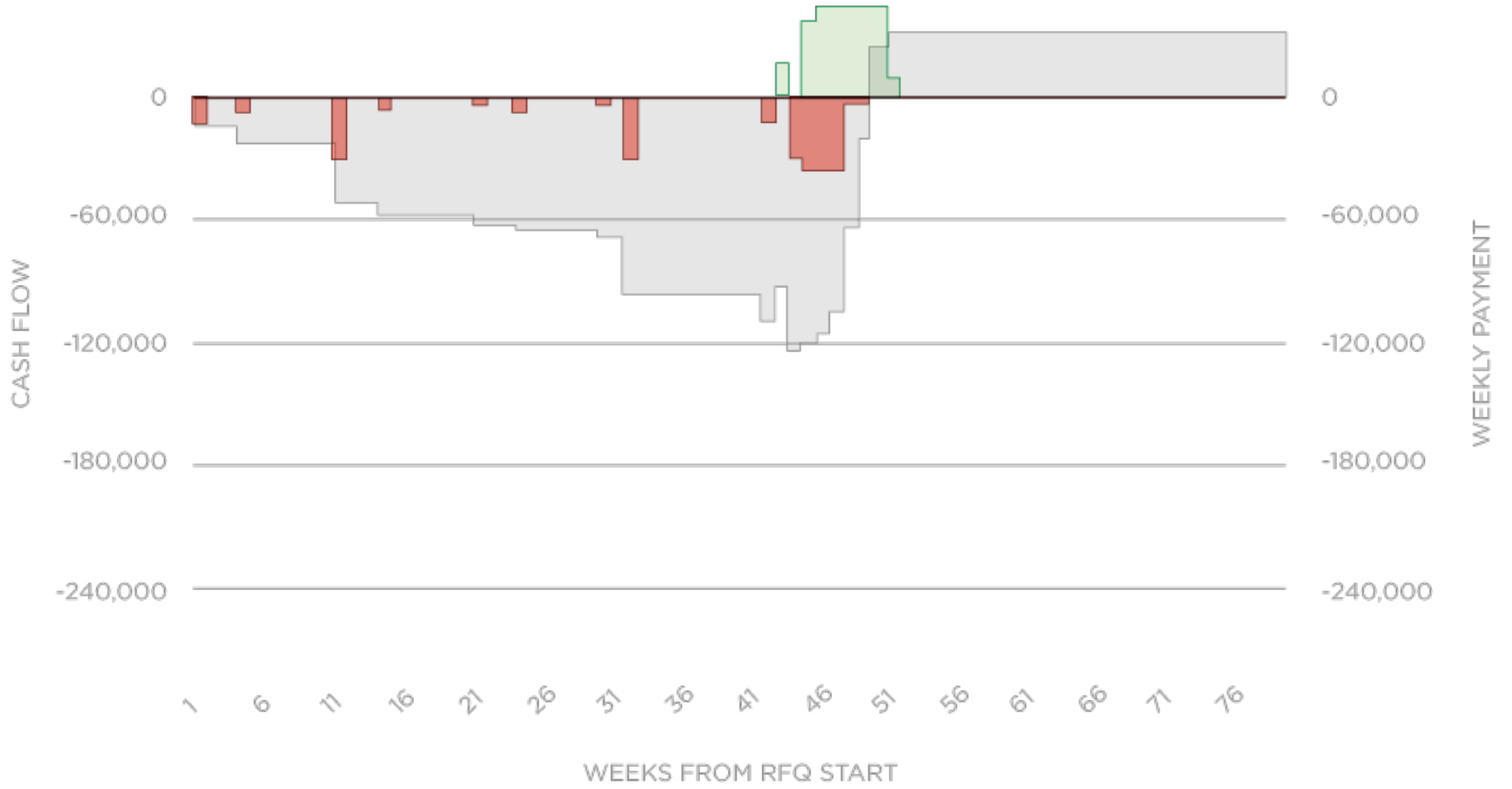
COMPONENT TERMS	CM TERMS	CUSTOMER TERMS	SHIPPING
0% at MAR	Net 30 Days	Net 30 from Delivery	Sea (5 Weeks)



WORKING CAPITAL: $232k

Improve Customer Payment Terms

COMPONENT TERMS	CM TERMS	CUSTOMER TERMS	SHIPPING
0% at MAR	Net 30 Days	On Delivery	Sea (5 Weeks)



WORKING CAPITAL: $123k

Kick off project
RFQ released
Client visit
RFQ negotiated
Select CM
MSA
Project kick-off
DFM activities
Pre-prod. Eng.
Tooling release
Tooling start
First shots
Tool mods complete
EP1/EVT
EP2/DVT1
FEP/DVT2
PP complete
Production start
Ex factory
arrives US
With customer
MSA Negotiations
Custom Comp.
Late Designs
Certification failure
Material Shortages

Getting a factory (12)	DFM (4)	Tooling (7)	EVT/DVT/PVT (17)	Prod/dist. (8)	Unexpected issues

46 weeks

+9

November 15

October 1

Dec. 5

Burn rate $50K/month
Missed market window
Invalidated your sales agreement

Quality: Think through what can go wrong now

Use/abuse	Production	Legal
Dropped	Miss-assembled	FDA
Vibrated	Failed parts	Shipment
Pulled	Programmed wrong	EMF
Pressed	Packaged wrong	Battery safety
Actuated	Wrong color	Overheating
Heated	Old parts	ITAR
Frozen	Testing equipment failures	Rohs
Rubbed	Strikes	California Prop 65
Handled	Obsolete parts	CE
Spilled coffee		UL
Used in new and unique ways		Recall risk

DFM/DFA FROM 10,000 FEET

Manufacturing costs

Total part cost including production costs, rework, shipping, support, excess raw materials.

