Respirator Recommender Proposal - B143

June 6, 2024

Objective

The goal of this proposed project is to make it easier for people to find masks that have a high probability of fitting their face. Respirators are one of the best tools for protecting against airborne transmission of pathogens such as SARS-CoV-2. The material used for protective masks can filter at least 95% of particles in the worst case scenario of 0.3 microns (i.e. high filtration efficiency). However, filtration efficiency isn't the only thing that matters – fit can have a strong effect on the protection of the device. Gaps between the face and the high filtration efficiency respirators (e.g. N95, FFP2/CA-N95/FFP3/N100) can introduce leakage, which means that more unfiltered air is coming through. Poor fit decreases the effectiveness of the device as a source control or as protection for someone susceptible. When properly fitted they can reach protection factors in the double and triple digits (e.g. 10, 100).

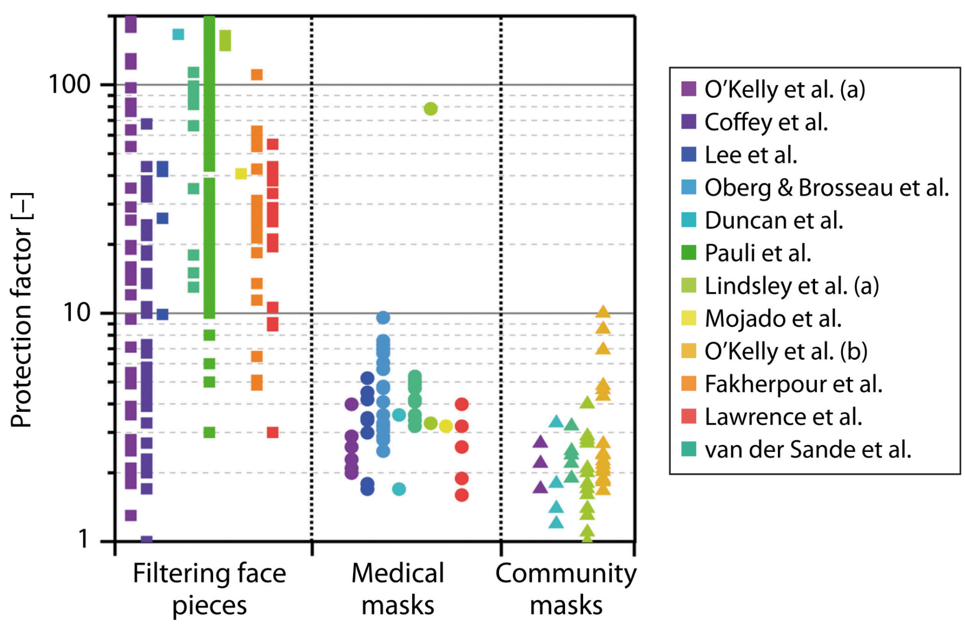


Fig 1. Protection factors from https://journals.asm.org/doi/10.1128/cmr.00124-23

The larger protection factors are more likely to happen when both filtration efficiency *and* fit are high. The higher the protection factor, the lower the dose one inhales, leading to a lower probability of infection, as theorized by Wells-Riley. It is important to get high fit factors especially for immunocompromised people. In one study, about 8% of COVID infections in hospital patients gotten from other people in the hospital have resulted in death. Likewise, Long COVID in a subset of the population has had a significant negative effect in people's quality of lives.

Poor Fit

There are two potential causes of poor fit:

- Mismatch between the geometric configuration of the face vs. the respirator (i.e. “static fit”)
- Structural stability of the respirator in response to dynamic movements (i.e. “dynamic fit”)

An example of poor static fit is if a respirator is too big / too small for a face (e.g. a kid wearing an adult sized respirator). It has also been shown that it is more challenging for Black, Asian, and minority ethnic groups to get a respirator that has a high protection factor, after multiple attempts (i.e. low pass rate). Another example of the interaction between facial features and the mask is that for the FloMask Pro, the manufacturer produces two versions of their adult mask: a high/medium nose bridge and a low/medium nose bridge. Likewise, in one study, women had an 85% pass rate compared to 95% for men. Thus, facial features and how those interact with the face matter. Design of the devices ultimately includes some part of the population, but also excludes others, and is an equity concern.

