HARDWARE DEVELOPMENT FLOWCHART

from idea to mass production

Molly McNeil

mollymcneil.com/flowchart

Design Phase 0: Ideation

Is it a good idea?

Product Research

Market Analysis

Potential Clients/Users

Legal Research

Safety Compliance

Business Development

Concept

Definition

Basis for Interest GATE

Design Phase 1: Prototyping

Can the product idea be made?

Marketing

ID

ME

EE/FW

Ops/ Logistics

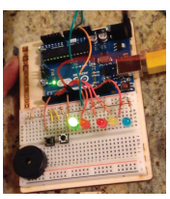
Legal/ Safety

Device SW

iOS/Web SW

Duct tape/Bread board Protoypes

System Layout Affectors



Feasibilty
Cost/Time/Qualtiy

Verify Risks
Reliability, ?'s

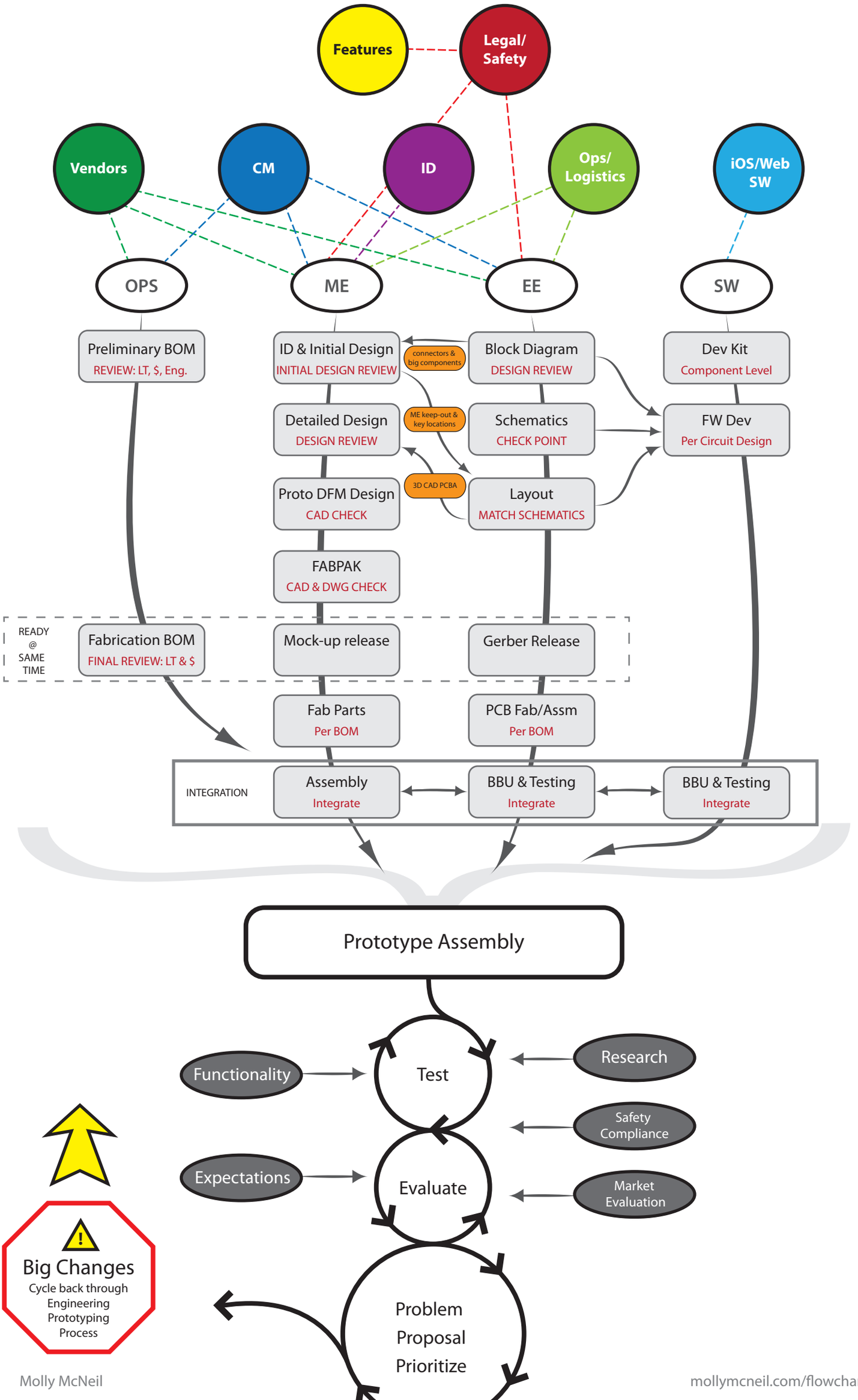
PRD
Detailed Features

Basis for Development

Development Phase 2:
Engineering Prototype

GATE

How can the product be made?



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ME OPS EE

ID ME

ID ME

Safety Compliance

Marketing Engineering

PM

SW FW iOS

BOM
LT, $, Alternatives

CMF
ID detail of product

FAPBAK
fabrication packages

Small Changes
List

PRD
Updated Features & tech spec

Schedule
CM & Eng

SW Sched
Chip Pre-Burn Dates

INEGRATED DELIVERABLES

Design Review GATE

Development Phase 3: EVT

Does the product work like the final product?

Features

Legal/ Safety

Vendors

CM

ID

Ops/ Logistics

iOS/ Backend SW

OPS

Packaging

ME

EE

SW

Prototyping BOM
REVIEW: LT, $, Eng.

