ENGINEERING FOR impact

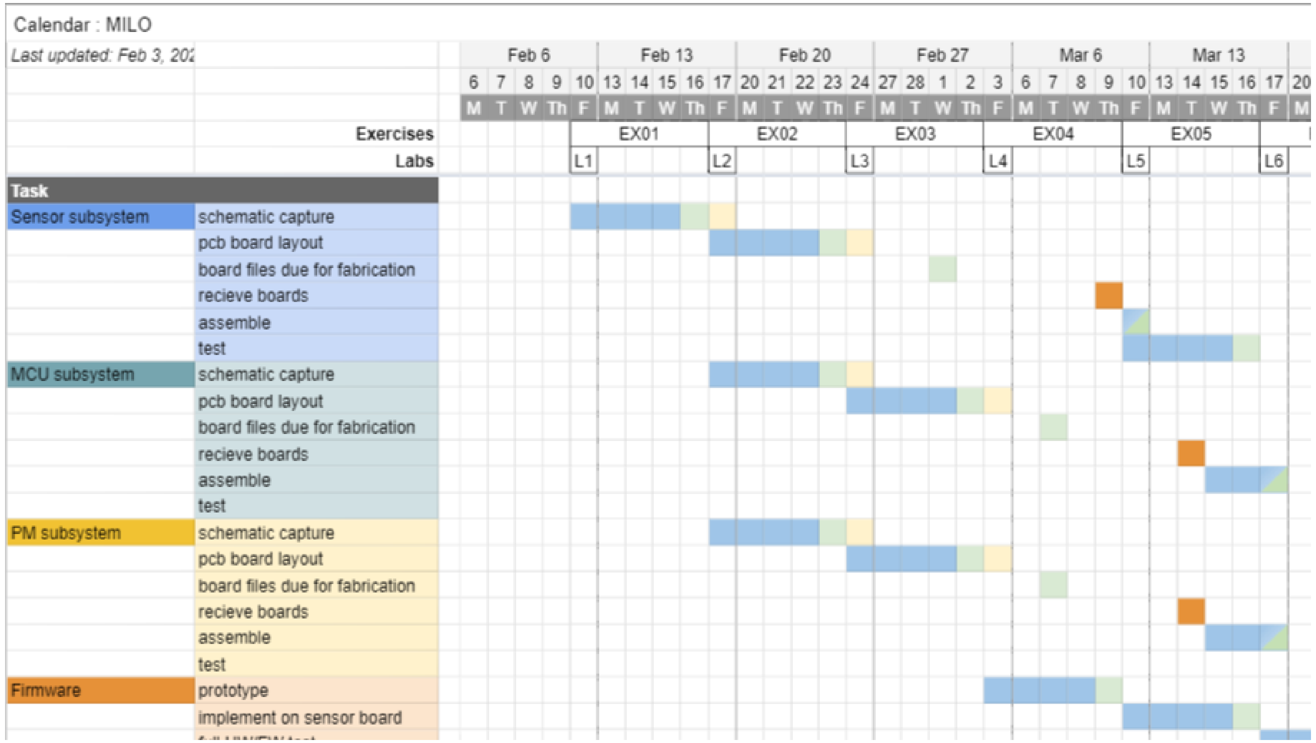
mit 6.900

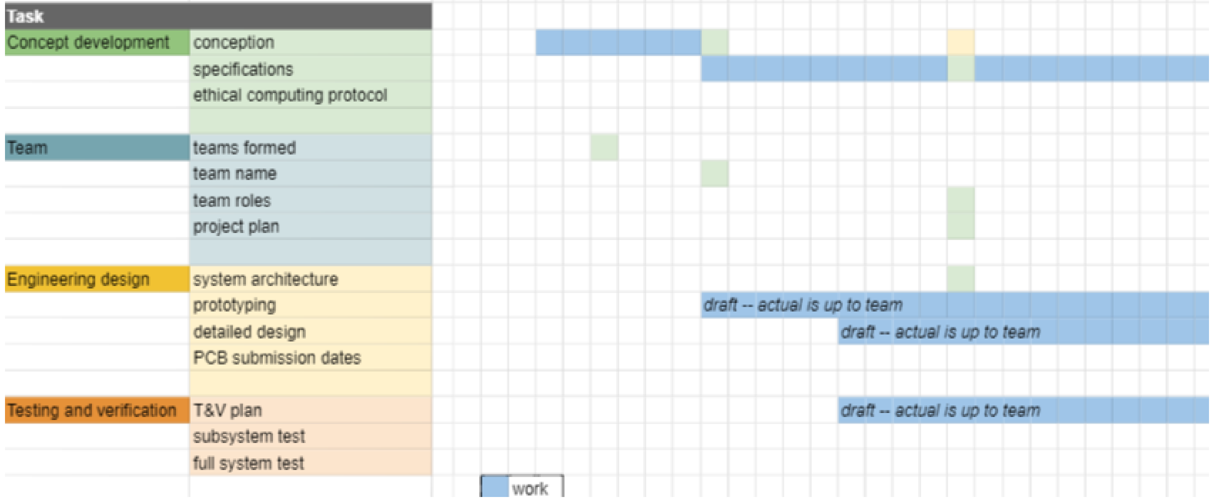
Lecture 3

February 14, 2023

This week

- EX01
  - Pebble wrap-up *aka* first team exercise
  - MILO sensor board schematic design
  - Valerie concept development
- Lab 2
  - Sensor board schematic review
  - Valerie concept discussion



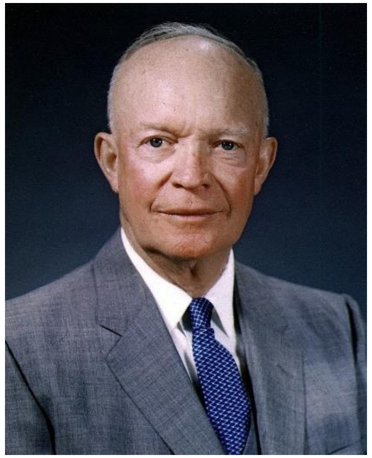


TODAY

- The HW/SW product development process *with a focus on engineering design*
- MILO

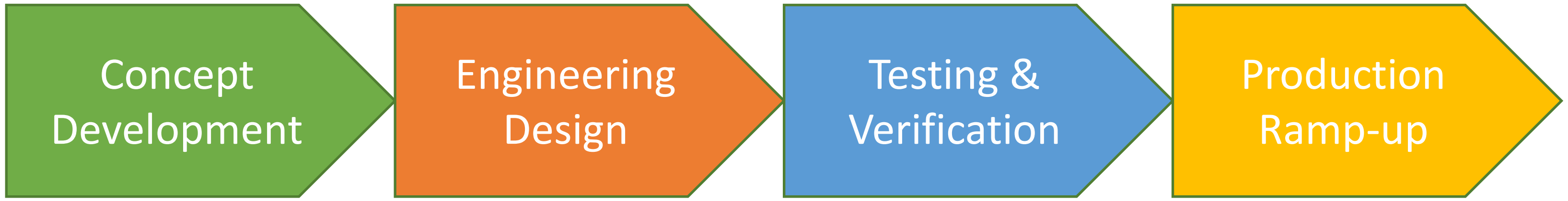
"In preparing for battle I have always found that plans are useless, but planning is indispensable"