Existing Work and Known Problems

Aaron Collins (MaskNerd), Armbrust, and Accumed have created data sets which take into account the filtration efficiency of the mask along with breathability. Those are important metrics but neglect the fit for individuals. Likewise, there are current attempts within the Twitter COVID-cautious community to assess performance of masks, such as the TestThePlanet website. It is great to see that a bunch of masks are being tested using quantitative fit testing methods with a PortaCount, and with rigorous testing for dynamic fit (e.g. jaw movements). Looking at the data that currently exists, one can see which respirators are performing well, relative to the sample of testers, and which ones aren’t. However, there are limitations to the current display of data. The website doesn’t currently personalize the information; it doesn’t answer the question “which respirator(s) will most likely fit on ***my*** face?” For parents: “which respirator will fit my kid's face now? or which respirator will fit next as my child outgrows their current one?” Fit is highly individual. In an ideal world, we would all have access to quantitative fit testing (e.g. PortaCounts) or qualitative fit testing (e.g. using Bitrex) to get an idea of how protective a respirator is for a user, and money and time to try out a bunch of masks. But in reality, these things could be too expensive for many, and/or others might think it’s too much work to do.

Amanda Abbott has created a repository of elastomeric respirators and a recommender system that accompanies it. The recommender uses nose-to-chin distances (min/max), along with the face width, and nose bridge height (high / med / low), but these tend to be focused for adults. There are not a lot of options for elastomeric masks for kids. Currently, there is only the Flo Mask Kids version, and there’s a gap in sizes from outgrowing Flo Mask Kids before fitting the smallest adult size elastomeric.

For kids, ParentMishMash did some testing to give an idea of how different masks compare to each other in terms of vertical face size. See chart in Appendix. However, one challenge with this approach is that it is one dimensional and is not sufficient for some children. Modifying the respirator is frequently necessary to accommodate smaller faces (e.g. people putting adjustable halo straps from Flo Mask Kids on Tridents, chin staples, mask tape, ear savers & DIY halo straps, etc.)

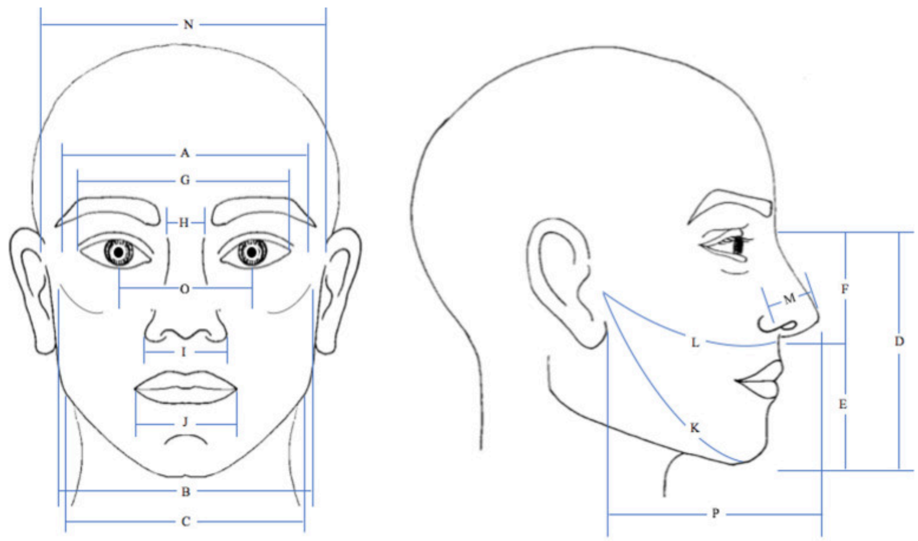
There is an iPhone app called Fit Mask that uses the iPhone camera to do 3D scanning of the face. It estimates two measurements and then makes some mask recommendations. However, some users have said that they've gotten very inaccurate results, since the app rounds to the nearest inch.