-and-

Amortized NRC

DFM Reduces cost by:

Designing the part to be easier/ cheaper/ faster to make

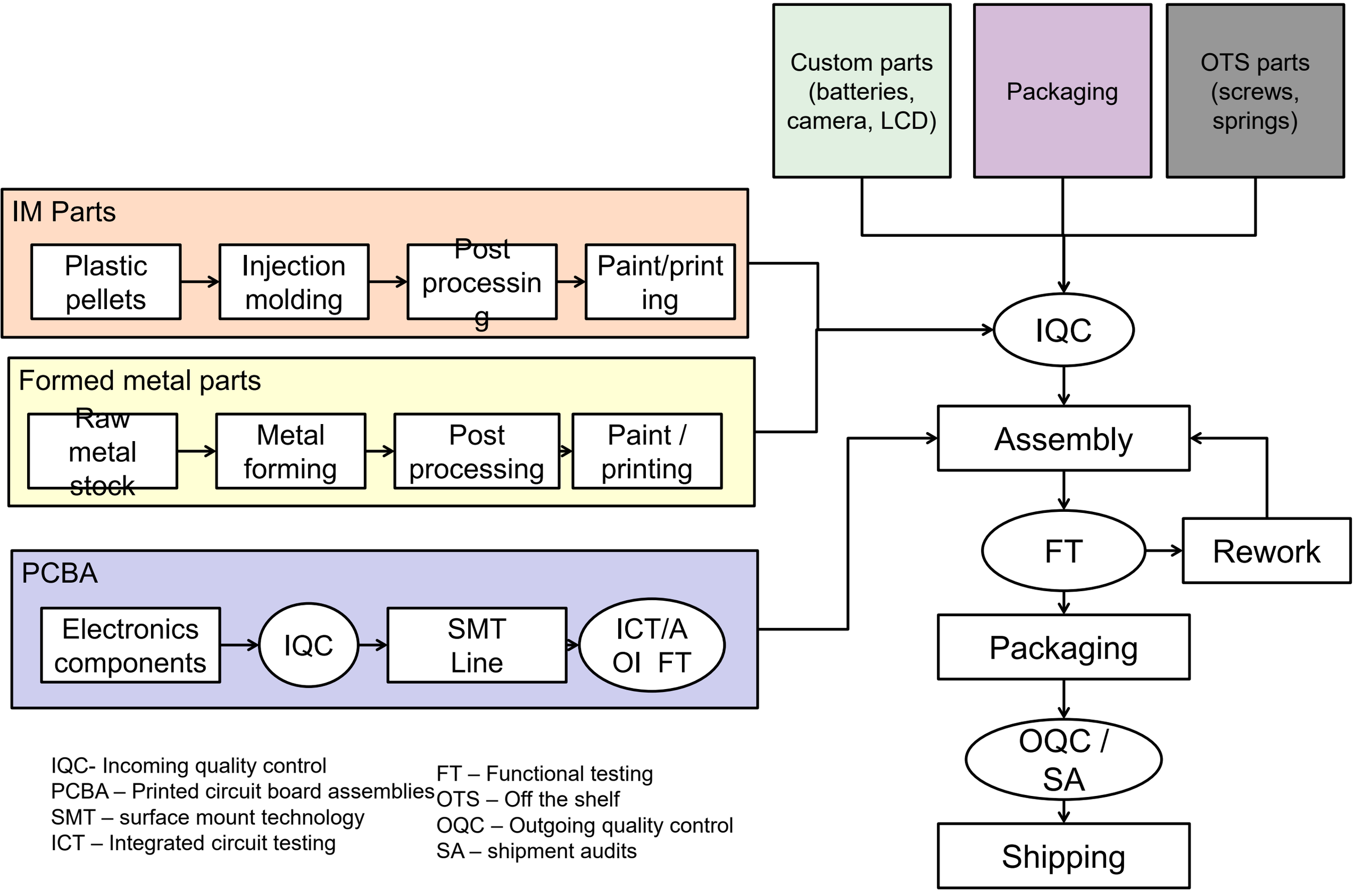
-and/or -

Reducing rework and scrap

-and/or –

Reduce redesigns and

TYPICAL PRODUCTION FOR CONSUMER PRODUCTS



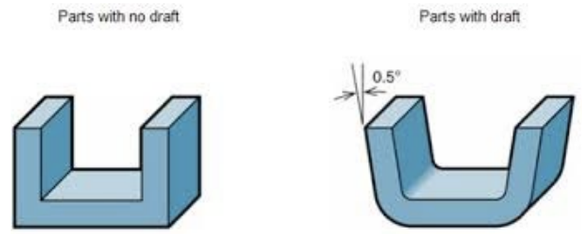
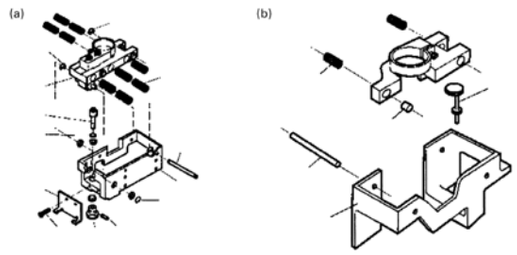
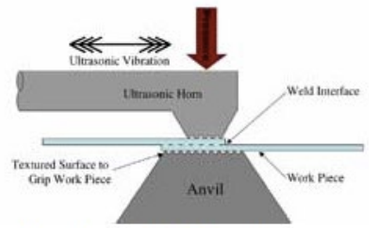
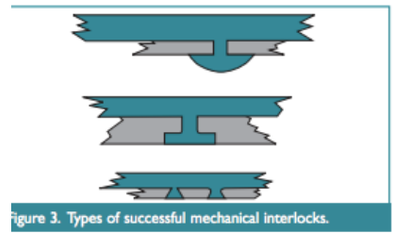
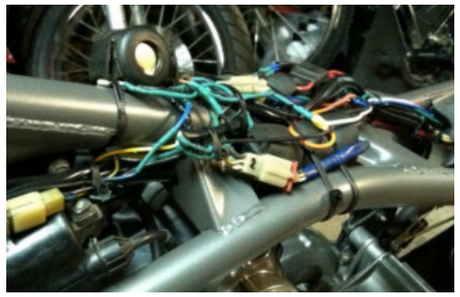
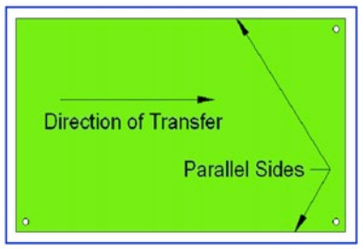
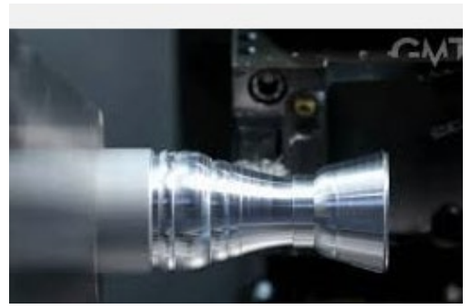
IQC- Incoming quality control
PCBA – Printed circuit board assemblies
SMT – surface mount technology
ICT – Integrated circuit testing

FT – Functional testing
OTS – Off the shelf
OQC – Outgoing quality control
SA – shipment audits

WHERE ARE THE LEVERAGE POINTS FOR DFM

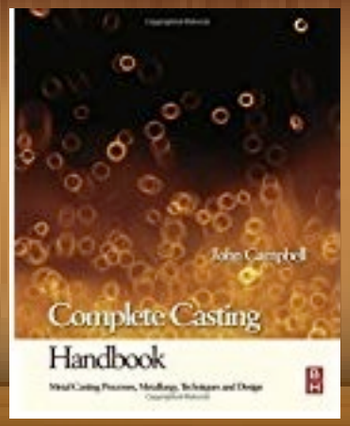
BOM	How to make the individual parts	• Packaging cost • Custom parts • Fabricated parts (cycle time, material usage) • PCBA costs