--Dwight D. Eisenhower



Product development process

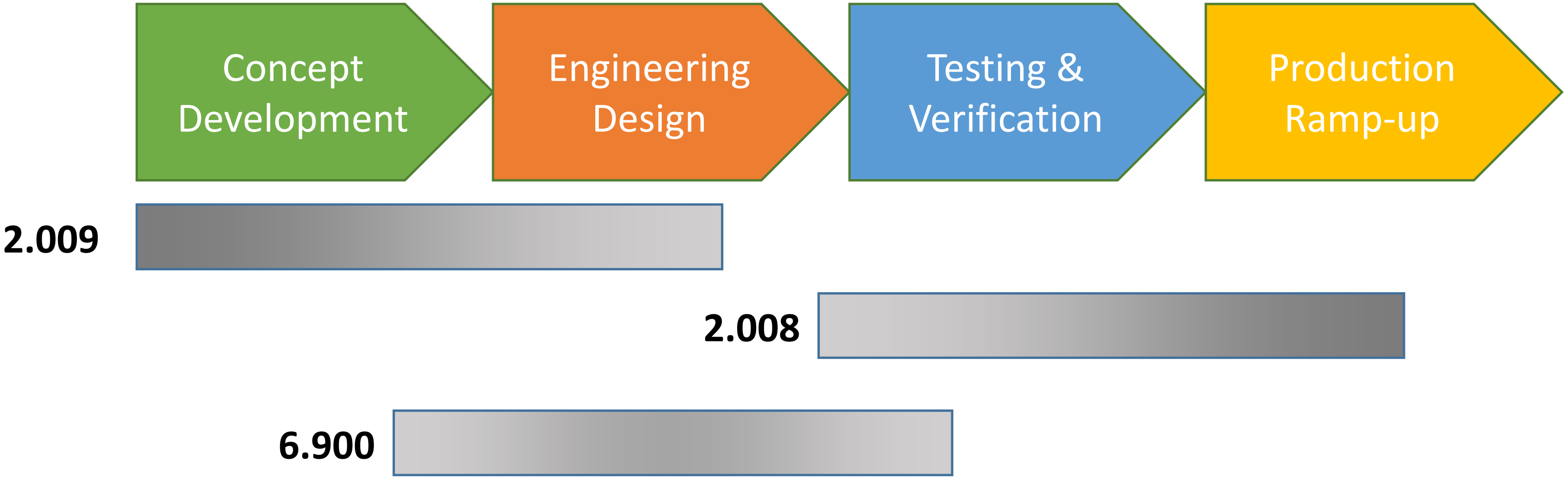
- Many different specific processes, terminology, number of steps, and so on, but generally



- Concept development: identify requirements, establish target specifications, generate concepts, refine and select most promising concept
- Engineering design: develop product's system-level architecture, partition into subsystems, design subsystems, prototype subsystems, integrate back into system
- Testing & verification: Evaluate the subsystems and complete system, verifying that it meets spec
- Production ramp-up: Transfer to manufacturing, verify quality, ramp up production, commercialization

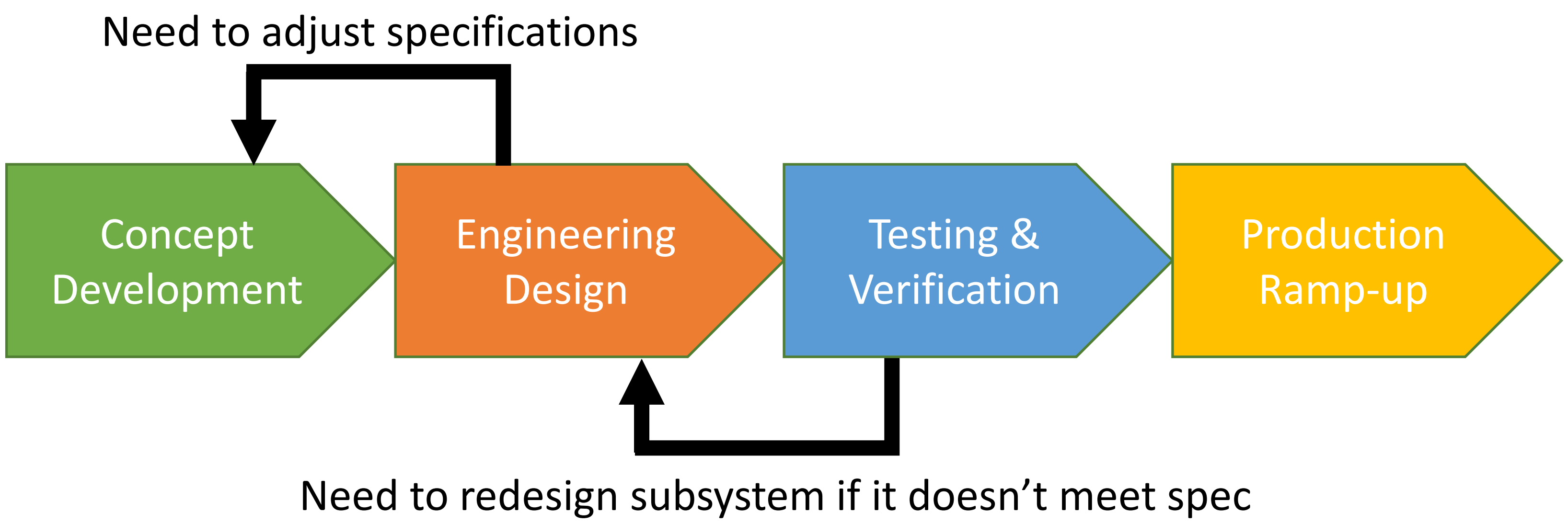
Product development process

- There are classes at MIT that focus on different aspects of this process
- It's too much for a single class!



Product development process

- This process is not linear…**iteration will be necessary**



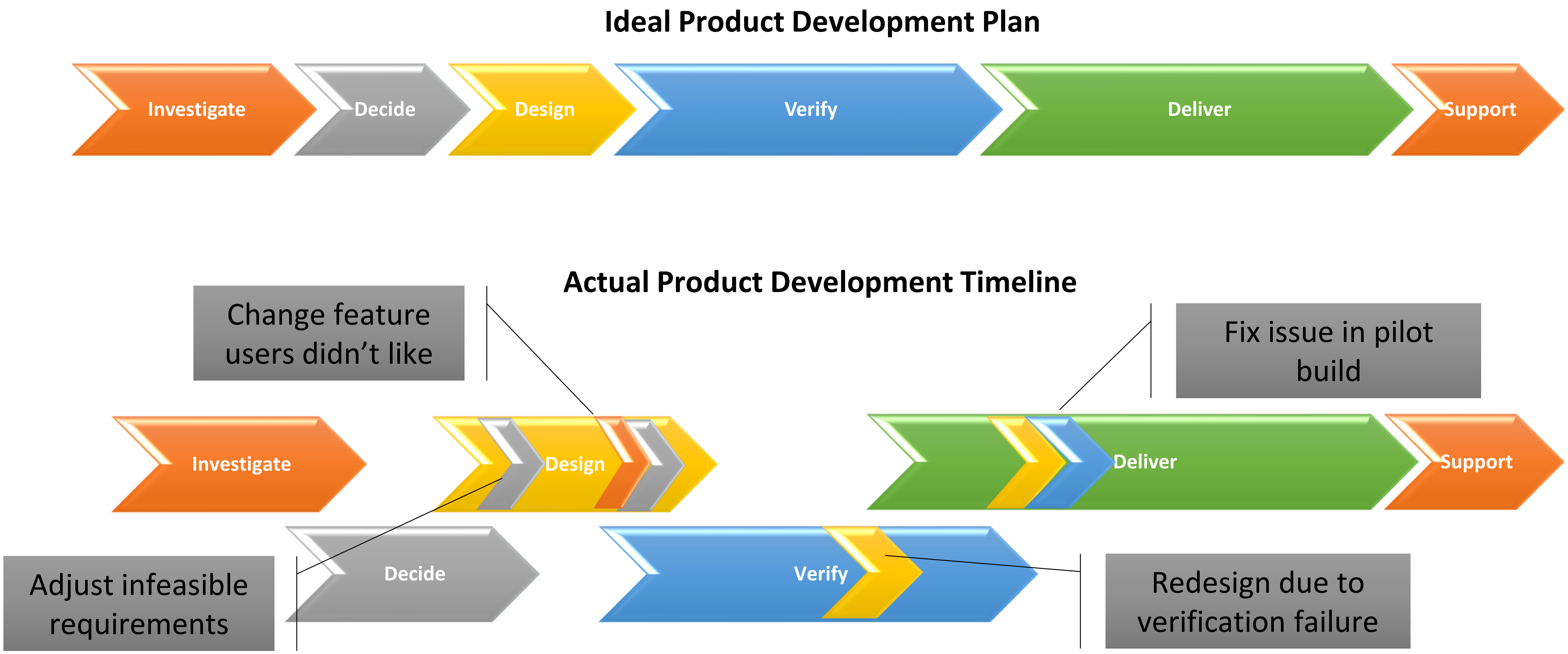
- But the farther you go to the right, retrenching gets more $$$
- So the more you can figure out early on…the better

Product development process

- Each step takes different amounts of time, depending on product, market, etc.

