FORGE

Workbook 5

Managing Development

Context

What is the story behind the problem you're trying to solve? Why is this product important to your customer(s). Does it solve a pain point? Increase efficiency? Open up new markets? Is this satisfying an internal need, i.e. tech debt, DFx?

This context is important as you write your requirements. You will create acceptance criteria along with the requirements to confirm that a particular requirement was completed but also as a tool to measure the impact that the requirements you've written have for your customers.

Hypothesis

Explain how the product will work to solve the above problems.

Customer Personas

Depending on whether this is a B2B or B2C (or something in between) product you may have more than one customer that you're writing requirements for. It's critical to take the same care with requirements generation for all personas.

In the section below explain who the users of your product are, (i.e. end user, prosumer user, professional installer, manager with/without industry experience) the action they need to take, and what goal they will achieve with the help of your product.

TYPE OF USER

As a(n)...

WHAT ACTION

I need...

ACHIEVE WHAT GOAL

To...

Hardware Requirements

Certifications & Compliance

Does this product require a regulatory listing to be manufactured? Do your target customers prefer that a regulatory mark be applied independent of any required regulation?

External Communication

Are there required external communication methods? If so, what is their intent? i.e. bluetooth for setup/configuration, dry contact for control of an external device, serial port for debug or integration.

Environmetal

Which environmental factors should be considered? Where will the product operate? Indoors, outdoors? Direct sun? Water and dust exposure?

Reliability

Is there an expectation that the product last a certain time period, under given environmental conditions? What are the functional and cosmetic expectations over that time period?

Power

How will the device be powered? Are there inherent limits? I.e. battery powered, PoE, etc.

Industrial Design

What ergonomic, functional, or cosmetic requirements will influence the design of the product? I.e. size, weight, mounting, sensor requirements.

Firmware & Software Requirements

Unlike hardware requirements, many firmware/software requirements will change as you work through the prototype phase and beyond. However, the core user stories that make your product unique need to be identified early. Understanding what architecture will support all the user stories required for launch and all the planned post launch features will allow you to align on the hardware design that enables you to meet your feature requirements, cost, and schedule.

Requirements should be written in a clear, concise manner as all requirements must include a measurable acceptance criteria. In some cases this criteria is simply that a feature exists i.e. can select an option. In other cases it will include performance criteria i.e. do X and Y level within Z time.

Requirement	Number	Acceptance Criteria	Priority
As an end user I want to be able to unlock my phone using my face as the unlock credential	1.0	1. Perceived unlock time is no longer than 2.0 seconds	P0
As an end user I want to be able to unlock my phone with my face partially obscured	1.1	2. Unlock time while wearing glasses is no longer than 2.5 seconds	P1

Introduction to Operating Documents

The three operating documents—**Bill of Materials (BOM), Bill of Process (BOP),** and the **Engineering & Assembly Drawings** work together to clarify:

- What and how many components form the product?
- What are the steps/sequence for fabricating the product?
- How can the product continue to be produced effectively as its complexity increase?
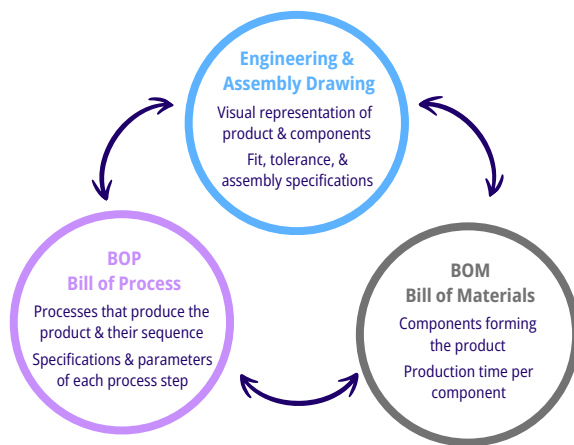

Figure 5.2.1: Operating documents

Bill of Materials (BOM)