ID Initial Design
Look & Feel

ID & Initial Design
INITIAL DESIGN REVIEW

connectors & big components

Block Diagram
DESIGN REVIEW

Dev Kit
Component Level

Detailed Design
Structural & Artwork/copy

Detailed Design
DESIGN REVIEW

ME keep-out & key locations

Schematics
CHECK POINT

FW Dev
Per Circuit Design

Sampling & Review
small # made, check

EVT DFM Des.
CAD CHECK

3D CAD PCBA

Layout
MATCH SCHEMATICS

FABPAK
CAD & DWG & Copy

FABPAK
CAD & DWG CHECK

EVT BOM
FINALIZE: LT, $, Vend.

Mock-up release

Gerber Release

READY @ SAME TIME

Sm Prod Run
Make more

Fab Parts
Per BOM

PCB Fab/Assm
Per BOM

INTEGRATION

Assembly
Test, review & iterate

Assembly
Integrate

BBU & Testing
Integrate

BBU & Testing
Integrate

EVT Prototype Assembly

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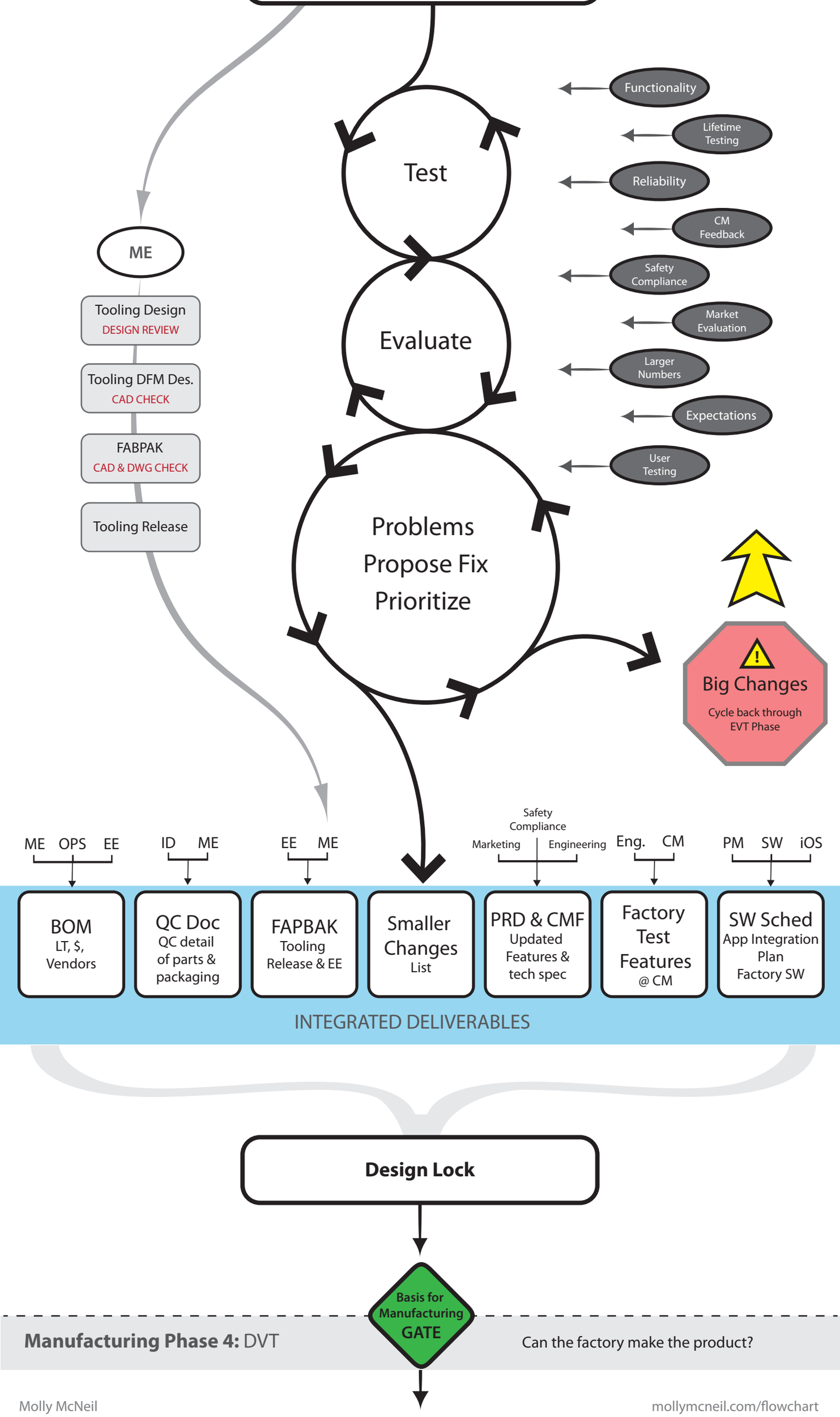
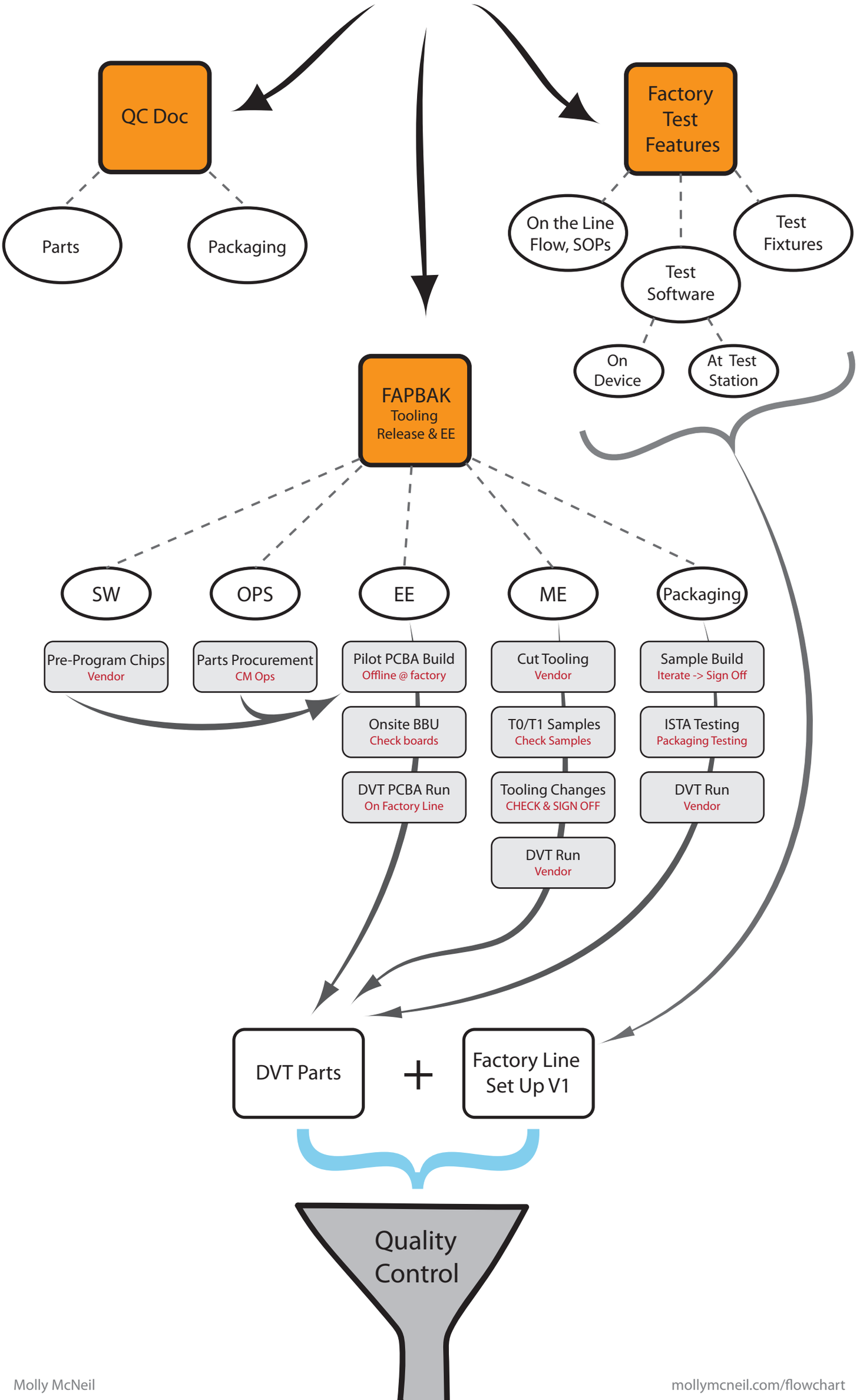