New Idea

I propose an alternative / supporting way to get more appropriately fitting masks to people:

1. Get facial measurements in a cheap way
2. Reuse lots of data that already exists such as those from TestThePlanet
3. Create a recommender system, displayed on a website
4. A user who doesn't have quantitative or qualitative fit testing equipment measures their face once.
5. User saves that in a database.
6. **Recommender makes use of facial measurements from the user to recommend masks that have a high probability of fitting the user.**

Facial Measurements



A	Biectoorbitale breadth	**I**	Nose breadth [nose width]
B	Bizygomatic breadth [Face width]	**J**	Lip length [lip width]
C	Bigonial breadth [Jaw width]	**K**	Bitragion-menton arc
D	Menton-nasion length [Face length]	**L**	Bitragion-subnasale arc
E	Menton-subnasale length [Lower face length]	**M**	Nose protrusion
F	Subnasale-nasion length [Nose length]	**N**	Bitragion breadth
G	Biocular breadth	**O**	Interpupillary distance
H	Nasal root breadth	**P**	Face depth

LANL Bivariate panel: Face length and Lip width (D + J)
Updated NIOSH bivariate panel: Face length and face width (B + D)
BSI standards: Lip length, face width, face length, face depth (B, D, J, P)

Fig 2: Taken from The influence of gender and ethnicity on facemasks and respiratory protective equipment fit: a systematic review and meta-analysis

Proposed Measurements

We can take a subset of measurements A-to-P above using a tape measure. Regarding having a dataset that focuses on half face masks, mask tester ParentMishMash suggested to include:

- Nose bridge height (low, medium, high) and breadth (broad, medium, narrow),
- Face width (B),
- Jaw width (C)
- Face depth (P)
- Face length (D
    - Lower face length (E)
- Lip width (J)
- Bitragion-menton arc (K)
- Bitragion-subnasale arc (L)

The TestThePlanet website has an accompanying spreadsheet that shows the protection factors for particular individuals when they tried out different masks & respirators. We can also ask testers who produced data from TestThePlanet to see if they'd be willing to share A-to-P so we can reuse the fit testing results that have already been done (which are plenty!).

Privacy

Facial measurements will be made private and hidden to protect users (both mask testers and mask searchers). Only people who will be able to see the facial measurements would be admins.

Recommendation System

We can then create a model using measurements above from individuals to make recommendations. We could see how the idea generalizes to unseen data by using machine learning / statistical techniques like cross-validation.

Bayesian Modeling

We can add assumptions into our model that will help it learn from data without requiring too much data.

One strategy could be to find min and max values for dimensions (e.g. face width, face length) that matter the most. For example: "Faces with face width in between A and B, face length in between C and D, nasal root breadth in between E and F…, will fit well with this mask." The statistical problem then becomes finding plausible values for those min and max values from data. From a Bayesian perspective, we can set prior distributions on those min and max values, and then the goal is to find posterior distributions of these min and max values. From the posterior distributions, we could then predict the range of fit factors that a face could attain.

Dimensionality Reduction

It is possible that not all the 16 facial measurements proposed above contribute equally to fit for a particular mask. Some might contribute a lot, and some only a little. We can experiment using the LANL Bivariate panel, the NIOSH bivariate panel, and BSI standards (see image above for details) using the regression techniques to see if we have better out-of-sample performance. If we find that using a smaller amount of dimensions is sufficient, then in the future, users who are looking for masks don't need to be asked to input 16 items – they can input just the ones that are sufficient for making good predictions.