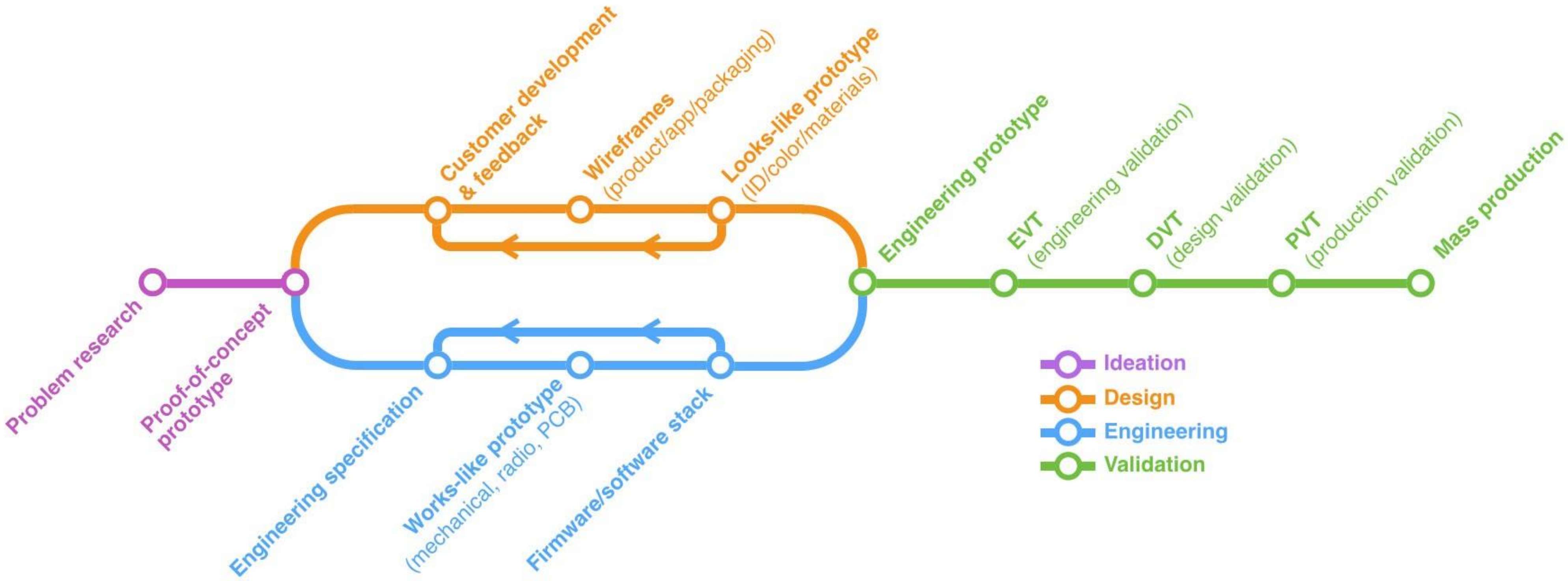
Product development process

- Here is Milwaukee Tool’s product development process



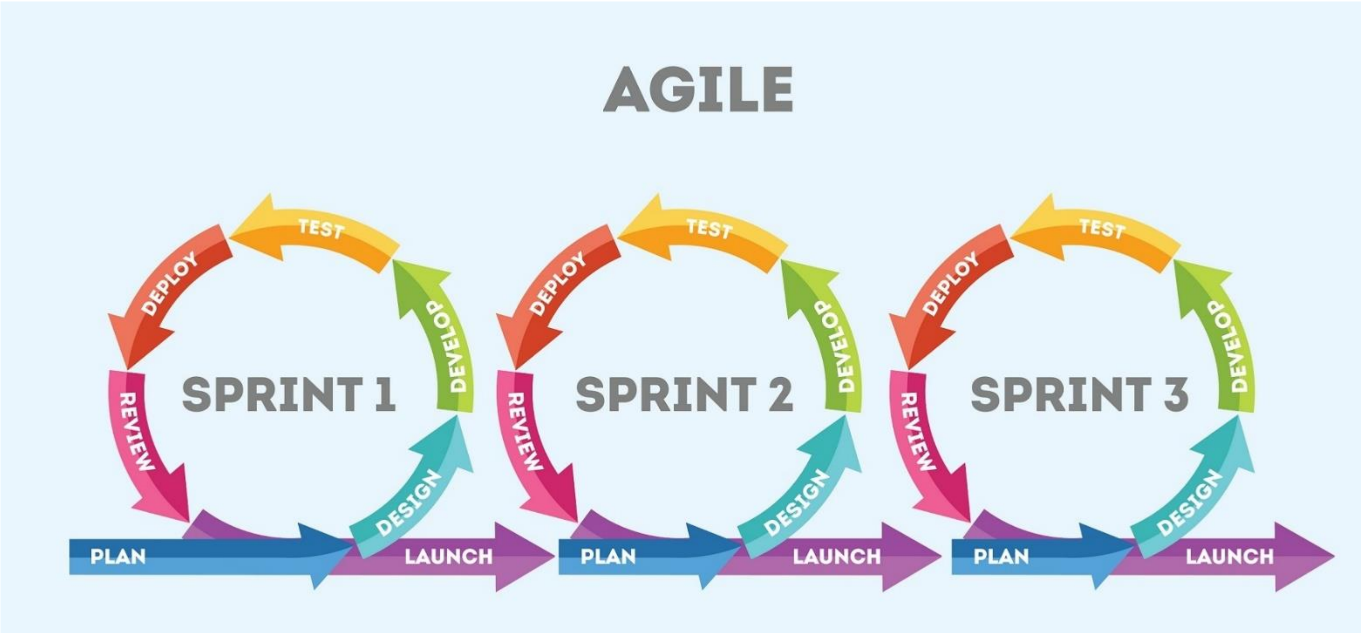
Product development process

- Here is Bolt.io’s HW/SW product development process

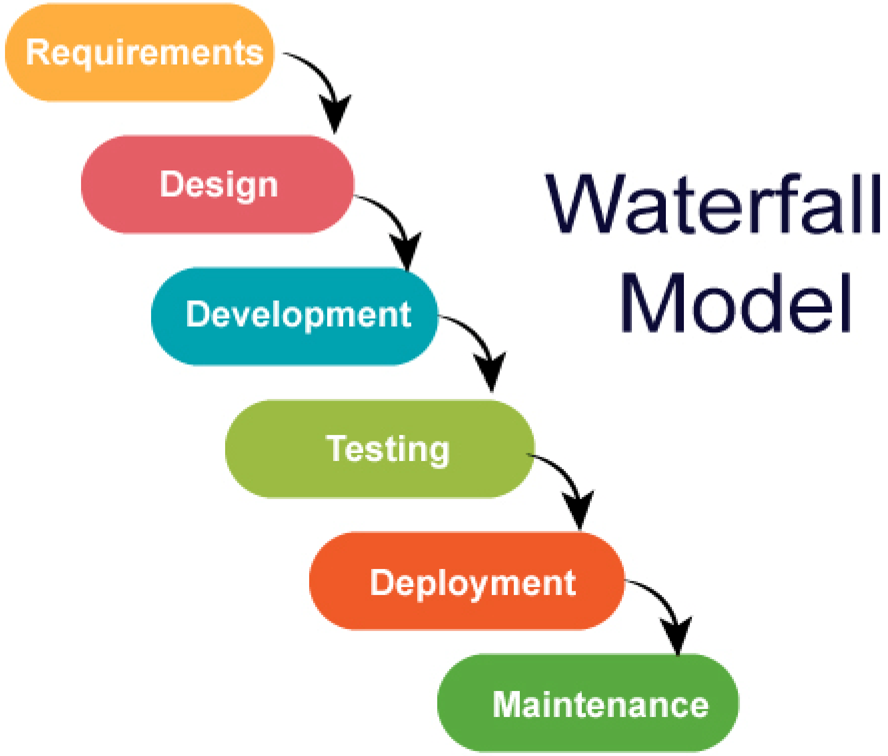


Product development process

- You may also hear about “waterfall” and “agile”



https://www.soldevelo.com/



https://medium.com/@chathmini96/waterfall-vs-agile-methodology-28001a9ca487

Product development process

This stuff gets quasi-religious…

…in practice it's often a mix

Product development process

The two most important points of today:

1. **Have a plan**
2. **Write stuff down**

HW/SW product development

What's special about HW/SW products?