Test
Evaluate
Problems
Propose Fix
Prioritize
Functionality
Lifetime Testing
Reliability
CM Feedback
Safety Compliance
Market Evaluation
Larger Numbers
Expectations
User Testing
ME
Tooling Design
DESIGN REVIEW
Tooling DFM Des.
CAD CHECK
FABPAK
CAD & DWG CHECK
Tooling Release
Big Changes
Cycle back through EVT Phase
ME OPS EE
ID ME
EE ME
Safety Compliance
Marketing Engineering
Eng. CM
PM SW iOS
BOM
LT, $, Vendors
QC Doc
QC detail of parts & packaging
FAPBAK
Tooling Release & EE
Smaller Changes
List
PRD & CMF
Updated Features & tech spec
Factory Test Features
@ CM
SW Sched
App Integration Plan
Factory SW
INTEGRATED DELIVERABLES
Design Lock
Basis for Manufacturing GATE
Manufacturing Phase 4: DVT
Can the factory make the product?

PASS TO PRODUCTION



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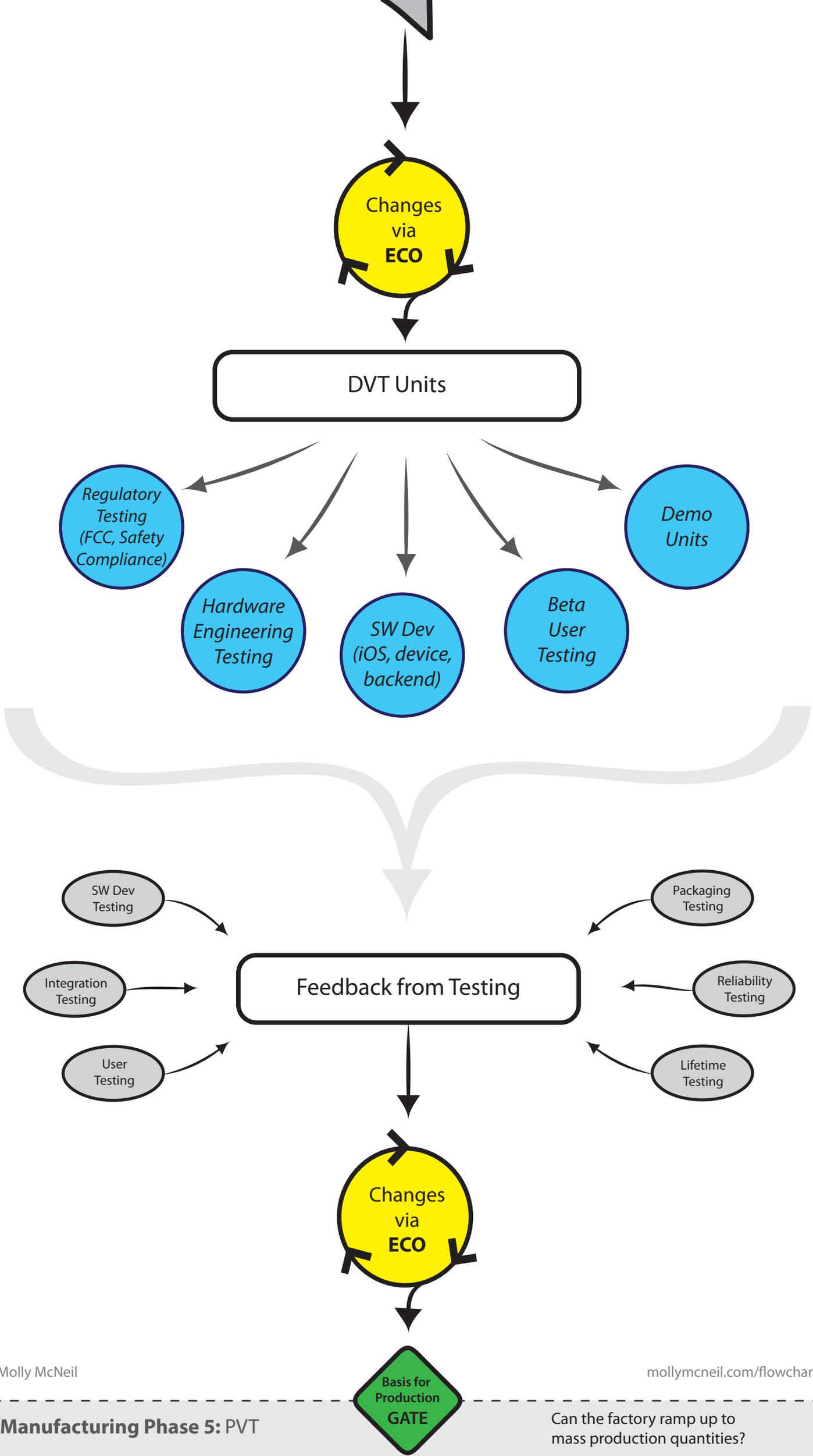

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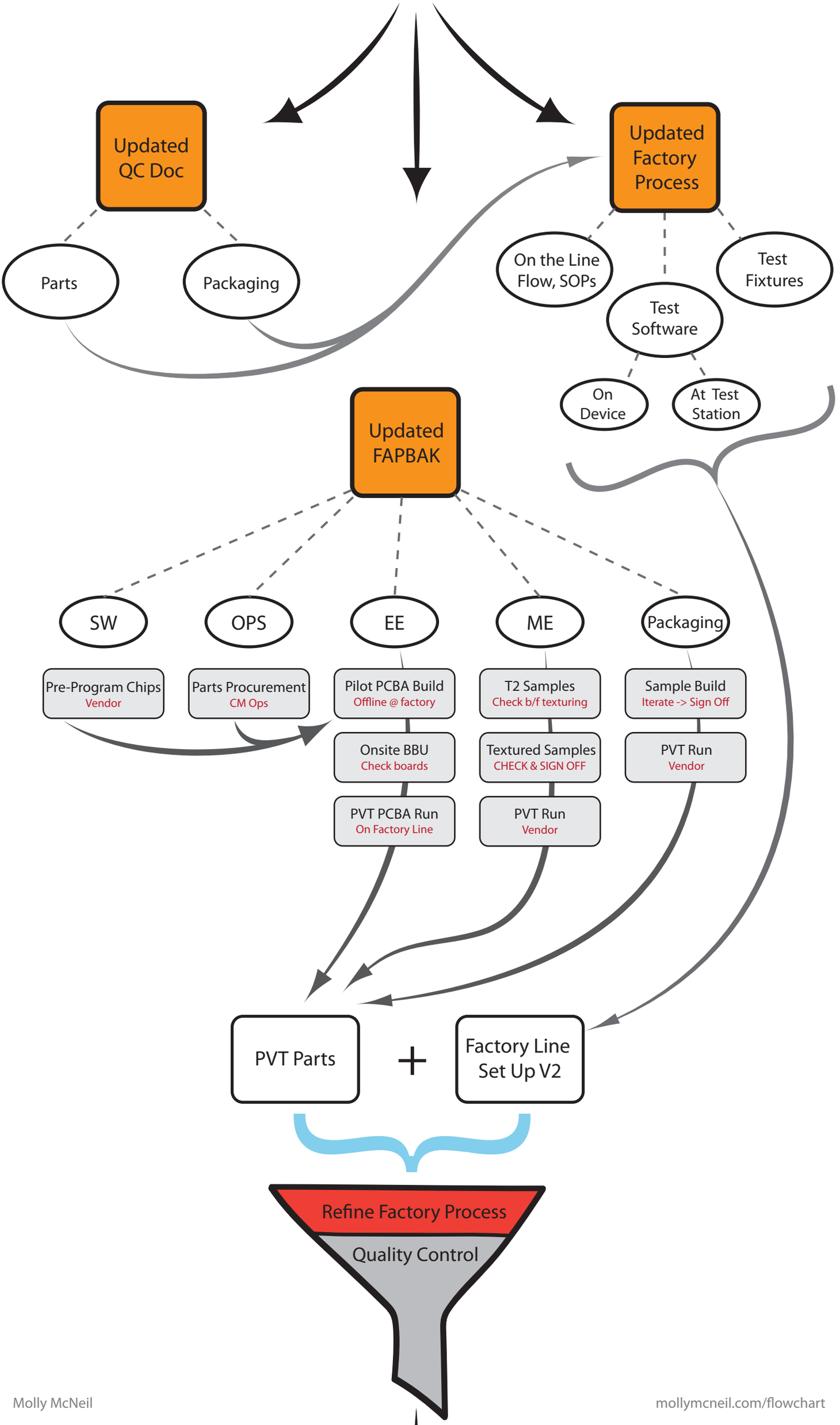
Manufacturing Phase 5: PVT