Web App

Roles

A web app will be built with two roles in mind:
1. Tester, who has quantitative fit testing tools such as the PortaCount. They can also give demographic information such as race/ethnicity, gender, age to help assess what products are generally good or bad for certain demographics.
2. Mask Searcher, who will input their facial measurements once, and get recommendations for masks. They could also be asked a survey about the recommendations with respect to fit (e.g. When breathing in and out, do you notice leaks? Do you notice air coming in/out at the sides in between the mask and the face? Do you wear glasses? Do your glasses tend to fog up when wearing this mask?) These qualitative fit data can be converted into a quantitative fit construct in the future that could perhaps be calibrated to quantitative fit testing results, and could then inform recommendations.

Stretch goal: 3D Face Scanning

Collecting facial measurements by tape measure could be cumbersome, though much more financially accessible than buying a PortaCount ($500 - $5000+ per unit) or buying a qualitative fit testing material. However, we could potentially make the collection of data easier by leveraging 3D scanning technology and running machine learning on it. iPhone apps like ScandyPro can generate point clouds of the face. APIs like Google Mediapipe can generate a face mesh. Given the face mesh, we can infer facial measurements such as face width, face length, etc.

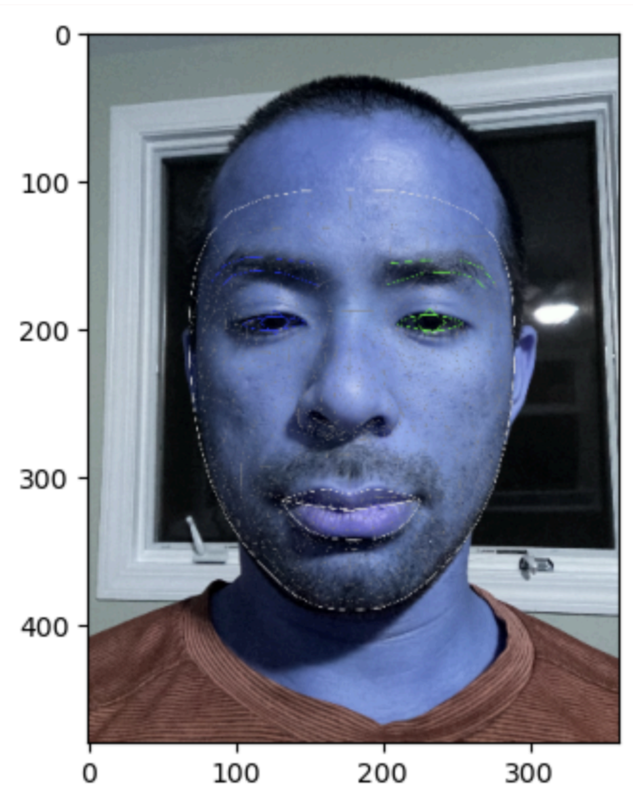


Figure 3. Google Mediapipe face mesh on Edderic's face

Privacy

Face scans are pretty invasive. Full scans of the face will not be stored. They will only be used to get some facial measurements, which act as a sort of summary of the face. Those facial measurements will be sent over the mask recommender. No one, including admins, will have access to a full face scan of someone else.

Timeline & Cost

Here is an outline of the timeline and cost.

Description	**Cost (Lower bound)**	**Cost (Upper bound)**
Data Collection	$25,000 (4 months)	$40,000 (4 months)
Recommender System	$9,000 (3 weeks)	$9,000 (3 weeks)

Web app Development	$12,000 (4 weeks)	$12,000 (4 weeks)
Stretch Goal: Research the possibility of accurately inferring facial measurements using smartphones	N/A (0 weeks)	$36,000 (3 months)
Stretch Goal: Implement 3D Face Scanning software on iOS and Android	N/A (0 weeks)	$72,000 (6 months)
TOTAL	**$46,000 (~6 months)**	**$169,000 (~15 months)**

The lower bound estimate assumes no PortaCounts need to be bought, and no loaner system for the financially challenged. Likewise, it also does not consider the stretch goal of trying to get an accurate enough system of facial measurements from a 3D scan of the face using a smartphone. However, the upper bound estimate does consider the PortaCount loaner system along with some time and money for inferring facial measurements from 3D scans via smartphone. See appendix for details.