Assembly	Getting the parts together	• Manual • Automation • Error proofing
Testing	Is the product functioning?	• Test fixtures • Rework • Scrap rate • Cycles time
NRC	Fixed costs	• Tooling • Fixtures
Material handling	Ordering/managing/tracking materials	• Lead times • Inventory management • Tracking • Shipping
Repair	Fixing what is broken	• Disassembly • Cost to fix • Spares

EXAMPLES OF PROCESS DFM RULES

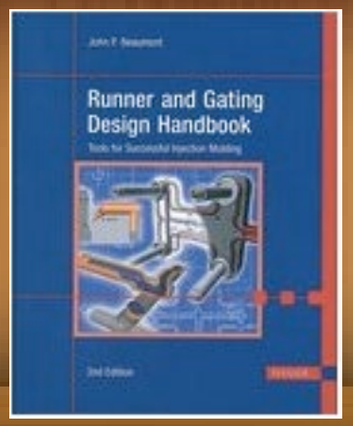
Metal bending  Minimum bend radius	**Casting**  Even wall thicknesses	**Injection molding**  Draft angles
Assembly  Minimize part count	Ultrasonic  Control material thickness and process settings	Over-molding  Use interlock if possible
Cable harness  Don’t route cables over sharp edges	Printed circuit boards  Boards need parallel sides. Use breakaway features if needed	CNC lathe  Set cut depth to avoid chatter