Can the factory ramp up to mass production quantities?



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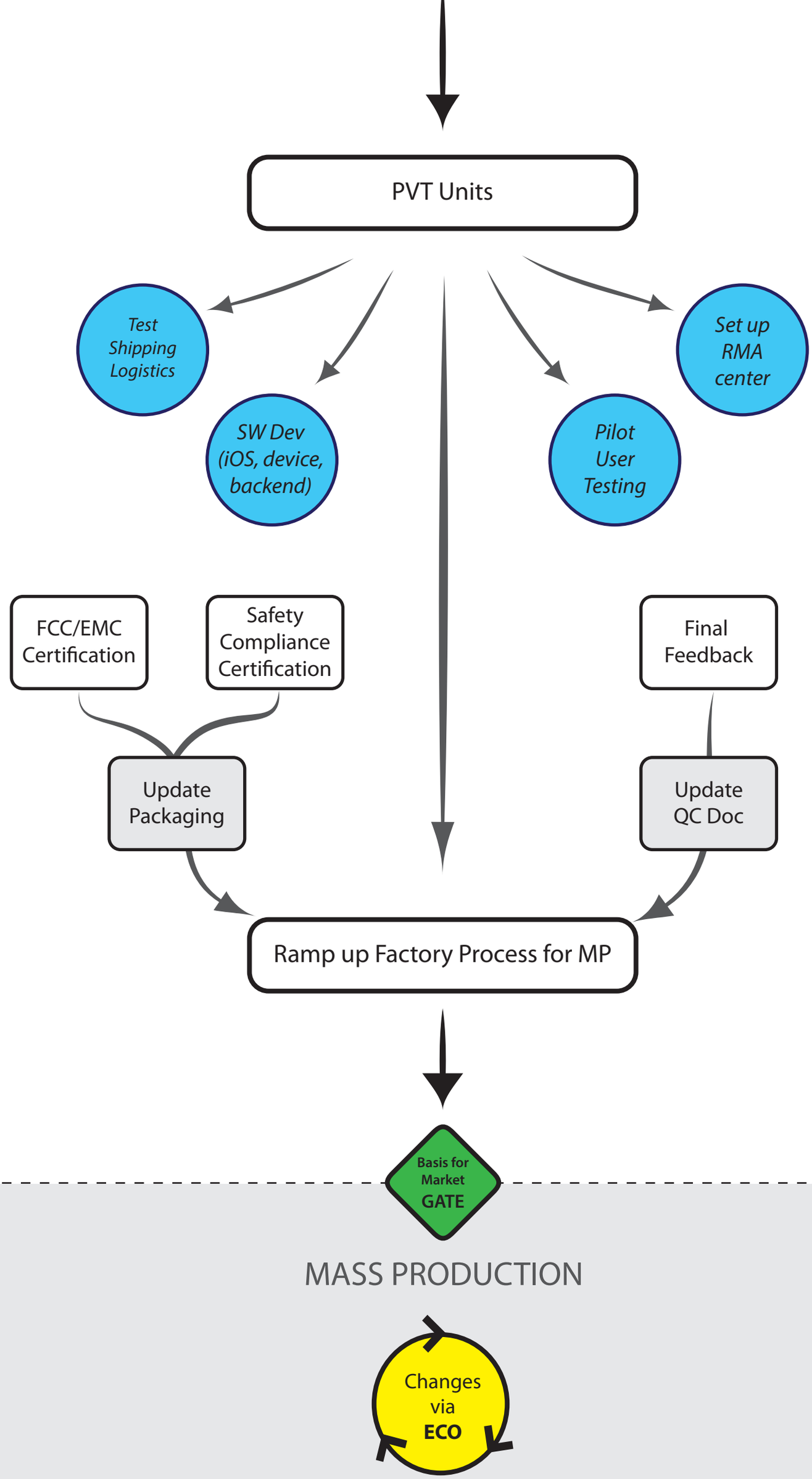
PVT Units
Test
Shipping
Logistics
SW Dev
(iOS, device,
backend)
Pilot
User
Testing
Set up
RMA
center
FCC/EMC
Certification
Safety
Compliance
Certification
Final
Feedback
Update
Packaging
Update
QC Doc
Ramp up Factory Process for MP
Basis for
Market
GATE
MASS PRODUCTION
Changes
via
ECO

HARDWARE DEVELOPMENT NOTES

Design Phase 0: Ideation

Ideation: Is it a good idea?