Key Elements
- Lists quantities of components, ingredients/ materials required to make a product
- Communicates the relationship between items at different **Product Levels**: indicate hierarchy with parent/child delineation
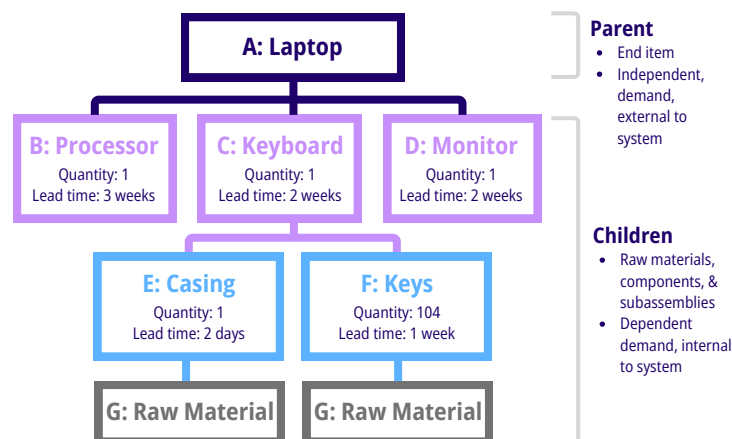

Figure 5.2.2: Product levels in a Bill of Materials (BOM).

Demand for an item depends on the demand for items "higher up" on the BOM. The two types of BOMs:

Engineering Bill of Material (eBOM) - Special type of BOM that defines the product as designed. Contains the list of items, parts, components, subassemblies, and assemblies in the product designed by engineering.

Manufacturing Bill of Materials (mBOM) - Most commonly referred to as the BOM. Contains all the parts and assemblies required to build a complete and shippable product.

BOM Generation Components:

Low-Level Coding (LLC)
- A number that identifies the lowest level at which a specific item exists in the BOM
- Allows for easily computing the requirements of an item existing at different levels of the BOM

BOM Processor
- Core component in most commercial packages; maintains the BOM and automatically assigns LLCs
- Essential for products with large BOMs (e.g. automobiles with approx. 30,000 components)

In *Figure 5.2.2,* Item G can be coded as Level 2 (under B) or Level 3 (under E), LLC convention has it coded as Level 3.

Bill of Process (BOP)

Process planning is typically documented on a routing sheet, also known as a bill of process (BOP)

Process Documentation
- Workflow process mapping (value stream mapping)
- ISO process documentation

Process planning organizes these production-related elements:

- Methods of production
- Tooling
- Fixtures
- Machinery
- Sequence of operations
- Processing time of operations
- Assembly methods

Factors to be considered during process planning:

- Dimensions/size
- Surface finish
- Geometric shape
- Tolerance
- Material being processed
- Product value & urgency
- Manufacturing capabilities & resources availability

Engineering Drawings

Information to include on an engineering drawing or "blueprint":

- Title
- Version
- Material
- Projection type
- Units
- Scale
- Other (i.e. assembly, instructions, intellectual property, tolerances)

Controlling variability in BOM and BOP:

- Adds to cost, complexity
- Impact quality control, inventory readiness, parts tracking, supplier contracts

Parts planning:

- Consider a parts tracking system (for inventory ordering/control and quality traceability)
- Highly recommend a plan for each part!

Dimensional tolerances:

- Defined as the allowable errors on a specific dimension
- Typically expressed as a range of values (i.e. the diameter of a hole is expressed as "3.5 inches ± 0.02," which means that the hole is acceptable if its actual manufactured diameter is between 3.48 and 3.52 inches in diameter)

Geometric tolerances:

- Defined as the allowable errors on shapes, locations, and profiles (as opposed to size or dimensional tolerances)
- Specified on engineering drawings as a box with a leader connected to the feature of interest

Material Effect on BOM & BOP Material Tradeoffs:

- Different materials require different tools and production processes, each with their own trade-offs
- Reduced cost of materials may mean higher per-piece price with volume
- More robust materials may require larger investment in tooling and capital equipment
- Lighter weight does not necessarily mean less material
- Lower volumes require different manufacturing process to control tooling and capital equipment investments
- Switch to high volume with less takt time process may require major investment in capital equipment but lower per-piece price over time

Material Selection drives:

- Cost and time to produce
- Performance and adaptability to design changes
- Look, feel, and sense of quality
- Reliability
- Environmental impact

Spend the time now to select the right material for your product - you may not have a second chance!