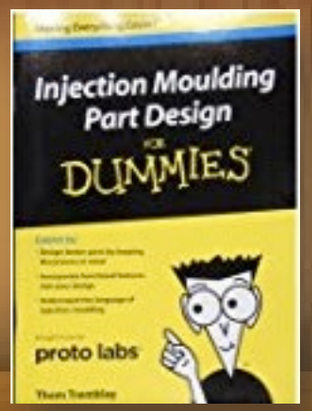
THE DFM BOOKS YOU WOULD NEED TO READ FOR TYPICAL CONSUMER ELECTRONIC PRODUCT

Metal bending

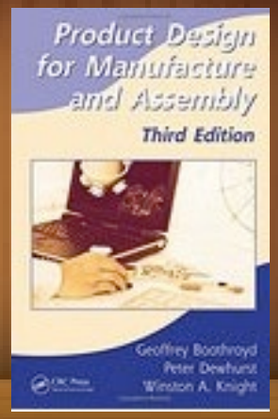


Casting



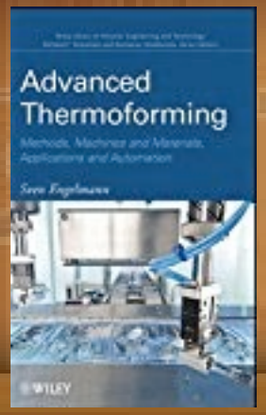


Injection molding



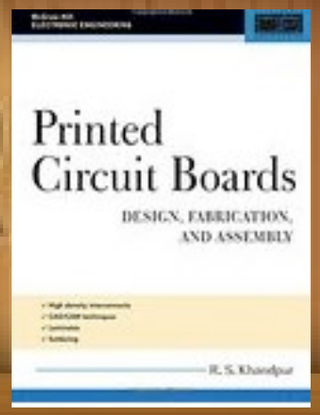
Assembly

Ultrasonic

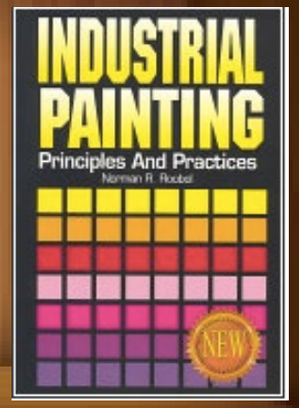


Over-molding

Cable harness

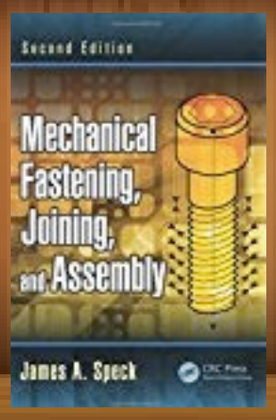


PCBAs

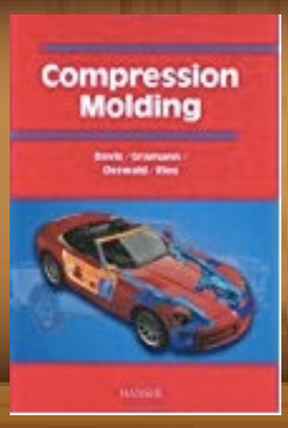


Painting

Metal stamping



Fastening



Compression molding

CNC lathe

DFM / DFA Simplified

1. If there is an opportunity to not follow directions, someone will.
2. Material will never stay where you put it and tries to go back where it started
3. Mfg. likes to be in 2 ½ D
4. Weird things happen when material goes from liquid to solid
5. Screws are bad but glue and tape are worse
6. The more you handle a product, the more defects get introduced
7. Vibration is your enemy
8. Things are always easier if you have fewer parts to manage
9. Material doesn’t like to go into sharp corners
10. The best DFM will fail if the process isn’t controlled

11. KNOW WHEN TO BREAK THE RULES

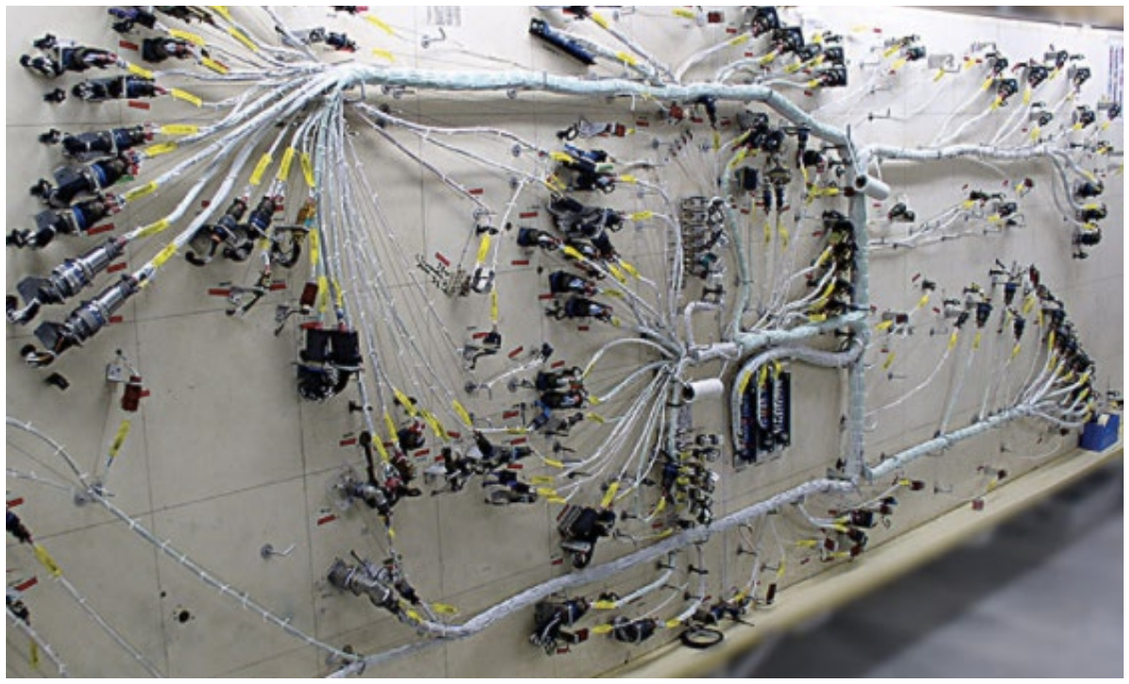
1. If there is an opportunity to not follow directions and get it wrong, someone will.

What does this mean?

- Operators won't always follow the SOPs

Errors are introduced by

- Wrong assembly: Disoriented and not tightening down parts correctly
- Wrong parts
- Damage: over tightening screws, breaking parts during assembly



Key failures

- Orientation
- Alignments
- Wrong parts (screws, old materials)