People involved

Edderic Ugaddan - Data scientist, passionate about public health. Created breathesafe.xyz, which lets people understand their risk of getting COVID at a venue. Owns Breathesafe LLC, an organization innovating in the air cleaning space. Latest product is the LaminAir, a personal HEPA that produces a relatively clean air stream to make spaces safer for people on the go. Loves software engineering, statistics, and machine learning.

ParentMishmash - I am a US military veteran and I like to make things. I don't share a lot of information as I try to stay anonymous but you can search my account for keywords DIY or USSOCOM if you are curious. https://x.com/ParentMishmash/

Understanding currency of grants:

I understand that grants are made in USDC, a cryptocurrency. I haven't used it but will figure it out.

IP strategy confirmation

All IP from this undertaking will be placed in the public domain, such as GPL-3 which allows for any and all uses including commercial, in accordance with best in class open source methodology. Personal data of mask testers and users (facial measurements) will be kept private for their own protection.

Appendix

ParentMishmash's masks for kids chart

Details of Timeline & Cost

Data Collection

- Ask for people who have PortaCounts to contribute their facial measurement data. Some of them have already expressed interest and/or committed to participating.
- Buy a bunch of sampler masks for testers who don't have much data yet. Assuming $2.50 / N95 mask, and there are 50 masks to go through, that ($125 / person). If we get 100 people to do fit testing, that translates to **$12,500.**
- Pay people to do the testing to get a lot of data across individuals. OSHA testing has 8 exercises. Let's say a suite of exercises takes about 10 minutes to do, to account for setting up each mask. If we want to get each person to test at least 50 masks once through the OSHA set of tools, that is 50 x 10 = 500 minutes. 500 minutes. If $15 / hour, then that translates to 500 minutes * 1 hour / 60 minutes * $15 / hour = $125 per person. If we wanna do at least 100 people in the data set, then that translates to about **$12,500** in funds for time spent to do fit testing.
- PortaCounts are expensive, even the used ones from Ebay ($500 - $7,000). We could buy a few PortaCounts to be used for loaners. We can send them to people who are interested in contributing data but do not have the financial means to do so. Assuming we buy 5 8020A PortaCounts, and 8020As can realistically be bought between $500-$1,000, then that comes out to **$2,500-$5,000.** Let's use the upper bound estimate: **$5,000**
- Shipping and handling the loaner PortaCounts once the testing is done for an individual. Let's say that's $100. If there are 10 people who already have PortaCounts who contribute data, but we want a sample size of 100, then that 90 other individuals who might in theory need to pay shipping and handling costs so that the loaner PortaCount could go to the next individual to do testing. So $100 x 90 = **$9,000.**
    - Another possibility is to have those with PortaCounts hold fit-testing events within their communities; however, not all data from those will be usable.

DURATION: *4 months*
TOTAL COST WITHOUT PORTACOUNT LOANER PROGRAM: $25,000
TOTAL COST *WITH* PORTACOUNT LOANER PROGRAM: $40,000

Recommender System

- Create a model to predict fit factors on someone's face for each of the masks.
- Examine the relationship between facial features and different masks. Test different methods such as KNN regression on data
- Equity & Bias checks
    - For each of the masks, see if there are discernible biases of masks towards/against certain groups. Some masks might be a better (or worse) fit than others for different racial groups, different ages, and perhaps different genders. Which masks work best for Black people? Which masks work best for kids?

How about for Asian women?