- They have commonly recurring sets of specifications
- Prototyping nowadays is easier & faster than in some other sectors
  - And in the past
- You can often change the SW after the product goes out…kinda hard to change the HW!
  - This makes part of the product static (HW) and part dynamic (SW) → we can use that!
  - In fact, the ability to update the firmware is often an important requirement ➔ implies some sort of connectivity, typically wireless
    - A great example of SW requirement impacting HW (need radio transceiver on-board)

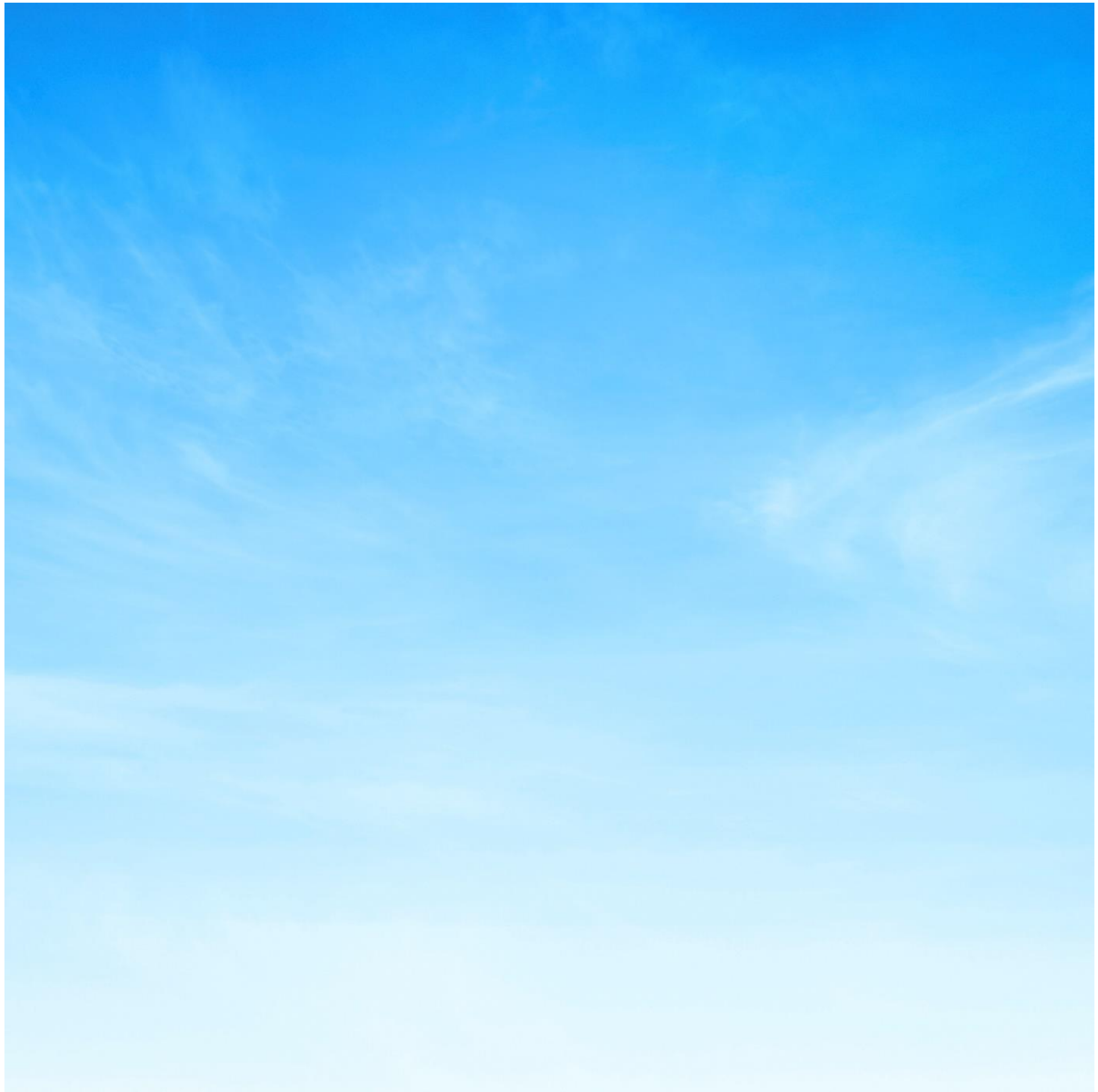
OK, let’s get started

MILO: the MIT AIr QuaLity MOnitor

- Air ideally is
  - 78% N_2
  - 21% O_2
  - 0.9% Ar
  - 0.03% CO_2
  - Water vapor
  - Trace gases