How to address

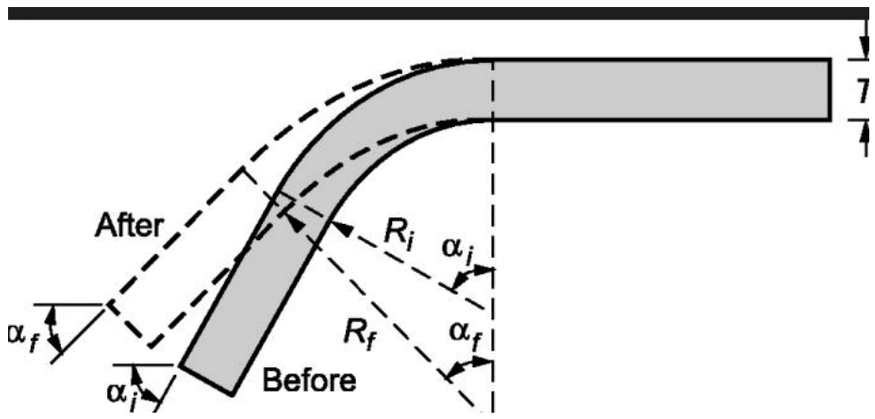
- Combine parts to reduce errors
- Make parts symmetric so they can always be assembled
- Poke-a-yoke (error proof) assembly

2. Material will never stay where you put it and tries to go back where it started

Corollary: Use compliance to your advantage

What does this mean

- Bent material will always spring back
- Material shrinks when it cools
- Screws will always try to back out

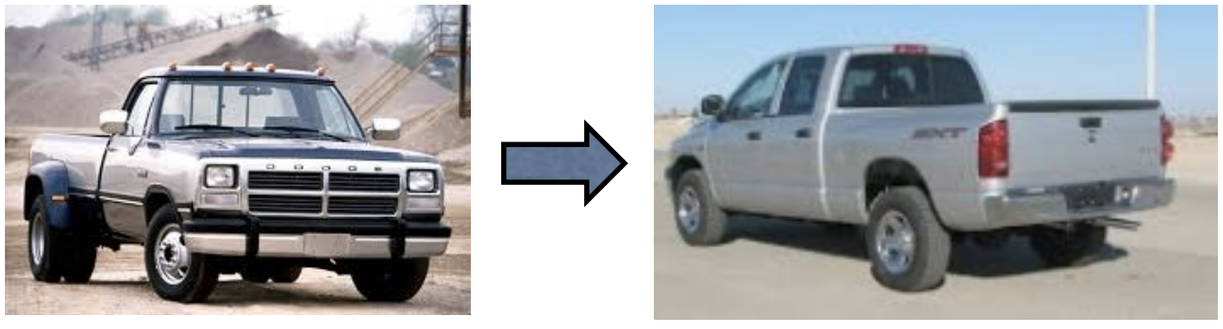


Key failures

- Dimensional errors
- Assembly difficulty

How to address

- Plan for spring back
- Create “compliant designs” that can adjust



Change from 1990 flat door to rounded door made it more difficult to tune the door fit

3. Mfg. likes to be in 2 ½ D

Corollary: You have to be able to get the tool into and out from the part

What does this mean?

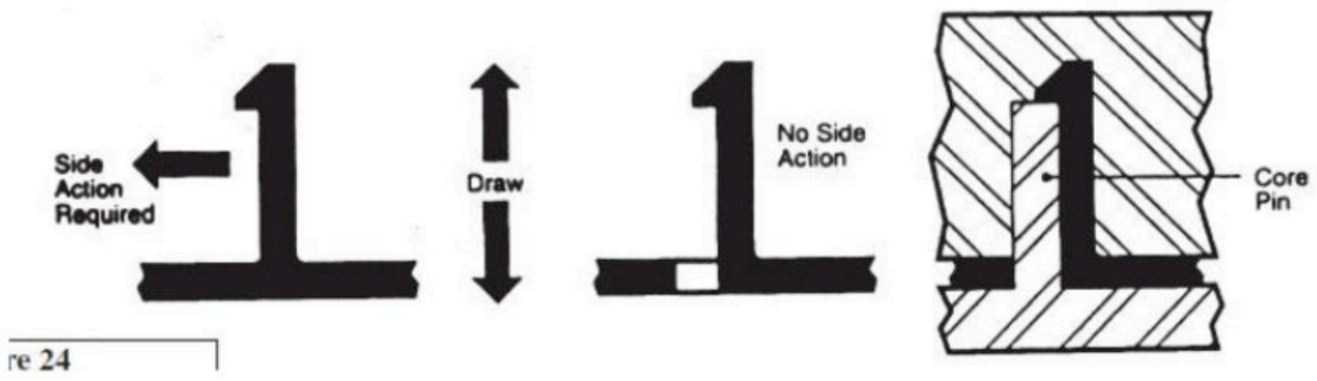
- Most tools open and close or move in a single plane
- CNC machines use vertical access
- Stamping creates 3D features out of a sheet of metal

Key failures

- Expensive to create tools for 3D
- Variability in end geometry

How to address

- Creative ways to make parts 2 ½ D
- Re-fixturing (adds variability)



4. Weird things happen when material goes from liquid to solid

Corollary: Materials don't like to go around corners or cool unevenly

What does this mean?

- When material cools unevenly it can cause material to come away from the tool and create sink marks
- Uneven cooling can result in internal stresses that will release and move the part

Key failures

- Sink marks
- Thermal stresses

How to address

- Controlling the cooling process
- Making sections even

5. Screws are bad but glue and tape are worse

What does this mean?

- Screws are expensive to install
- Tape and glue are messy, have to be controlled environmentally

Key failures

- Glue and tape require a lot experimentation to get the right kind
- Tape is hard to lay down flat
- Wrong screws, incorrect torque

How to address

- Mechanical connections
- Single parts
- If you have to use screws use loctite

6. The more you handle a product, the more defects get introduced

What does this mean?

- Every time the part is picked up and put down, there is risk of scratching and dirt
- Every time it is handled there is a risk of mis-assembly
- Finger prints

Key failures

- Dirt, damage
- Mis-assembly
- Damage
- ESD

How to address

- Reduce part count
- Modular assembly
- Easy assembly
- Single direction assembly
- Automation

7. Vibration is your enemy

Corollary: Assembled things want to disassemble themselves

What does this mean?