This is where it all starts. Ideation. The initial idea goes through a series of formal or not so formal vetting processes by major stakeholders. The key is to determine if the idea can develop past the the initial vetting by the stake holders to be worth spending engineering resources on to prototype. By the end of this phase, the idea should be thoroughly fleshed out into a concept with fairly well defined scope for Engineering to start working on it. (Potential informal prototyping can be done to help with some of the early proof of concept.)

Questions to ask:

- Who comes up with the idea? (brain child?)
- Who influences the idea? identify key stakeholders. Make sure the idea is thoroughly vetted.
- Who makes the decisions about what to make? (R&R: roles and responsibilities)
- They say: "Quality, Time and Cost. Pick two." Who makes this call?
- What are the communication lines and who defines the idea concepts and fleshes it out into a definition that can be prototyped?
- Who owns the Feature List? How are changes communicated? Who decides to kill a feature or keep it?

Gate: Basis for interest - is there enough research behind the idea to support it and did it survive the vetting process? Is it defined enough for engineering resources to prototype?

Design Phase 1: Prototyping

Initial Prototyping Phase: Can we make the product?

The idea is now defined and it is time to start deciding if it can actually be made and what the potential risks of the idea are. The key for this phase is to assess the feasibility and verify/identify the risks by pulling in all the different stakeholders and engineering fields. These type of prototypes are known as "Duct Tape/Breadboard" prototypes where their main focus is testing basic function and determining anything that will affect the system layout and design.

To Do:

- Initial ID: 3-D printed ideas - not super details but prove product concept (key features)
- Make ~1-5 "duct tape/breadboard" prototypes
- Component Level Testing (prepare for system integration) - make sure all the components work on their own before putting them together.
- Identify and plan how to mitigate risks in these areas: logistics/supply, design, component level, integration, and manufacturing
- Research and verify legal, safety compliance, and regulation implications and impact to design and features
- Dial in on Key System Architecture - what affects system layout? How will it all come together?
- Create the initial draft of the Product Requirements Document (PRD) - list of features and technical specifications
- Verify with product research to identify that the key features are something actually marketable
- Check again with stakeholders/features owner if there are any adjustments to the idea based on the prototype and testing results

Questions to Ask:

- What is ID's intent and purpose of design? Is this understood by ME and others that might request changes to ID?
- What requirements come from: EE, ME, legal/safety, manufacturing that would affect design for ID? (ie. vent holes, IR transmissible plastics, speaker/mic holes, plug dimensions, space for electronics)
- Are there additional product requirements that need accommodation, like labels? (i.e. serial, certifications, product info)
- Each prototype exists to answer a question. What kind of question does this prototype answer?
- Has each component been tested alone and does it work as intended?
- Can the selected components or material be sourced at higher qtys? Any risk for EOL (end of life)?

Lessons Learned:

- Good communication across teams at this early stage is critical.
- Communicate changes from requirements to ID early in the process.
- Component level testing is critical: not testing before integration WILL cause issues later. Problem with integration? maybe it's not the integration, but the component level that is an issue. Component testing!

Gate: Basis for Development: Is the product idea technically feasible from an engineering standpoint? Is it feasible from a cost, time, and quality standpoint? Does the market research support the case to move forward? Are there solid technical/functional specifications? Each group involved identifies the risks and makes a plan for mitigation. A PRD (product requirements document) is created to describe the features and initial technical spec to give the stakeholders a full product view and can be used as a communication tool between the internal and external parties (i.e. CM, contractors, safety compliance).

Development Phase 2: Engineering Prototype

Engineering Prototype: How do we make the product?

This phase is about integration development where all the teams work together to create a fully integrated prototype that looks and works like what the production unit will be. The main effort is for integration and testing that affects layout interactions while always thinking ahead to how it would be manufactured at a larger scale.

To Do:

- System integration to build ~5-10 working prototypes
- Integration between: Industrial Design (ID), Mechanical Engineering (ME), Electrical Engineering (EE), Firmware (FW), Device Software (DS) to create: mechanical housing, PCBA, sensors firmware, cables, and SW interactions.
- Think about Design For Manufacturing (DFM).
- Contact suppliers/vendors to analyze logistics and supply of components and materials.
- Consider buildability and testability at the factory.
- Test and validate over and over and over at a component level AND at an integrated level. Determine if the features can be implemented in a way that is right for marketing/product.
- Methods: SLA, 3-D printing/rapid prototyping, machining, PCB fabrication and assembly of a few boards, parts from digikey etc.
- Make a gate to insure that the integrated system is well tested before moving into the EVT phase.

Questions to Ask:

- Can this be made at a large scale? How will manufacturing techniques or factory line testing affect the parts/components/system design?

- How is the demo of the integrated system? Any feedback from marketing/execs/etc?
- Where can communication between stakeholders be better? Are there areas of potential issues in communication?
- What are the regulatory requirements? Safety compliance (NRTL: UL, CE, RoHS, WEEE, Prop-65, etc)? FCC? Legal issues? Will it affect the design or features?
- How will the device be tested on the factory line? Will there need to be a testing port to plug the unit in or other that will affect the design?
- Each prototype exists to answer a question. What question do each of these prototypes answer?
- Alpha user testing that might influence the design/features?
- Does the CM get involved here at all?

Lessons Learned:

- Make sure all the components/sensors/parts/materials are tested at the component level before system integration and are sourcable for the application.
- ID team - if they are internal it is easier! External people need to kept in the loop. Have clearly defined the roles and responsibilities people should take. Have a plan about what to do when engineering requirements need to change the form factor or cosmetics - who owns these decisions?
- Start thinking about packaging upfront. The packaging is part of the product.
- Have a formalized review/demo with the stakeholders before moving into the next phase so everyone is on the same page and okay to move forward.
- Identify and mitigate all the risks possible. Design for back-ups, alternate solutions, and worst case scenarios.

