So You're Going Outside: A Physics-Based Coronavirus Infection Risk Estimator for Leaving the House

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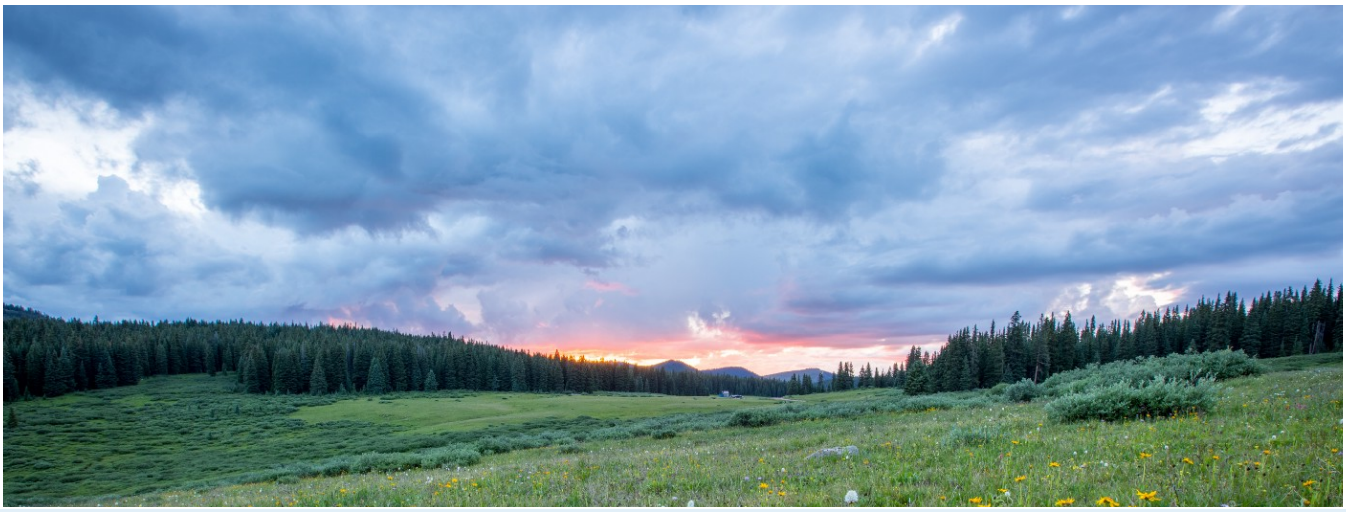
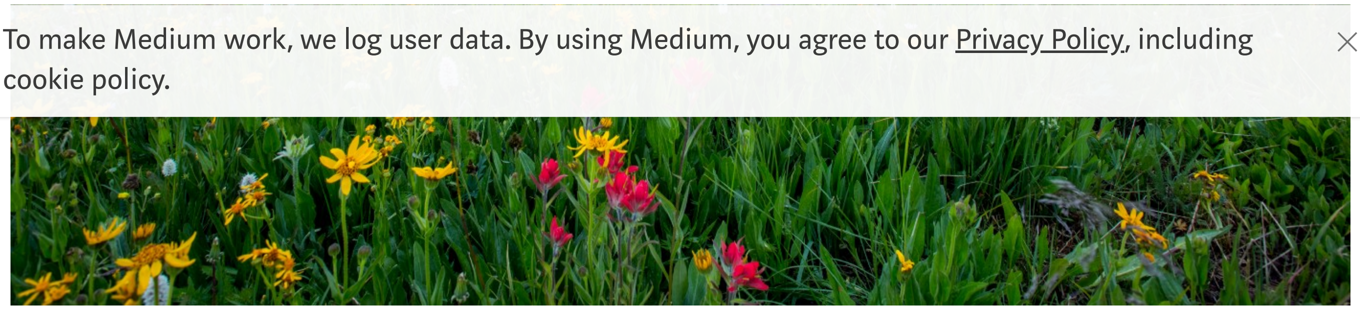
So we're quarantined. We're social distancing, avoiding groups, and staying 6 feet apart as much as possible. But this still leaves so many questions!

- What if the sidewalk is only 4 feet wide — should I #stayHomeSaveLives?
- How does "riskiness of the hangout" scale with "length of the hangout"?
- How risky is going to Costco vs. going to the corner store?
- How does this all change if we're wearing masks?