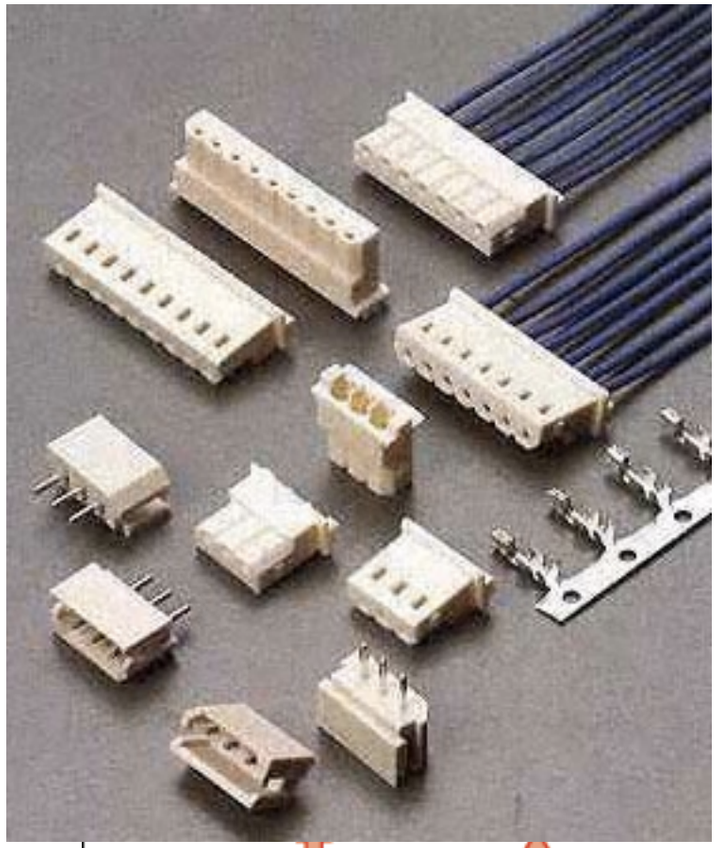
- Mechanical connectors will become disassembled with vibration
- Vibration can cause fatigue and cracking in critical areas

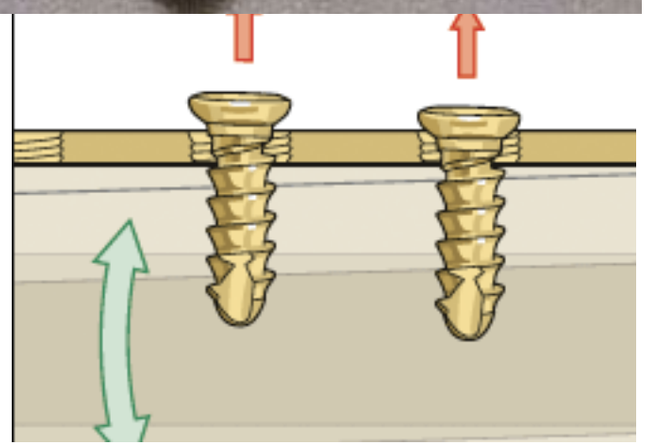
Key failures

- Loosened parts
- Electrical issues

How to address

- Use a secondary mechanical lock
- Avoid connectors and screws
- Test for vibration





8. Things are always easier if you have fewer parts to manage

What does this mean?

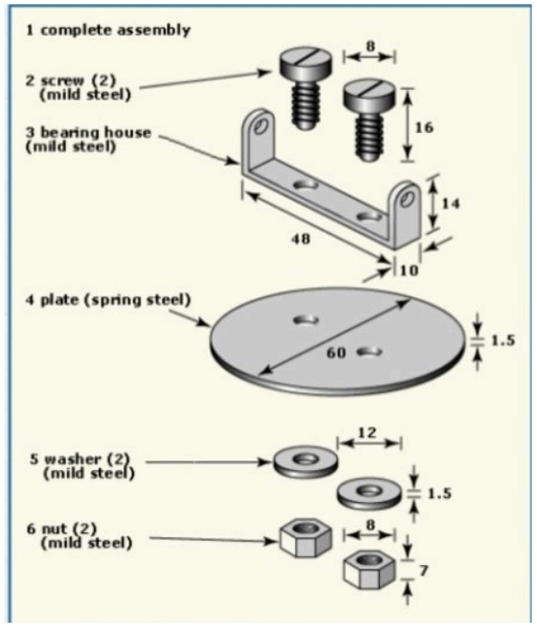
- More parts mean more room for error
- More work to assemble
- Easier to be short a part

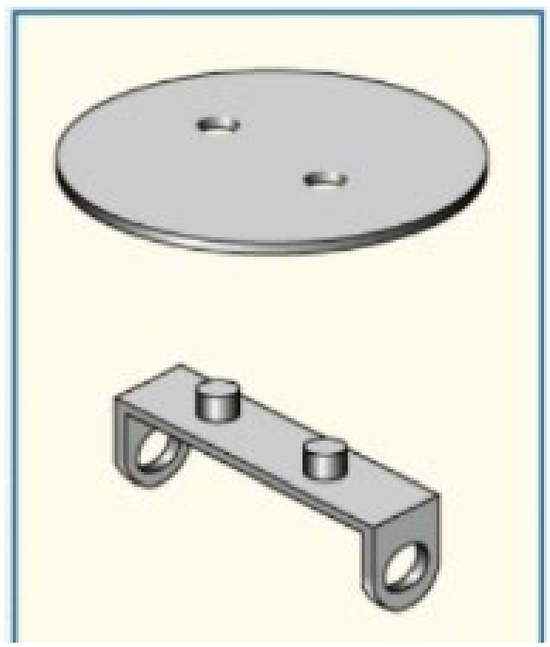
Key failures

- Missing part
- Incorrectly assembled
- Damage

How to address

- Part consolidations





9. Material doesn't like to go into sharp corners

What does this mean?