Gate: Design Review: Does the product do what it is supposed to do? Is this product ready to start the marathon to mass production? Demo the integration to the stakeholders and make sure everyone is ready to move the product forward.

Prepare the following:

- preliminary BOM (bill of materials that has been initially vetted by lead time, cost, vendor supply, and all components have been tested)
- CMF (Color/Material/Finish cosmetic details & ID specifications)
- FABPAK (fabrication package for EE and ME)
- PRD (Product Requirements Document - list and description of features and the technical specifications)
- Schedule (Timeline and milestones for EVT-DVT-PVT-MP, critical pathway as well as coordination between engineering teams and CM)
- SW schedule (software milestones for when the device software needs to be pre-programmed on the the chips)
- Small Change list - if any small changes, determine if they need to go back into prototyping, or if they are okay to address in EVT

Development Phase 3: EVT

Engineering Verification Test: Does the product work and has it been reliably tested?

This phase is a design iteration of the previous first generation prototype that focuses on integration and testing of the integration of components as well as the shift from being engineering focused to production focused. It is to make sure that the product can be made, that the design is solid, and that it withstands thorough testing. By the end of the phase the units should represent the final production intent of the design in form, function, and surface ID (color, finish, texture).

To Dos:

- Make a larger number of units ~30-50 units.
- Focus on assembly, integration testing, and think actively about manufacturing and sourcing for larger quantities.
- Address the short list of problems/changes from the previous phase.

- Start DFM (design for manufacturing) - tooling release for ME happens by the end of this phase. ME is on a different schedule than the other development. It has to be a step ahead since lead times (LT) for tooling are so long.
- Potential field testing and reliability testing.
- CM may get involved to comment on engineering design, manufacturing techniques, and start sourcing the BOM (Bill of Materials).
- Prepare a go/no-go decision to release the design to manufacturing.

Questions to ask

- When does one bring in the CM? Depends on how much they will be involved (OEM vs ODM, etc) - they will have input on DFM and potentially internal design.
- Is the product ready fro DFM (design for manufacturing)?
- By the end of the phase, is the design ready to be locked? Really expensive tooling is about to be ordered, so if it changes, make sure they are tool-safe changes.
- Who makes the call about what changes are small enough to not have an EVT2? (the go/no-go decisions)
- Beta/User testing that might influence the features/design?
- Any changes from product/business development/marketing? Make sure they see a demo at this phase to make sure everyone is on the same page

Lessons Learned

- Safety compliance should be addressed earlier so if there are design changes it happens before the design lock.
- Make sure component level testing is done before integration!
- The CM is not typically very creative - they get stuck in their processes. Use the engineering power of creativity to balance their process oriented-ness.
- Start making a QC doc early!
- Packaging is the part of the product. It should be prototyped at this phase and tested as well.

Gate: Basis for Manufacturing: Is the design ready to lock and make a lot more? Do all the features work and has it passed integration testing?

Ready to pass to production - lock the design (no more major changes).

Prepare the following:

- BOM (complete bill of materials that has been vetted by lead time, cost, vendor supply, and all components have been tested)
- QC document (detailed quality control specification for tolerances for imperfections cosmetically on unit and packaging)
- Production FABPAK (fabrication package for EE and ME that includes the DFM tooling release)
- Updated PRD and CMF (Product Requirements Document and Color/Material/Finish cosmetic details & ID specifications)
- Factory Test Features (list of features that should be tested on the factory line during assembly and on the final assembly)
- SW schedule (factory software milestones for when the device software needs to be pre-programmed on the the chips, and when the factory test sw needs to be ready to test on the assemblies for the next couple phases)
- Small Change list - if any (basically there shouldn't be any ME or EE changes, but rather minor SW adjustments. If there are major changes that come up from testing, cycle back and do an EVT2).

Production Phase 4: DVT

Design Verification Test: Can the factory manufacture, source, and build the designed product at increased quantities?

The purpose of this phase is to teach the CM to make, source and build the product.They should identify any DFM issues, develop assembly and test fixtures as well as calibration SW.

To Do:

- Make larger numbers of units using production methods ~50-200 units.
- The factory will design and develop the factory line process: SOPs (standard operation procedures - step by step building and testings of units), test fixtures and test software for test stations.
- The CM will source and manufacture all the components as well as packaging.
- Then they will take all the parts and build them on the factory line using the test fixtures and test software refine the factory line process.
- The QC doc is crucial at this stage - make sure it is followed and modified as necessary.
- Design changing must be on lockdown - if there must be changes, then use an ECO to control it
- Submit DVT units for regulatory testing (using the tooled ME parts).
- Start thinking about the warehouse and frontend logistics and distribution.
- DVT prototypes being built on the factory line is not the end of DVT. They need to be tested at the factory and by the engineers (i.e. BBU, mechanical testing, packaging testing, more integration testing, reliability testing, lifetime testing, lots of testing).