A peaceful meadow, or a brewing disaster? (Photo by Joel Holland)

I'm a mathematician, and I'm quarantined in a community house with nine other people. I also worked part-time for three years as a network epidemiology research assistant at MIT. Burning questions like this came up at all my house meetings, so to sync our collective understandings, I made a physics-based activity risk model and fed our questions into it.

In the rest of this article, I'll step through the answers, and I'll show you how to use the model to answer questions of your own!

Disclaimer: all models are wrong, but some are useful. I think this one is useful, but please bear in mind that I made it in a week. The exact percentages are definitely inaccurate. I'm sharing because I think the general, directional trend information it reveals — distinguishing between a 1% risk and a 10% risk — is much better than no information at all.

The Model

How to Use It

Here's the link to download my Jupyter notebook on GitHub. And, here's a link to a Google spreadsheet version, if you prefer that format. The parameters are documented in the code — change them to match your scenario!

Derivation

Many specifics of coronavirus transmission are still being debated, so I kept my math at a high level. I considered three widely-agreed-upon kinds of transmission:

1. **Surface-based**: you touch an object that has virus on it, then touch your face.
2. **Warm-body-based**: you come near a living, breathing infected person, and viral particles from their breathing then infect you in a diffusion-based way.

Fluid dynamics of airborne particles are weird enough that this term is definitely nonzero, though it's hard to say exactly how big it is. Probably small?

Many pencils and pieces of paper later (check out my full handwritten derivation if you want to know how many), here are the summary equations! I explain the parameters in more detail in the code and spreadsheet, and show them for the calculated examples.

$$\boxed{P\left(\begin{matrix}\text{you're}\\ \text{infected}\end{matrix}\,\middle|\,\begin{matrix}\text{you went}\\ \text{outside}\end{matrix}\right) = \left(1 - \underbrace{\left[1-(1-p_{hu\_vs})N_s N_{p_s} p_i\right]}_{\text{surfaces}}\underbrace{\left[1 - N_{p_b} p_i + p_i \sum_{N_p}\left(P\left(N_v < \frac{r^2}{\rho}\right)\right)^{N_b}\right]}_{\substack{\text{warm-body}\\ \text{(ppl breathing + diffusion)}}}\right) + \underbrace{N_{p_b}\frac{p_w}{r^2}}_{\text{wildcard (small)}}} \qquad (22)$$

$$\boxed{N_v = \mathcal{N}(\underset{\mu}{18}, \underset{\sigma}{6})}$$

Parameters:

global

p_i = probability that any given person outside is infected

p_{hu_vs} = probability your hand is uncontaminated after touching a contam. surface

wildcard { p_w = probability of fluid dynamics glitch from 1 breath of 1 infected person (small)

situation-specific

surface-based { N_s = # surfaces you touch; N_{p_s} = avg. # of people that have touched the same surfaces as you, since the surfaces were last sanitized

breathing-based { N_{p_b} = # people that breathed on you; N_b = avg. # of "breath events" they did so for; ρ = "projectiness" = scale factor for # viral particles in the breath event, relative to a cough $= \begin{cases} 1 & \text{cough} \\ 0.5 & \text{normal breathing} \\ 0.3 & \text{t-shirt mask} \\ 0.1 & \text{surgical mask} \end{cases}$; r = your distance (feet) away from the breathing person

The Questions — What'd We Learn?

General Takeaways

When I ran the numbers, some results immediately stood out.

- For an individual, the riskiness of going outside scales linearly with four factors: the number of people they encounter (*N_p_b*), the number of surfaces they touch (*N_s*), the number of other people that have touched those surfaces since the surfaces were last sanitized (*N_p_s*), and the probability p_i that any given person outside is contagious.

In a networked pandemic where all the scariest stats are exponential, this is good news! It means that if your region sees cases increase by 2x, your midday walk only gets twice as risky. Not, like, four or eight times riskier.

This also means that you can cut your infection risk in half by avoiding half the people,

- Your surgical mask offers people around you the same protection as 3x increased distance. T-shirt mask? Same as 2x distance.

The viral particles emitted by an infected person spread out to the surface area of the sphere around them. Cutting out 90% of the emitted viral particles, as a surgical mask does, offers you a 10x protection factor. Distance offers a squared protection factor, so achieving protection = 10 requires standing sqrt(10) ≈3 times further away. T-shirt masks block 70% of particles, so sqrt(10/3) = 1.8 ≈ standing twice as far away.