Material Properties to Consider:

- Mechanical properties: response of the material to force and load
- Physical properties: based on the inherent behavior of the material (usually driven at molecular level)
- Thermal properties: reaction of the material in the presence of heat or cold
- Electrical properties: ability of a material to transmit, store, or impede electricity
- Optical properties: ability of the material to transmit, reflect, or absorb light
- Environmental properties: ability of the material to maintain performance in its application environment

Often overlooked Material Considerations:

- The choice of material constrains manufacturing process selection for a given geometry (this affects both ongoing and capital costs)
- Some material prices fluctuate based on the market with significant effects
- "Brand name" materials (especially plastics) can be significantly more costly than others (make sure you understand your product's requirements)
- Quality: Material attributes can dramatically affect quality
- Material quality must be monitored to maintain product quality (material specifications are critical to this)

Reference Materials:
https://build4scale.llnl.gov/docs/modules/Module_2A.pdf

FMEA

Failure Mode Effects Analysis is a highly structured, systematic, product-design methodology for pre-evaluating potential products and processes. There are two primary types of FMEA:

- **Design FMEA (DFMEA)** - analyze material properties, geometry, tolerances, systems, and environments
- **Process FMEA (PFMEA)** - analyze human error, communications, machinery, materials, measurement, and environmental factors affecting process

FMEA is often the first step of a product or process reliability study, involving reviewing as many components, assemblies, and subsystems as possible to identify failure modes, their causes and effects. For each component/process, failure modes and resulting effects on the system are recorded in a specific worksheet.
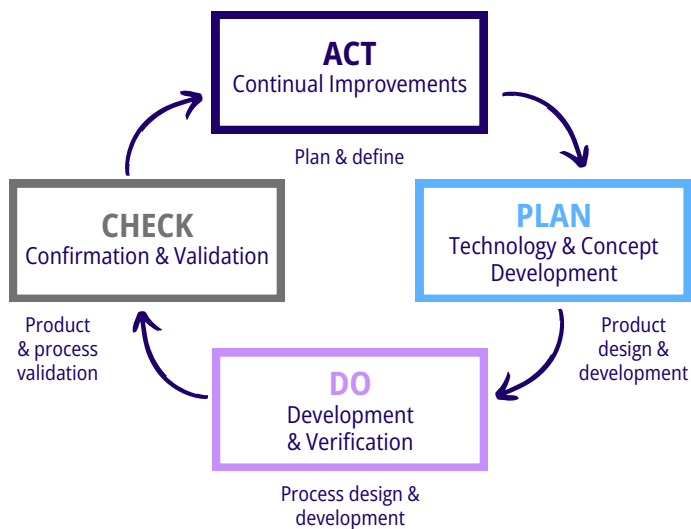

Figure 5.3.1: FMEA flow

Steps

1. **Review** the design: Use a blueprint or schematic and if available the actual product/prototype of the design/product to identify each component and interface
2. **Brainstorming** 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
6. **Assign** detection ranking: Based on the chances the failure will be detected prior to the customer finding it
7. **Calculate** the risk priority (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 FMEA
10. **Calculate** the resulting RPN: Re-evaluate each of the potential failures once improvements have been made an determine their impact on the RPNs

Step 1 - Review the Design

- Assemble a cross-functional team (design, manufacturing, quality, supplier, sales, and marketing)
- Help 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
- Ensure you are studying all components defined in the scope of the FMEA
- 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

Step 2 - Brainstorm Potential Failure Modes

- Before you begin the brainstorming session, review documentation for clues about potential failure modes
- Use customer complaints, warranty reports, and reports that identify things that have gone wrong, such as hold tag reports, scrap, damage, and rework, as inputs for the brainstorming activity
- Identify the scope of FMEA; such as process functions and boundaries, customer requirements, and product or parts to analyze
- Additionally, consider what may happen to the product under difficult usage conditions and how the product might fail when it interacts with other products
- Consider potential failure modes for each component and interface
- A potential failure mode represents any way the product component could fail to perform its intended function or functions
- Many components will have more than one failure mode. Document each one. Do not leave out a potential failure mode because if rarely happens.

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 affect customers; others effect the environment, the product-production process, and the product itself

Step 4 - Assign Severity Rankings

The severity-ranking scale is critical to the success of FMEAs because they establish the basis for determining the risk of one failure mode relative to that of another:

- Based on a relative (not an absolute) scale, often ranging from 1-20 (A "10" means the effect has a dangerously high severity, leading to a hazard without warning whereas a severity ranking of "1" means the severity ranking of "1" means the severity is extremely low). The example shown in Figure 5.3.2 below uses a 3 point scale.
- The FMEA ranking scale should be used consistently throughout an organization; this enables comparison of the Risk Priority Number (RPN) of different FMEAs to one another
- The best way to customize a ranking scale is start with a generic scale and modify it to be more meaningful to your organization
- By adding organization-specific examples to the ranking definitions, FMEA teams will have an easier time using the scales (the use of examples saves teams time and improves the consistency of rankings from team to team)
- As you add examples specific to your organization, 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. However, remember that each row should reflect the same relative impact, or severity, on the organization or customer.