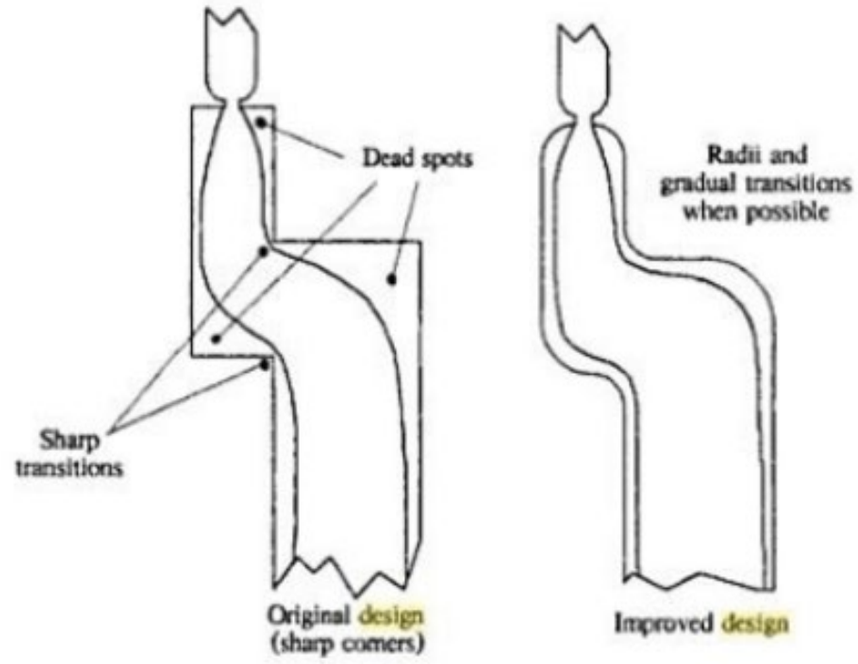
- There is no such thing as a sharp corner

Key failures

- Having to add material to a tool is painful, expensive and you will NEVER get a good surface finish

How to address

- 3-D printing first
- Soft tooling
- Cutting to the max tolerance and adjust by removing tool material (make the part small first)



10. The best DFM will fail if the process isn't controlled

What does this mean?

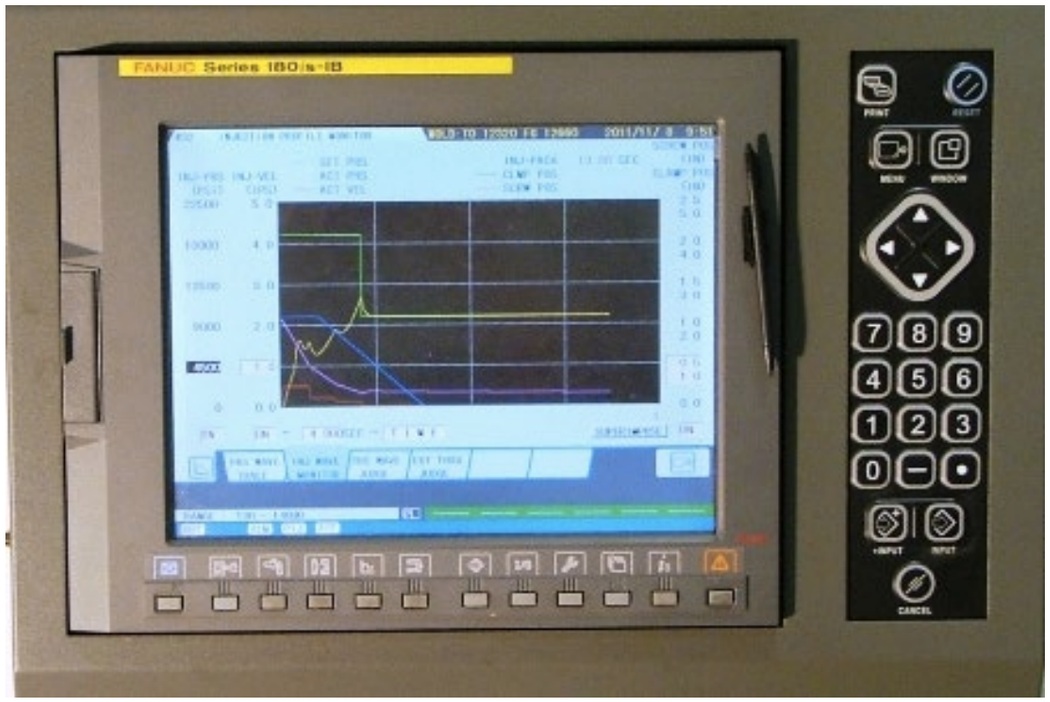
- Process parameters will impact quality dramatically