- See how using a subset of the 16 measurements affects predictive performance
- Assuming this is 3 week's worth of work, at $75 / hour, that's $75 / hour x 8 hours / day x 5 days / week x 3 week = **$9,000**

DURATION: *3 weeks*
COST TO BUILD: $9,000

Web app Development

- Setup webapp (Ruby on Rails or Django backend?)
  - Could use existing Breathesafe app to speed up development:
    - www.breathesafe.xyz

Adding Data to the App

- Talk to people who have contributed to the TestThePlanet data set, and see if they would be willing to send over facial measurements and demographic info
- Save data to database
- As a mask tester, when signed in, create a profile page
  - Show validation errors if exist
  - Within profile page, be able to add facial measurements

- As a mask tester, when signed in, edit profile page
  - Show validation errors if exist
- As a mask tester, when signed in, delete profile page

Displaying Recommendations

- As a mask searcher, show me an ordered list of mask recommendations
  - Each item in the list will have an estimated protection factor score
  - Show name of the mask/respirator
- As a mask searcher, clicking on a mask recommendation gives more details
  - Give context about why a mask is being recommended: "2 of the tester faces in the data set are quite close to yours (Potentially show components of the distance score via heatmap). This mask had a conservative (harmonic) mean fit factor of 90 for these 2 testers."
  - If the mask searcher's face is too different from the testers', show warning that the recommendations might not be good

Equity Page

- Have a filter where user can choose which demographic(s) to filter on
- Display information about "which masks have worked well with demographic X?

Privacy

Users will be asked about demographics. They can choose to share or not share information. This info will only be used to report aggregate data about bias of masks

- “Mask X works well for White Male Adults, but doesn’t work well for Black Female Adults.”
- “Mask X has 29 testers’ worth of measurements. For those who provided race/ethnicity information, 30% are Asian, 50% White, etc.”

Assuming 4 weeks of work, at $75 / hour, that’s $75 / hour x 8 hours / day x 5 days / week x 4 weeks = **$12,000**

Maintenance Costs:

- Heroku Monthly cost estimate: **$36 / month**

DURATION: *4 weeks*
COST TO BUILD: $12,000

Stretch Goal: 3D Face Scanning Research

To make the data collection of facial measurements easier:

- Examine different existing apps that can create a point cloud of 3D objects, and choose the best one.
- For each of the most valuable facial measurements (e.g. face length, face width, etc):
    - Find a way to estimate using point clouds and machine learning tools.
- Investigate existing methods for “parts-of-face” detection:
    - What existing APIs are there?
    - What lower-level tools could be useful?
        - Convolutional Neural Networks (CNN): Perhaps treat the 3D space as a 2D image, use existing tech to distinguish facial features (eyes, nose, mouth, etc. Then from the classified 2D image, assign a label to each 3D point (e.g. eyes, nose, mouth, jaw, etc.). Then measure distances accordingly
- Iterate. Test accuracy of the algorithm and tweak as necessary.

DURATION: *3 months*
COST TO BUILD: $36,000

Stretch Goal: Build Phone App to Easily Collect Facial Measurements

Once the algorithms for getting facial measurements using 3D face scanning are successful enough, then I could code phone apps so that testers and mask searchers can actually record their data instead of using a tape measure.

- Research how to create a simple iPhone app
- Figure out how to access the camera
- Reimplement 3D scanning algorithm from above
- Iterate. Tweak accordingly.
- Send facial measurement data to the server (or could have users just get the estimates of measurements and they input these themselves into the webapp).
- Repeat the steps for Android

DURATION: *6 months*
COST TO BUILD: $72,000

Mask sampling packs

To be used for mask testers

https://aiden.health/products/fit-kit…

https://armbrustusa.com/products/armbrust-mask-sampler-kit…

https://shop.evidencebased.ca/collections/mask-sampler-packs… (for any Canadian ones, if they won't ship to USA, you can use http://reship.com, or I'm happy to receive and resend to you)

https://family-masks.com/collections/sample-packs…

https://canadastrong.ca/collections/other-items-from-canada-strong…

https://canadamasq.com/product-page/q100-sample-pack…

https://protectly.co/products/sample-of-n95-kn95-kf94-masks… (sells single masks)

https://thefacemaskstore.co.uk (sells single masks)