See DFMEA Checklists at **www.qualitytrainingportal.com**

Risk	D	P	S	Risk	Mitigation Activity
Use life for component X is less than the required product use life	2	3	2	12	Plan for service strategy to replace part if more cost effective than increasing component performance
Product downtime has significant impact on customer operation	3	2	1	6	Plan for fast-responding repair service or achieve sufficient reliability confidence through additional test and data collection

Figure 5.3.2: FMEA Example, using a 3 point scale

Step 5 - Assign Occurrence Rating

- For each failure mode, determine all the potential root causes
- For each cause, determine the occurrence rating (O) decisions
- For each progress function, identify all the ways failure can occur. You need to know the potential cause 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

If we know the cause, we can better identify how frequently a specific mode of failure will occur

- This rating estimates the probability of failure occurring for that reason during the lifetime of your scope
- Occurrence is usually rated on a scale of 1-10, where 1 is extremely unlikely and 10 is inevitable. An occurrence is very high; it happens all of the time (Conversely, a "1" means the probability of occurrence is remote)
- Your organization may need to develop a customized occurrence-ranking scale to apply to different levels of 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 and select the one that applies to the design or product
  - time-based
  - event-based
  - piece-based

Step 6 - Assign Detection Rankings

- This rating estimates how well the controls can detect either their cause or their failure mode after they have occurred, but before the customer is affected
- For each control, determine the detection rating (D) by considering 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

- Detection controls detect 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
- For each cause, identify current process controls: these are tests, procedures, or mechanisms that you now have in place to keep failures from reaching the customer
- Detection is usually rated on a scale of 1 to 10, where 1 means the control is certain to detect the problem and 10 means the control is certain not to detect the problem (or no control exists)
- 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

Step 8 - Develop an Action Plan

Identify recommended actions and how to address:

- These actions may be design or process changes to lower severity or occurrence
- They may additional controls to improve detection
- Identify the key person for the actions and target-completion dates

Common areas of focus include:

- The RPN can be reduced by lowering severity, occurrence, or detection individually or in combination with one another
- A reduction in 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 an RPN above a maximum target of 200 presents an unacceptable risk and must be reduced. If so, then an action plan identifying who will do what by when is needed.

Step 9 - Take Action

- Assemble a cross-functional team (design, manufacturing, quality, supplier, sales, and marketing)
- Identify the scope of FMEA; such as process functions and boundaries, customer requirements, and product or parts to analyze
- For each cause, identify current process controls: these are tests, procedures, or mechanisms that you now have in place to keep failures from reaching the customer

Step 10 - Recalculate RPN

Recalculate the RPN to gauge the impact of changes from these changes.

Continue the Process

DFMEA and PFMEA should be done periodically throughout the lifecycle of process and product design for analyzing potential failures due to changes over time.

Create a copy or **this FMEA template** for each component of your design.

Flowchart Software

Your ideal software environment should be dynamic and versatile—choose platforms that can be used for many applications such as process flow, materials handling flow, product development, plant layout, etc.

1. LucidChart is a web-based application with a variety of templates and real-time collaboration tools.
- Forever free plan with 3 editable documents
- Real-time collaboration
- 100+ free templates
- Wide range of import options including Microsoft Visio, OmniGraffle, Gliffy, diagrams.net
- Export to Microsoft Visio, PDF, image files, SVGs

Watch this **one minute tutorial** to get to know LucidChart's design interface.

PRICE: Forever free basic plan, paid plans start at $8/person/month

2. Miro is a collaborative whiteboarding that can also be used for flowcharts and diagrams.
- Web, desktop, and mobile apps available
- Import data directly from Excel and Google Sheets
- Visuals are highly customizable

Check out **this deep-dive into Miro's diagramming features.**

PRICE: Forever free plan available including 3 templates, subscription plans available for $10-$20/person/month.