- 6 feet of distancing keeps you pretty darn safe. BUT any amount less than that is much, much riskier!

So, no passing others on narrow sidewalks! Either swerve into the road to do it, OR wear a mask. As we learned above, masks ⟷ distance, so this means masks can earn you the right to pass others on the sidewalk. No mask? Stay 6 feet away, even if it means you might get stuck behind someone slow.

Scenarios

Let's assume the global default parameters I calculated and estimated in the spreadsheet. In San Francisco as of April 17, 2020, that gives us probability $p_i = 0.002$ that any given person outside is infected.

What if the sidewalk is only 4 feet wide — should I #stayHomeSaveLives?

Takeaway #2 gives us a clue here — this answer depends heavily on mask usage.

The main parameter in this question is the four foot distance: $r = 4$. We also get zero for *N_s,* and *N_p_s*, the two parameters concerning surfaces, because I don't know about you, but — I don't touch anything when I take walks. This question asks about **warm-body-based** transmission only (and some **wildcard**, but again, we expect that to be small).

This leaves us to specify the number of people that breathe on you (*N_p_b),* the number of times they each breathe on you (*N_b*), and the intensity they do it with (*projectiness*). Let's assume that "passing" someone on a walk means they breathe on cough on me but aren't wearing masks, all wear t-shirt masks, all wear surgical masks)? Corresponding to *projectiness* = (1, 0.5, 0.3, 0.1).

2. What are the same probability numbers if our radius grows to 6 feet?

Plugging these numbers into the model returns this grid of outcomes:

Infection Probabilities: Taking A Walk

4-foot sidewalk		every breath is a cough	normal breathing	t-shirt mask	surgical mask
number of people passed	10	1.90%	0.06%	0.0001%	0.0001%
	30	5.70%	0.18%	0.0002%	0.0002%
	100	18.99%	0.58%	0.0006%	0.0006%

6-foot sidewalk		every breath is a cough	normal breathing	t-shirt mask	surgical mask
number of people passed	10	0.0001%	0.00003%	0.00003%	0.00003%
	30	0.02%	0.0001%	0.0001%	0.0001%
	100	0.08%	0.0003%	0.0003%	0.0003%

We can see that, if you're coughed on by people who aren't wearing masks, a 4-foot sidewalk is wayyyy riskier than a 6-foot sidewalk! But fortunately, the difference disappears when people put on masks: infection probabilities tank to near-zero.

If everyone coughs on you while passing you, you have a 19% chance of getting infected after passing 100 people in SF at a 4 foot distance, but only a 0.8% chance at a 6 foot distance. Truly, masks and distancing each make a world of difference. Masks *and* distancing make a god-like level of difference.

How does "riskiness of the hangout" scale with "length of the hangout"?

I'll skip most of the parameter discussion this time — check the code if you're interested in that! But, I assumed a breathing rate of 16 breaths per minute, and that everyone stayed a socially-distant 6 feet apart.

Here are the results for my test scenarios:

every breath is a cough		30sec	15min	1 hour	3 hours
number of people	1	0.002%	0.06%	0.15%	0.20%
	5	0.01%	0.28%	0.73%	0.98%
	30	0.06%	1.66%	4.36%	5.88%
	100	0.22%	5.54%	14.53%	19.59%

just talking		30sec	15min	1 hour	3 hours
number of people	1	0.000003%	0.000003%	0.000003%	0.000003%
	5	0.00001%	0.00001%	0.00001%	0.00001%
	30	0.00008%	0.00008%	0.00008%	0.00008%
	100	0.0003%	0.0003%	0.0003%	0.0003%

Turns out, keeping the contact length shorter does keep you meaningfully safer if you're doing something risky! Hanging out with 100 maskless, constantly-coughing people is 3 times riskier after one hour than it is after 15 minutes. This also means that the more you suspect someone might be sick —the riskier they get, so the less time you should spend with them.

On the flip side, if your baseline level of safety is already pretty safe — like it is with "just talking" at 6 feet apart — whether you hang out for 30 seconds or 3 hours doesn't matter at all. Any gains are dwarfed by the already-small wildcard background probability.

How risky is going to Costco vs. going to the corner store?