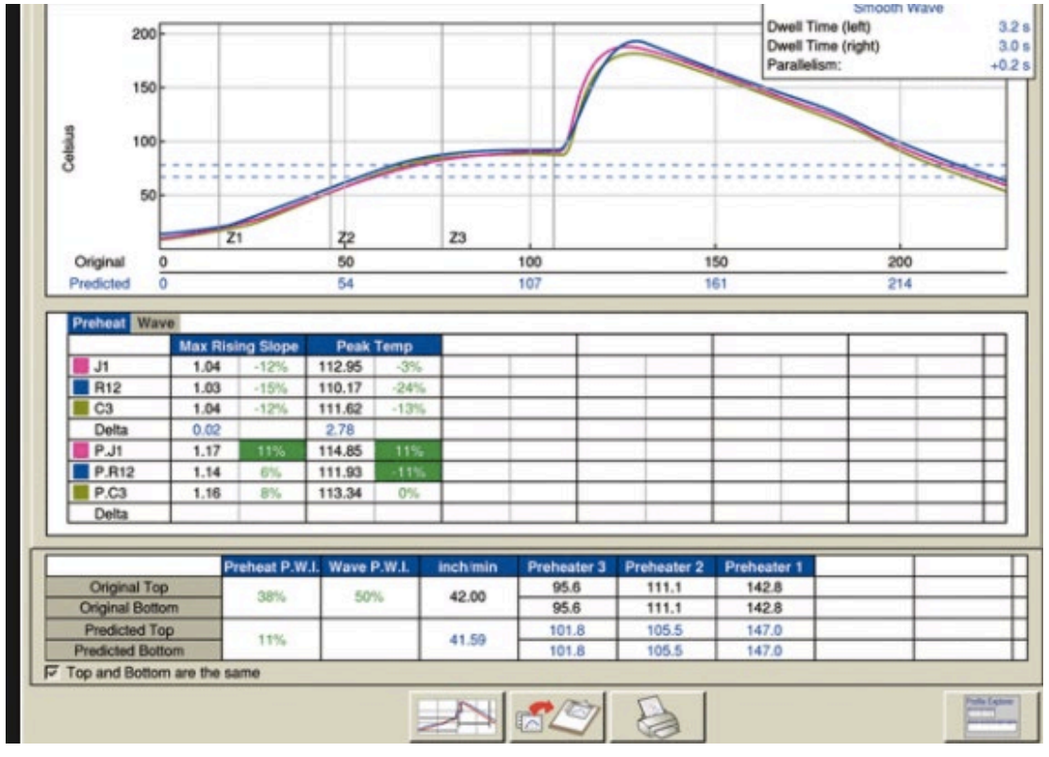
Key failures

- Incorrect geometry
- Surface quality
- Internal defects

How to address

- Validate process parameters
- Controlling the process





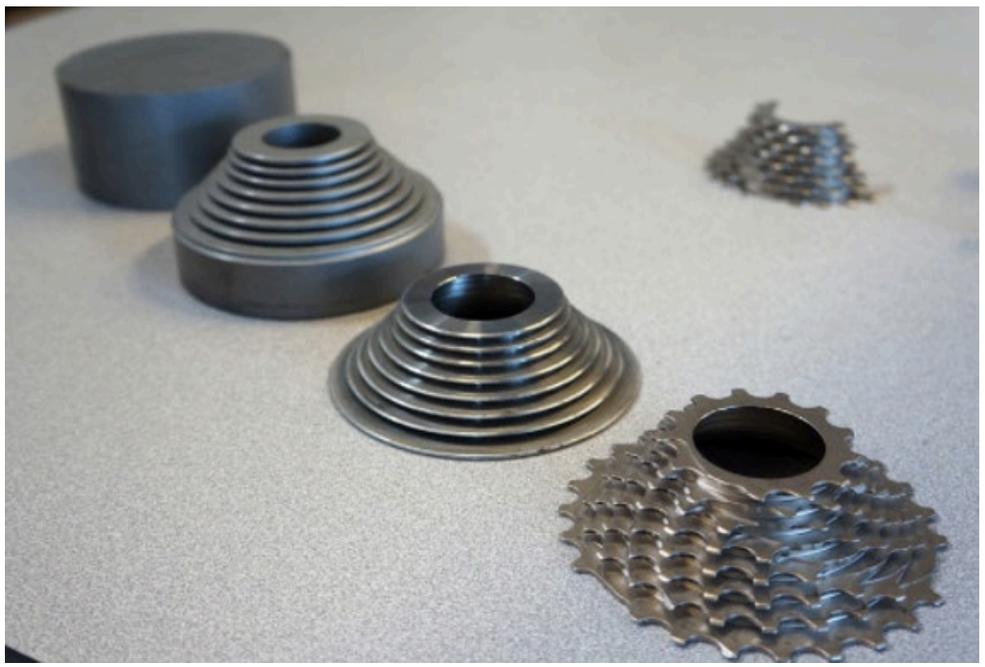
11. Know when to break the rules

What does this mean?

- There are times that not following DFM is the right decision
- You might have two rules in opposition (2 ½ D vs. fewer parts)

How to address

- Need to make an analytical tradeoff
- Need to understand all of the cost implications



Oven controller: separate out the clock from the main board?

One board to reduce cost and assembly
$167

>2.1 % failure rate

Two board to reduce the cost of repair
$170 for both
($20 for just the clock)

<2.1 % failure rate

DFM / DFA Simplified

1. If there is an opportunity to not follow directions, someone will.
2. Material will never stay where you put it and tries to go back where it started
3. Mfg. likes to be in 2 ½ D
4. Weird things happen when material goes from liquid to solid
5. Screws are bad but glue and tape are worse
6. The more you handle a product, the more defects get introduced
7. Vibration is your enemy
8. Things are always easier if you have fewer parts to manage
9. Material doesn’t like to go into sharp corners
10. The best DFM will fail if the process isn’t controlled

11. KNOW WHEN TO BREAK THE RULES

Q&A

RESOURCES

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www.DragonInnovation.com

PRODUCT PLANNER
https://tools.dragoninnovation.com/planner

VIDEOS ON DFM
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