Anything else is undesirable… such as

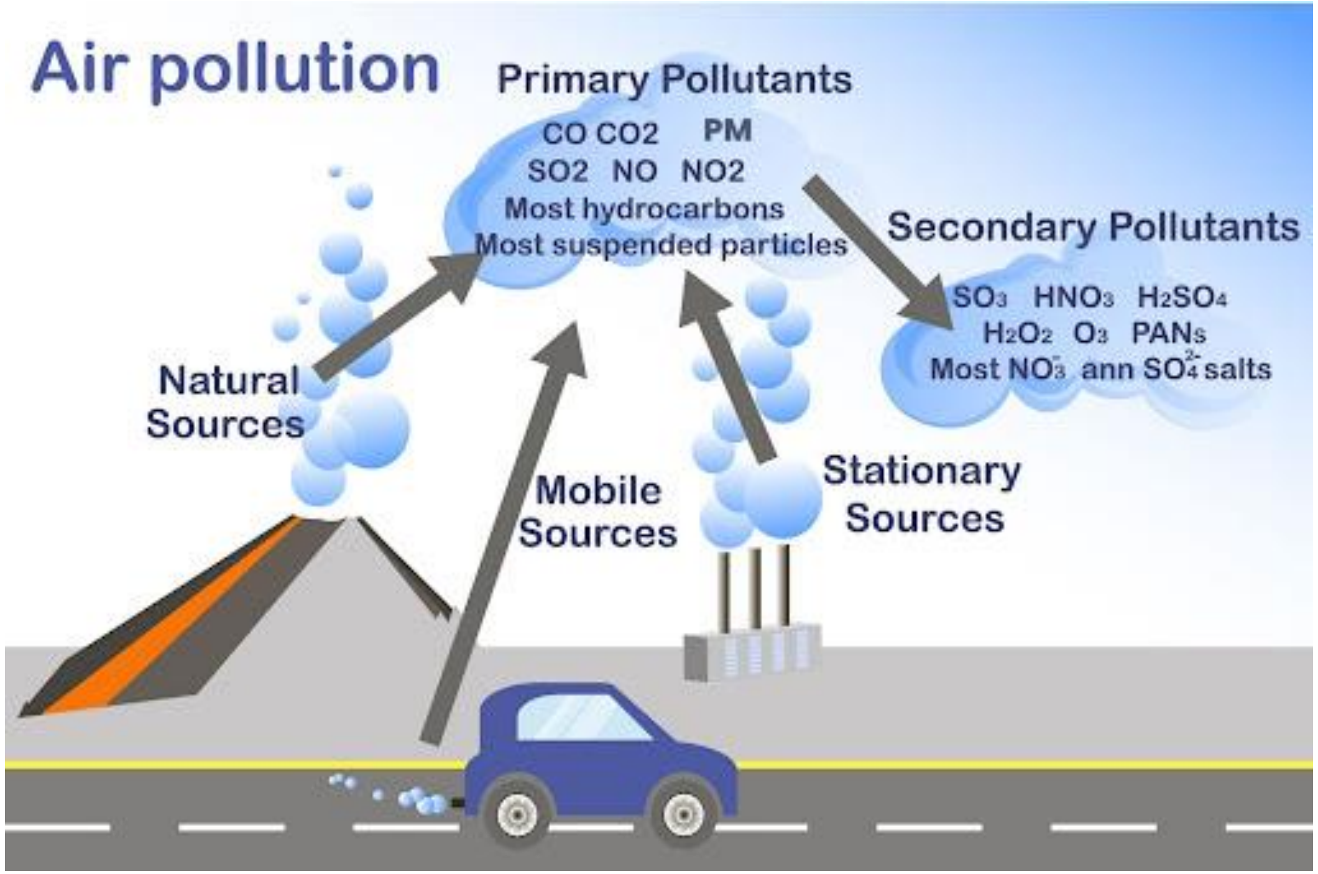
- Reactive species
- Aerosols
- Dust



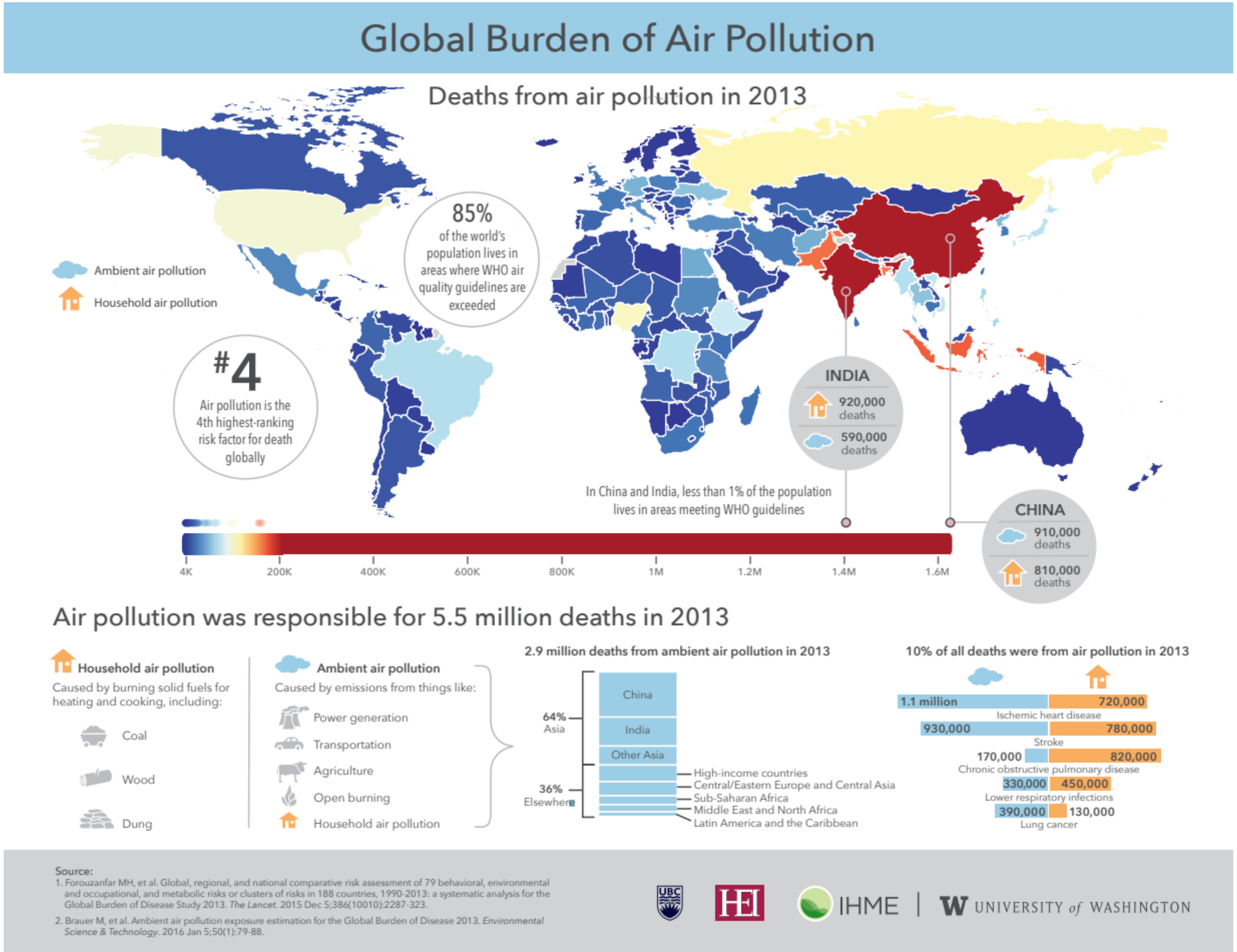
MILO: the MIT AIr QuaLity MOnitor

Why do we care?

- Harms human health
- Damages ecosystem
- Contributes to climate change



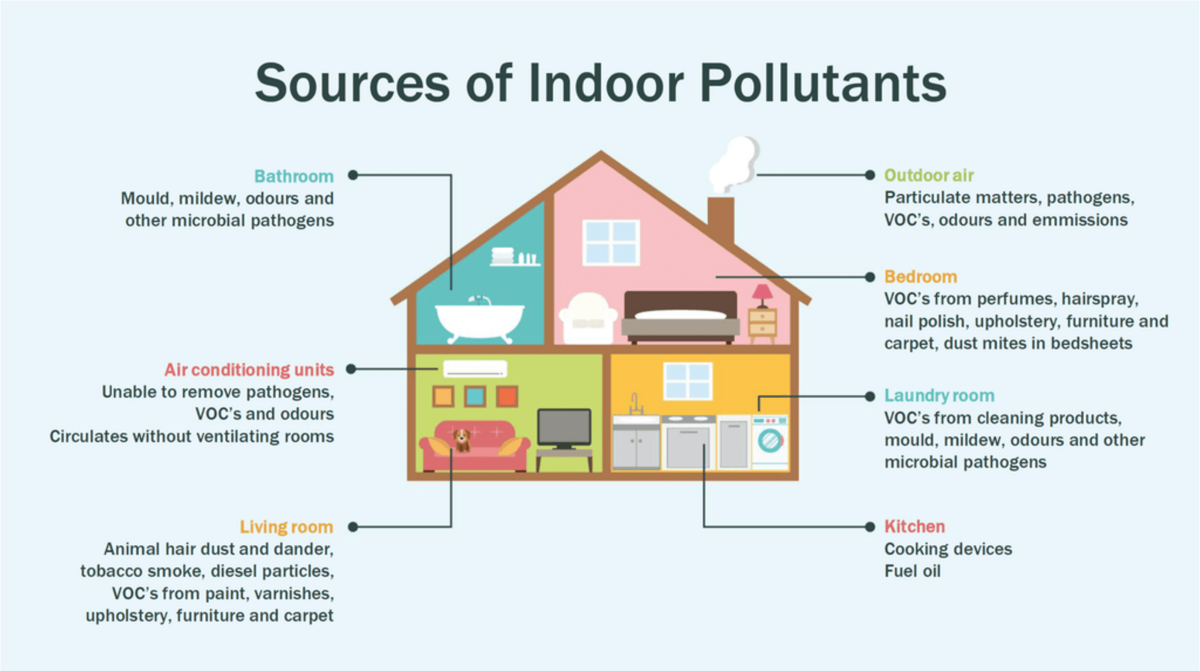
MILO: the MIT AIr QuaLity MOnitor



MILO: the MIT AIr QuaLity MOnitor

Indoor and outdoor air quality

- Indoor air is not just outdoor air
- Sources of pollutants differ



MILO: the MIT AIr QuaLity MOnitor

Smoke from Oak Fire prompts Bay Area air quality advisory, chokes Sierra Nevada

California's biggest 2022 wildfire has burned more than 18,000 acres

The Mercury News

JERSEYDALE, CALIFORNIA – JULY 24: A column of smoke rises above the Oak Fire on July 24, 2022 near Jerseydale, California. The fast moving Oak Fire burning