3. Microsoft Visio is often considered the industry standard for flowcharts and graphics. Because Visio is a Microsoft product, the familiar user interface makes it easy to get started if you're a Microsoft Office or Teams user, but visual customization and access on MacOS are limited.
- Web & desktop app. For Max users, web app only
- Convert Excel process maps into Visio diagrams directly within Excel with Data Visualizer
- Automatic sorting of flowcharts makes it easy to clean up
- Limited visual and customization opens

See this **one minute overview video** of Visio

PRICE: No free plan available. Subscription plans range from $5-$15/person/month, one-time purchase licenses are priced at $310 (standard) and $580 (professional)

4. FigJam is a collaborative whiteboarding web and desktop application run by design software Figma. The functionality, design features, and real-time collaboration are very similar to Miro. If your team is already using Figma to design assets or wireframe/prototype applications, this would be an easy switch for a small additional cost.
- Highly customizable and great for working in real-time with your team
- Import from CSV or copy/paste from a spreadsheet
- Export to image, SVG, PDF, and other file formats
- Visuals are highly customizable

Read **FigJam's one minute overview** here.

PRICE: Free forever plan with 3 editable documents and unlimited collaborators. Paid plans from $3-$5/month.

5. Visual Paradigm has broken down its user interface by very relevant agile topics that may help direct efforts. I.e. Process improvement, customer journey maps, process design, etc.
- In-depth, industry-specific templates and tools following methodologies for software developers and systems engineers
- Limited visual customization options

PRICE: No free plan available. Subscription plans range from $6-$89/person/month or $99-$1999/lifetime license.

6. Edraw has been around a long time with many recalling its CAD programs in the 90's. Now they have a huge variety of software. It can be a little overwhelming for non-tech users, however, all the software options appear very complete. Edraw has 3 min products with varying levels of complexity:
- EdrawMax is the most comprehensive product best for complex software and system planning
- EdrawMind is a collaborative mind mapping and brainstorming tool
- EdrawInfo is a beginner-friendly design tool best for simple flowcharts and infographics

Check out this **2 minute overview of EdrawMax** to get a better idea of their features.

PRICE: EdrawInfo is FREE. EdrawMax is $245 lifetime or $99/year. EdrawMind is $145 lifetime or $59/year. Lifetime bundle of all 3 is $312.

7. Smartdraw is an easy-to-use option for both chart- and graph-based diagrams. The pricing is low compared to its competitors, but it has limited visual customization options.
- Integrates with Google, Microsoft, Atlassian, Trello, AWS
- Import Visio and LucidChart files
- Exports to Visio, SVG, and images
- Limited visual customization options

Check out this 2 minute overview of Smartdraw.

PRICE: No free plan, 7 day free trial. $10/person/month, or $6/person/month with 5+ members.

8. Diagrams.net is an open source technology stack for diagrams and flowcharts—their mission to "provide free, high quality diagramming software for everyone." The software is run by JGraph Ltd of Northampton, England.
- Security focused
- Downloadable apps that allow you to edit flowcharts on Google Docs/Sheets/Slides, Atlassian apps, Git, Dropbox, and Notion. This is where you may end up paying for a software product—when a software company builds a third-party integration on top of the open source software.
- Import files from Visio, Gliffy, and LucidChart
- Export files to image files, SVGs and other vector files, and more
- Offline version for Windows, macOS, Linux, and Chromebooks
- No real-time collaboration available

PRICE: Completely free!

9. Visime is an amazing visual creation tool for creating presentations, documents, data visualizations, videos and other branded content—like Canva for your data. Visime has a variety of easy-to-use methods for traditionally harder to achieve visual communications, like making your own videos and animations. If you're a designer, this may be a great option for creating sales content and impressive graphics for your investor pitch deck. But, it is one of the more expensive options and may require too much setup time for your team to use day-to-day.
- Visuals are highly customizable
- Animations and video creation tools

PRICE: Forever free plan (with Visime logo watermark and limited export options), $29/month personal plan, $59/month business plan. Price is greatly reduced when billed annually.

Other Options To Consider:
- Google Drawings
- Textografo
- Cacoo
- Zenflowchart

Insight from Established Companies

Reaching out to engineers and manufacturing experts in established larger companies, they mentioned the importance of some factors to consider:

1. Ability to integrate into a collaborative environment (i.e. merge info into other programs, multi-used simultaneous),
2. Long-term maintenance and usability of files (what happens if software is changed, or you drop service),
3. Ability to tie into other data systems
4. Confidentiality

Many established companies use Microsoft Visio as the standard. There has been concern expressed about the number and cost of software updates and inability to use Visio on a Mac system.

Reference Materials:
- **Softwaretestinghelp guide** to flowchart software
- **Zapier's review** of flowchart software
- **Stackshare's list** of hardware company tech stacks