https://alliantbiotech.com/product/readimask-strapless-n95-niosh-approved… (ReadiMask only)

https://breatheteq.com/products/breatheteq-kn95-sample-sizing-kit-non-medical-face-mask… (breatheTeq only)

https://hlpmedical.net/products/trident-p2-surgical-respirator-level-3-hospital-grade-sample-pack-4-masks-sizes-xs-s-regular-extended-straps… (Trident only)

https://bloxdirect.com/products/blox-n95… (10x Blox for $2.50)

https://ppeo.com (sells a lot of singles, expensive shipping, I might order from here in a month, could reship to you; major source for Zimi respirators) https://wellbefore.com/products/kn95-3d-kn95-sample-pack-all-sizes... (almost every WellBefore mask, except the good ones)

https://jedx.fi/ffp3-fish-type-masks-without-valve/... (FREE!)

https://shop.purdefense.com/products/purdefense-n95-mask-sample-pack... (expensive, only 4 types)

Design

Database Design

Here is an outline of the tables that should exist in the database.

User

- Email
- password

Profile

- Demographics (json)
  {
      'Race_ethnicity': "Asian",
      'Gender': "M"
  }

Mask

- Unique Internal Model Code (string)
- Manufacturer (string)
- Id
- Modifications: {object}
- misc: JSON
  {
      type: 'bifold'
      Where_to_buy_urls: [
          'www.amazon.com/...',
          'www.projectn95.com/...'
      ]
  }

FitTest

- facial_measurements_id: UUID
- mask_id: UUID
- User_seal_check: {
  Positive_pressure: pass/uncertain/fail
  Negative_pressure: pass/uncertain/fail
  },
  Comfort: {
  “How comfortable is this respirator?”:
  “Very comfortable, comfortable, ok, uncomfortable, very uncomfortable”
  “How comfortable is the position of the mask on the nose?”:
  uncomfortable/sufficiently comfortable/very comfortable,
  “Is there adequate room for eye protection?”:
  Yes / no
  “Is there enough room to talk?”
  Not enough, Somewhat enough, enough
  “How comfortable is the position of the mask on face and cheeks?”
  Uncomfortable, comfortable, quite comfortable
  }

- Facial_hair: {
  beard_length: (0mm, 1.5mm, 3mm, 6mm, 9mm, >10mm),
  resistance_band: {
  Model: (none, SmarterLife, etc.),
  …
  }
  }
- protection_factors: JSON
  // Flexible enough to handle different protocols (e.g. OSHA, etc.)
  {
  ‘Protocol’: OSHA,
  ambient_particle_count: 1200,
  ‘Exercise_results’: [
  {
  Exercise: ‘normal breathing’,
  Fit Factor: 12
  },
  {
  Exercise: ‘deep breathing’,
  Fit Factor: 10
  },
  …
  ],
  ‘overall fit factor’: 123

}
…

FacialMeasurements

- id
- created_at
- User_id: UUID
- face_width: (mm)
- Nose bridge height (low, medium, high)
- Nose bridge breadth (broad, medium, narrow),
- Jaw width (C)
- Face depth (P)
- Face length (D) (size bands)
    - Lower face length (E)
- Lip width (J)
- Bitragion-menton arc (K)
- Bitragion-subnasale arc (L)

MaskFitBounds

This will contain bounds for each of the most useful facial features (E.g. face_width). When an individual wants to use the recommender, the app can run through a simulation and see how often the individual's set of facial measurements coincide with the mins & maxes of the mask. I.e. What is the probability that individual A's nose bridge height is in between nose_bridge_height_min and nose_bridge_height_max AND their face width is in between face_width_min and face_width_max AND so forth.... This probability becomes a fit score.

- Mask_id: UUID
- Face_width_min: (could be an array of 10000 elements)
- Face_width_max: (could be an array of 10000 elements)
- nose_bridge_height_min: (could be an array of 10000 elements)
- nose_bridge_height_max: (could be an array of 10000 elements)
- …