THE CLIMATE 202

Gas stove pollution causes 12.7% of childhood asthma, study finds

Analysis by Maxine Joselow
with research by Vanessa Montalbano

January 6, 2023 at 7:30 a.m. EST

The Washington Post
Democracy Dies in Darkness

MILO: the MIT AIr QuaLity MOnitor

Calls for post-Covid 'revolution' in building air quality

BBC

14 May 2021 · Comments

Coronavirus pandemic

MILO: the MIT AIr QuaLity MOnitor

Chinese capital issues first smog alert of winter

By Reuters Staff

2 MIN READ

A thermal power plant is seen near residential buildings in Beijing, China November 21, 2018. Picture taken November 21, 2018. REUTERS/Jason Lee

REUTERS

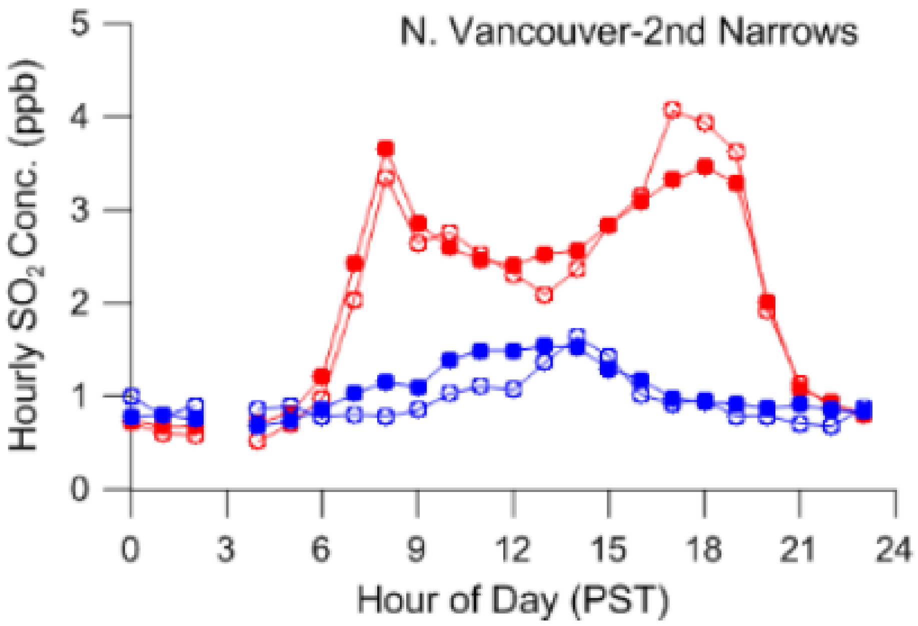
MILO: the MIT AIr QuaLity MOnitor

Why measure?

- We can do something about it
  - Clean air, turn on fan, open window, etc.
  - Inform policy, legislation
- We can learn about health effects
  - Measure exposures, correlate to outcomes
  - Beyond zip-code level, can we get to street-level, building-level, personal exposure monitoring?

MILO: the MIT AIr QuaLity MOnitor

- Why measure locally, frequently?
  - Air quality can change block by block, and hour by hour
  - Get to accurate & precise exposure monitoring



North Vancouver–Moodyville Air Quality Monitoring Study (2016)

Apte Research Group

MILO: the MIT AIr QuaLity MOnitor

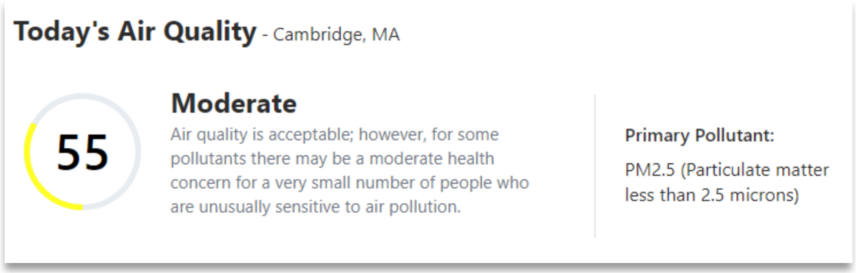
What exactly are we trying to measure?

- Multiple classes: **primarily arise primarily from combustion: cars, trucks, tobacco smoke, cooking, etc.**
  - Nitrogen oxides (NO_x: NO + NO_2)
  - Sulfur dioxide (SO_2)
  - Particulate matter (PM)
    - Complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air
    - Are also derived via reactions of SO_2, NO_x, etc.
    - Classified by size
      - PM_{10} : particles with a diameter of 10 microns or less
      - $PM_{2.5}$ particles with a diameter of 2.5 microns or less
  - Volatile organic compounds (VOCs)
    - Higher indoors
    - Acetone, benzene, formaldehyde, etc.
  - Ozone O_3
    - Arises via reaction of sunlight + volatile organic compounds (VOCs) and NOx
  - Carbon monoxide (CO)

That's a lot of stuff to measure…

MILO: the MIT AIr QuaLity MOnitor

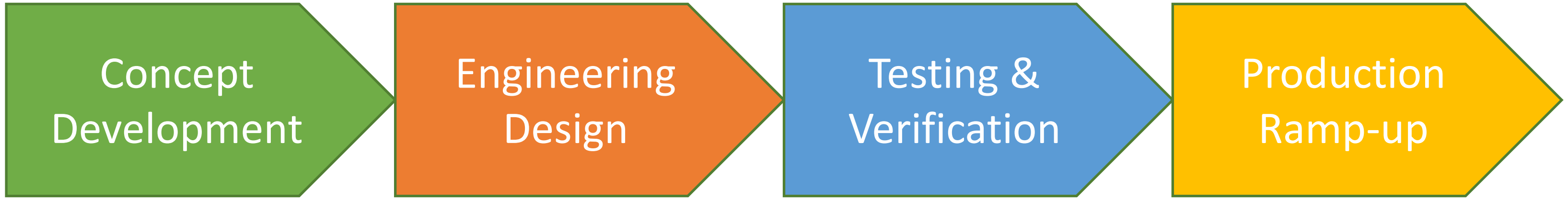
- Need to condense down into simple metric that *people* can understand: air quality index (**AQI**) ➔ scalar rather than vector
- Overall agreed-upon metric for reporting air quality
  - Comprised of $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3 [1h & 8h]
  - Quantities averaged over 1h, 8h, 24h
  - Piecewise-linear model for each pollutant
  - Overall AQI = highest (worst) AQI of all measures



Category	AQI	$PM_{2.5}$ (µg/m^3) 24hr avg	PM_{10} (µg/m^3) 24hr avg	NO_2 (ppb) 1hr avg	SO_2 (ppb) 1hr avg	CO (ppm) 8hr avg	O_3 (ppb) 8hr avg	O_3 (ppb) 1hr avg
Good	0--50	0--12.0	0--54	0--53	0--35	0--4.4	0--54	-
Moderate	51--100	12.1--35.4	55--154	54--100	36--75	4.5--9.4	55--70	-
Unhealthy for Sensitive Groups	101--150	35.5--55.4	155--254	101--360	76--185	9.5--12.4	71--85	125--164
Unhealthy	151--200	55.5--150.4	255--354	361--649	186--304	12.5--15.4	86--105	165--204
Very Unhealthy	201--300	150.5--250.4	355--424	650--1249	305--604	15.5--30.4	106--200	205--404
Hazardous	301--500	250.5--500.4	425--604	1250--2049	605--1004	30.5--50.4	-	405--604

https://blue.cs.sonoma.edu/cs115/F17/proj/p1/cs115_p1.html

MILO: concept development



- Concept development: identify requirements, establish target specifications, generate concepts, prototyping (as needed), refine and select most promising concept
- Requirements [needs]
  - Focus on **what** the system should do, rather than **how** to do it
- Identify requirements: who's requirements? ➔ stakeholders' requirements
- Stakeholders: the people affected by your product
  - Customer, end-user 🡐 these often most important
  - But also retailer, employee, installer, etc.