Questions to ask

- Can the factory source all the components? Are there any backups (were they designed for) to make sure there are no logistic/sourcing issues?
- Is there device software that needs to be written for testing on the device - not just on the factory test stations?
- Who is supposed to write the factory test software? The CM or the engineers? Identify the R&R (roles and responsibilities) for factory SW early.
- What is the progress and timeline milestones for the rest of software? (ie App, Website, Backend, other device software)
- What environment is the factory test SW written in? How will that affect how the chip SW is written?
- Are there any changes that require more testing or that could affect design?
- Packaging design - who owns this and tests it?
- Packaging testing? Did someone drop the unit in the packaging? In the master carton? How will it pack on the pallet?
- Packaging testing: ISTA-2A testing means what? just not damaged product? Or not damaged packaging as well? Be clear about what is acceptable damage.
- Any changes from product/ID/business development/marketing/execs? Make sure they see a demo at this phase to make sure they know what the product is still.

Lessons Learned

- Put trusted people on the ground at the factory to help control the process and quality.
- If there are a lot of changes at DVT (i.e. removing key features by removing sensors) make triple sure that it does not change the safety compliance ramifications causing delays for product launch.
- The factory environments for testing PCs were windows (writing code for windows is a pain!)
- Start building QC doc early and don't change it to be more strict. Start very detailed and very strict, then loosen up after discussions with the manufacturers only if necessary.
- Be clear about what the standards are desired to come out of testing (i.e. packaging testing).
- Check for cosmetic damage on the line - can units be prevented from damage during building (better handling, protective clings, etc)?
- Ideally there should be little to know changes between EVT and DVT/

Gate: Basis for Production: can the factory make this product exactly how it will be for mass production (functional requirements and cosmetic/appearance)?

Review manufacturing test systems and processes. Are all parties ready to move on? PVT readiness gate. If there is any feedback from testing control the changes and decide what is go or no-go before moving on.

Production Phase 5: PVT

Process (or Production) Verification Test: Can the factory ramp up to build mass production quantities of the product that meet all functional requirements, cosmetic/appearance requirements, with have optimized manufacturing processes?

The purpose of this phase is to test the manufacturing ability and factory line processes developed during EVT and DVT. It is all about refining the processes at this point, nothing to do with changing the product design.

To Do:

- Make more units using the production processes: ~200-500 units.
- NO engineering changes. This is all about process optimization.
- Pay attention to issues that come up on the factory line - make tweaks to the process.
- QC DOC!!! Review, refine and update this document so that it is very clearly communicated to the factory exactly the quality expected and executed on the line.
- The units and packaging built in this phase should be exactly the same as MP units, except maybe they have a different product label.
- Regulatory testing should be complete by the end of this phase and then the correct certification numbers and marks can be added to the production labels (for packaging and products).
- Make sure the logistics are ready to ship product from factory to warehouse, and beyond.
- Demo again to product/business development/marketing/everyone? Make sure know what the product is still, since this is last stop before mass production.

Questions to ask

- What kind of issues arose with the increased number of units to build?
- Where are the units going to ship for PVT and shortly after for MP? Are the operation logistics ready?
- Is there a reason to set up an RMA center and prepare the same documentation from the factory for them to build/repair units?

Lessons Learned

- Make sure the QC doc is updated and clearly communicated
- If your ID is external, make sure they were in the loop before now and helped develop the QC requirements.
- Make sure the packaging is ready and that the testing results from DVT made their changes into the PVT iteration.
- Pay attention to changes made to the test fixture sequencing. Also, if payment was made for the test fixture equipment, make sure the factory is using it in the way it was intended.
- Communication - with everyone all the time. It's really important.
- Shipping a partially full pallet might result in a crushing of the boxes since the pallets don't stack well if one is not full. Use empty boxes to fill up the pallet if a partial shipment must be made.

Gate: Basis for Market: is everyone ready for mass production?

Have a final review with the CM and make the decision to move forward into the ramp up to mass production.

Final Phase: MASS PRODUCTION

Mass Production: make lots of units.

As more time passes and more units are produced, work will be done on sustaining the engineering to stabilize the manufacturing of the product to get the desired high quality of production. At the beginning there may be a lot of 'infant mortality' issues in design and/or process where OOB (out of box) the unit does not work. This is where a lot of changes via ECO (engineering change order) happen to fix the manufacturing issues and decrease incidence defects. It's a good idea to sample test the MP units to make sure the quality is being upheld over time.

Potential Issues in production:

- The factory does not pay attention to the QC requirements. Make sure someone is watching over the line to train them and to keep checking that they are following the requirements.
- Sometimes there is a mismatch between serial numbers on the packaging box and product itself. This is bad for inventory tracking.
- Old inventory can get mixed back in with newer revisions. (Especially risky with tooled parts between tooling changes - make them check the versions)
- Increased quantities of PCBA production can lead to interesting issues (i.e. soldering parts crooked).
- New OPs (operators) on the factory line make mistakes in building, and their senior might not be paying attention.
- The factory policies are difficult to deal with. If not all the parts are ready by the beginning of the build shift, they may skip your product and do a different customer's product instead.

Roles and Responsibilities (R&R) Questions:

- Who does what?
- Who pays for what?
- What are the phase gates and who makes the go/no-go decisions?
- Quality, Cost, Time - who decides what gives in a compromise?
- When do you bring in the CM?
- How will the CM's work on logistics, EE design , ME design, factory testing and shipping affect the design?
- How does the ID team play a role? Are they a product owner? Are they a QC gate for ME? How proactive should they be?
- Packaging - who 'owns' this design?
- Project/product owner - how does this morph as the product develops? Identify roles as product moves forward.
- Who is the owner of the PRD and QC docs?
- At what point do you do App integration? How much influence does this kind of software development influence hardware? How much communication happens between these two development tracks?

THE END

"Everything will be fine in the end. If it's not fine, it's not the end."

-Wilde