Stakeholders

Customers are not always end-users…

ICU monitor

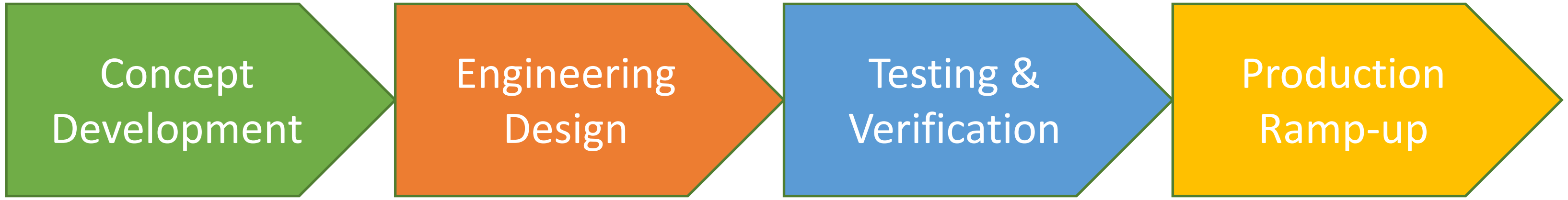
Hospital procurement

Customer

End-user

Stakeholder

MILO: concept development



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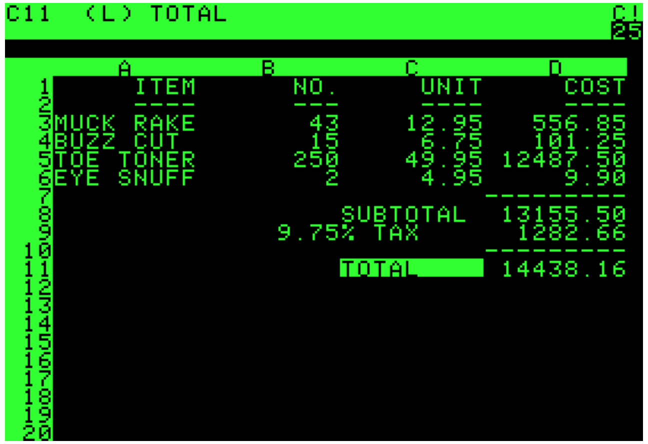
  - Customer, end-user 🡐 these often most important
  - But also retailer, employee, installer, etc.
- For MILO, stakeholders are 6.900 staff, 6.900 students, EDS staff
- *What about for Miami-Dade project [aka Valerie]*?

MILO: requirements

- Talk with stakeholders (esp. customers and end-users)
- Assemble list of requirements
- If extensive, organize into hierarchy
- Prioritize
    - Must have *vs.* Should have *vs.* Might have
    - ***, **, *
- Sometimes the customer doesn't know what they want – *latent* need



MILO: requirements

We developed requirements based on internal staff discussions and talking with EDS staff

Why not with students?

1. It should accurately measure indoor air quality **
2. It should be portable ***
3. It should be possible to get the data off the device **
4. It should be a useful pedagogical exercise ***
5. It should maintain privacy *
6. It should be low cost *
7. It should be rugged and robust **
8. Multiple systems should be able to be used simultaneously ***
9. It should be easy to view the current and past data **
10. It should leverage MIT facilities **

Valerie: requirements

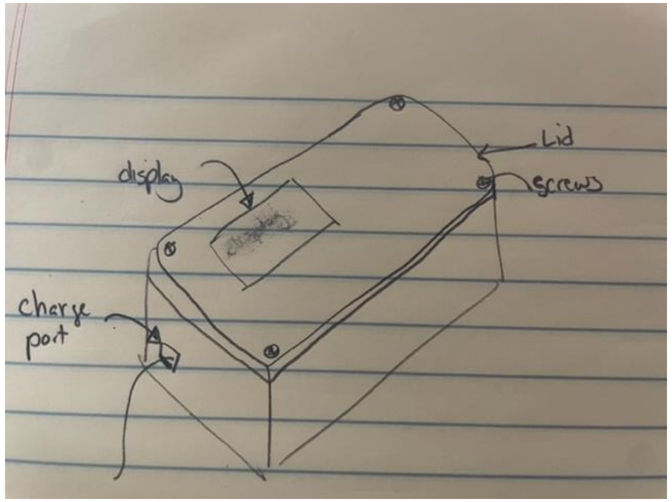
What do you think?

1. It should measure the "heat experience" at each bus stop, at least temperature and humidity, but also could include air quality.***
2. It should be able to measure how many people are waiting, and for how long.***
3. It should operate without being connected to line voltage. ***
4. It should be installable by a technician, and should be easy to set up.***
5. It should not be too expensive. *
6. Data from a sensor node should be able to be tied to a location.***
7. It should maintain privacy. ***
8. It should be rugged and able to withstand shipping, setup, and operation in the Miami-Dade environment. ***
9. Multiple systems should be able to be used simultaneously. ***
10. The system should incorporate data from Swift.ly and present that information to the operator in a useful way. ***

Next up

- You will iterate between concepts, setting specs, and doing design
- Here, we'll start with specs
- In EX01, we'll start with concepts

HW node sketch

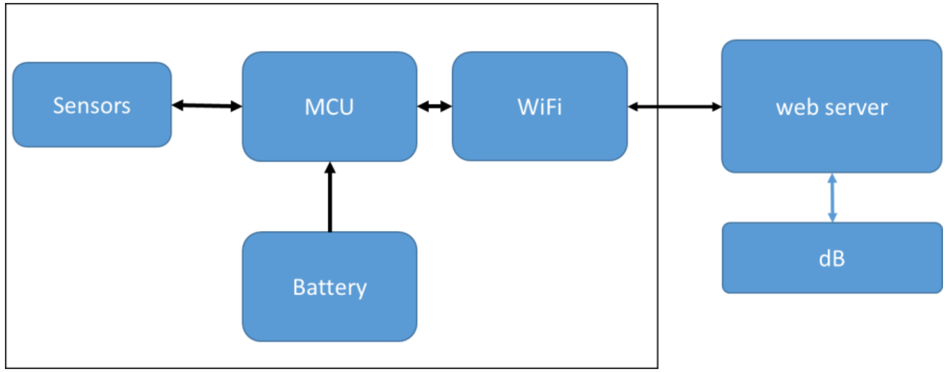


Questions:

- What exactly do we need to measure?
- How much will these sensors cost?

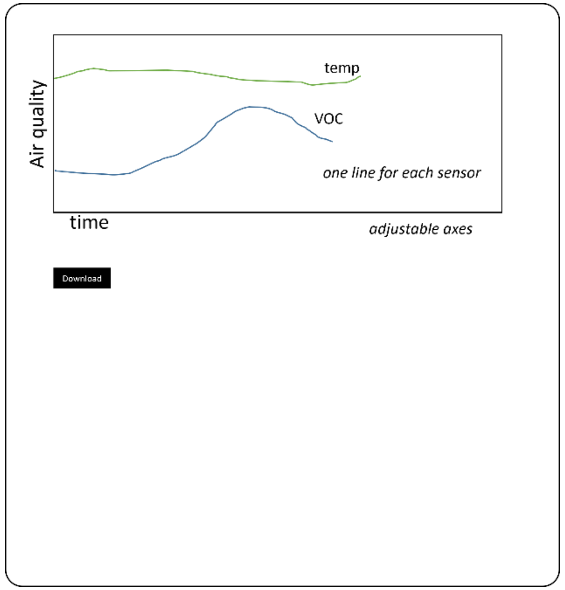
…and so on

System diagram



This is not a great system diagram – it's pretty generic, no details inside the MCU or server

Web wireframe



Next up

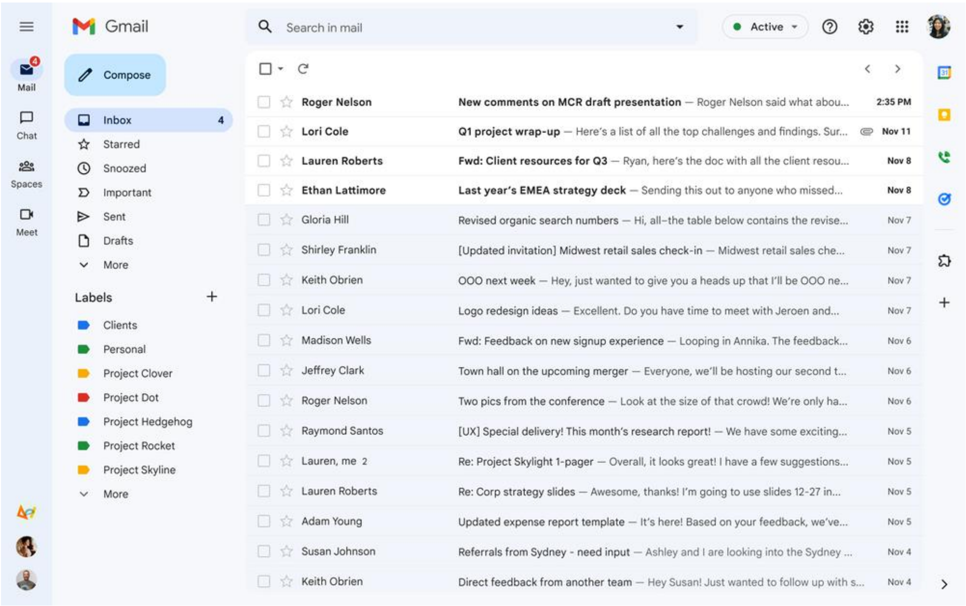
- You will iterate between concepts, setting specs, and doing design
- Not everything will necessarily be defined yet (and thus able to be concretely specified)
  - This may not be ok for some products (aerospace, medical) but often the case for consumer, etc. ➔ Iteration can be important
- HW and SW are specified differently
  - We'll see this

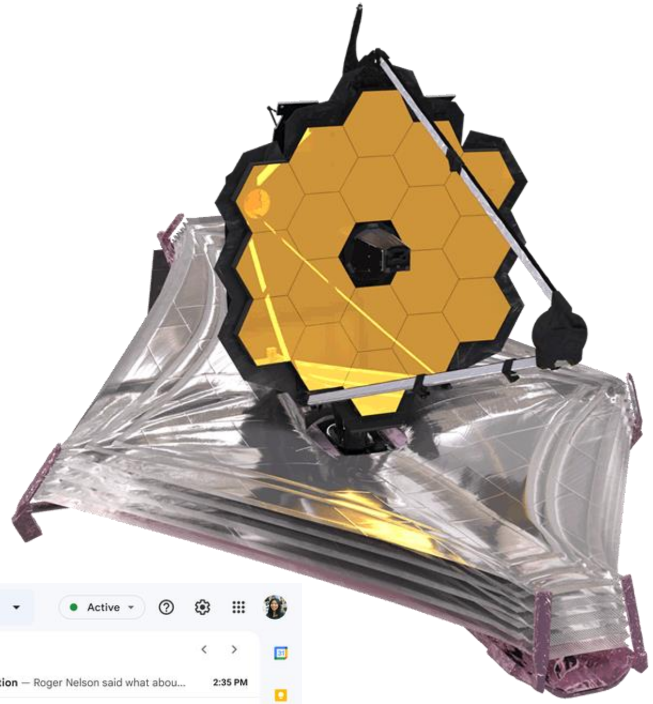
Specifications

- Translate requirements into a specification document
  - Covers both HW and SW aspects
  - The goal is to have constraints for our system→ *engineering is design under constraints*
  - If our specs are complete, if we build something that meets spec, then it will meet our requirements
  - Some specifications will directly imply a specific approach
    - The need for interoperability with another product may immediately specify WiFi
    - The company may impose use of MySQL dB or STM32 MCU because that's what's used by the rest of the company
  - Sometimes specifications will be much more open-ended
    - An opportunity for creativity & innovation!

Specifications

- What aspects do we need to specify?
  - There is no all-encompassing approach
  - These products are all specified differently





Common specifications for HW/SW products

Typically,

- Financial
  - BOM, COGS, price
  - Time to market
- Regulatory – safety, emissions
  - Anything with a radio, plugged into wall, etc.
  - For medical (and other regulated sectors) this can be quite extensive
- Industrial design
  - What does it look like, what materials are used, etc.
- Environmental resistance
  - Is it used indoors? In salt water? In an auto engine? On Mars?
  - IP [Ingress Protection] rating
- Engineering
  - Sensing, actuation, compute, comms, firmware, software, etc.
- Security & Privacy
  - Typically, user data is being communicated…what data? how is it being secured? who has access?
  - There may be regulatory requirements here as well: HIPAA
- Packaging
  - How is sent to the customer, could be simple/elaborate
- Installation and servicing
  - How does one go from “in the box” to “in use”?
  - Will it be serviced in the field? Will the SW be updated? Can the HW be fixed? Warranty?

These are not disjoint:

Needing to be updated after install: is that installation or engineering?

Needing to work outdoors will impact the materials used in the industrial design

Don’t worry. Just make sure it’s somewhere in document

Ultimately, specification document should encompass all requirements

MILO: from requirements to specifications

1. It should accurately measure indoor air quality **

- What is air quality?
  - Based on before, this is PM2.5,PM10, NO2, SO2, CO, O3 [1h & 8h]
  - Will generally also need to measure temperature and relative humidity, since many other variables depend on those
- What is accurate?
  - Need to establish for each sensor – TBD for now!
- What does indoor imply?
  - Has implications for environmental resistance
  - And availability of power [there are wall plugs, USB ports] indoors

MILO: from requirements to specifications

2. It should be **portable** ***

- What does this mean?
- Can work without being plugged in ➔ we really mean it should be small and light…watch vs. toaster
- For how long? 1 min? 1 h? 1 day? Other?
  - User is student: how long is student away from charger? 12h seems about right

These are both portable

MILO: from requirements to specifications

3. It should be possible to **get the data off** the device **

- It needs to be “connected” somehow
- Probably not just looking at a display and writing data down…
- Wired or wireless? Left unspecified ➔ Let’s go with wireless ➔ this then has regulatory implications because of the radio
- Lots of wireless comms approaches – specific one is TBD for now

MILO: from requirements to specifications

4. It should be a **useful pedagogical exercise** ***

- Should be possible for each student to learn some skills: PCB design/fabrication/assembly, 3DP, server set-up
- Want to connect to other classes
- Learn how to work as a team

Not sure how this will translate to specs…let's revisit

MILO: from requirements to specifications

5. It should maintain **privacy** *

- No personally identifiable information should leave the device
  ➔ implications for processing on server
- Information should be secure, only available to authorized users

MILO: from requirements to specifications

6. It should be **low cost** *

- What does that mean? $100 BOM [for electronics]

7. It should be **rugged and robust** **

- Able to be transported by holding and placing in backpack ➔ it will require an enclosure
- Able to survive 12” drop onto table

MILO: from requirements to specifications

8. Multiple systems should be able to be used **simultaneously**

- This has implications for server set up ➔ one server for class with multiple accounts? One server/student? One server with one db w/ different permissions?

9. It should be **easy to view** the **current** and **past** data

- Needs some storage, some sort of display ➔ exactly what, TBD
- The choice will implications for firmware, software, server

10. It should **leverage MIT facilities**

- Must only require tools & equipment we can readily access