Takeaway #1 gives us a clue: risk scales linearly with number of surfaces touched and the number of other people that have touched those surfaces. Assuming you get the same number of items at Costco and the corner store, we should see the biggest differences come from the number of people that are currently in the store, and the total number that have been there before you.

Let's say we get 20 items at each place, and no one's coughing but no one's wearing masks either. I'll try two kinds of social distancing: perfect ($r = 6$) and lax ($r = 4$). I'll estimate that the average Costco is open for 9 hours and probably processes an average 400 people an hour, maxing out at 3600 people of total daily foot traffic.

Infection Probabilities: Foot Traffic of Store

fixed-volume store; socially distant		10 people total foot traffic	100 people total foot traffic	1000 people total foot traffic	3600 people total foot traffic
number of people passed	1	0.15%	1.50%	15.00%	54.00%
	5	0.15%	1.50%	15.00%	54.00%
	30	0.15%	1.50%	15.00%	54.00%
	500	0.15%	1.50%	15.00%	54.00%

fixed-volume store; not socially distant (r=4)		10 people total foot traffic	100 people total foot traffic	1000 people total foot traffic	3600 people total foot traffic
number of people passed	1	0.17%	1.51%	15.01%	54.01%
	5	0.23%	1.57%	15.06%	54.03%
	30	0.60%	1.95%	15.39%	54.21%
	500	7.73%	8.98%	21.45%	57.49%

volume of store increases as foot traffic increases; socially distant		10 people total foot traffic	100 people total foot traffic	1000 people total foot traffic	3600 people total foot traffic
number of people passed	1	0.15%	1.20%	7.50%	13.50%
	5	0.15%	1.20%	7.50%	13.50%
	30	0.15%	1.20%	7.50%	13.50%
	500	0.15%	1.20%	7.50%	13.50%

Woah. These tables are a sobering reminder that while social distancing is great at protecting you from **warm-body-based** transmission, it leaves **surface-based** transmission as a huge open risk. So, social distancing is *not* a replacement for washing your hands and/or sanitizing high-touch surfaces. Comparing the first and second results table, we see that with perfect social distancing, the warm-body risk from "shopping at the same time as 1 vs. 500 other people" is completely swallowed by the much larger surface-based risk from foot traffic. Infection probabilities don't change at all between the rows of the first table. When social distancing gets sloppier in the second table, though, you can once again see the difference between one and 500 co-shoppers.

Costco foot traffic in the tables above, I’m using “daily” as an approximation. What really matters is “foot traffic in the last X time frame,” where X is whatever is most relevant to the lifetime of the virus on surfaces. This could be “time since the last deep clean,” “half-life of the virus on the specific material,” or whatever else emerges from ongoing research.

Another thing stuck out to me in these simulations: if you hold foot traffic constant, the spatial size of the store matters a lot! Bigger, sparser stores can be protective, for the simple reason that in a bigger store you’re less likely to touch the same surfaces as someone else. At Costco, a sick person trying out the mattresses isn’t going to affect you if you’re only grabbing frozen foods…until you bottleneck again when you use the same cash register. At that point you’ll still need to wear gloves, or sanitize, or wash your hands. Most of the risk is concentrated in the most-touched surfaces.

So how much riskier is Costco than the corner store? Judging by the third table, probably about a hundred times — but you can cut down this risk by **sanitizing high-touch items, washing your hands — and never touching your face inside the store**. You could also head to the store in the morning OR right after a deep clean, when fewer people have been around to touch the surfaces before you.

Finally: should you sanitize every single item you purchase? As per takeaway #1: risk from a surface scales linearly with the number of people that touched it before you, so sanitizing just the high-touch items will already confer most of the benefit. What fraction of the benefit? I wish I had a formula, but that’s outside my time scope for this post. I suspect the answer is at the bottom of a power-law distribution for touch frequency in stores.

How does this all change if we’re wearing masks?

This was answered across the other questions, but the summary is — masks work!

For the love of public health, if you’re not wearing a mask, please don’t go within 6 feet of anyone. Crunching these numbers really gave me an appreciation of how the 6 foot distance, while it might not seem like much, is doing a *lot* of heavy lifting to keep us safe. Cutting corners is not a good idea.

Not wearing a mask? Better hop off this walkway if you want to pass someone else. (Photo by Jordan

After all this math, my biggest impression is a hopeful one. The virus may be scary, but our quotidian safeguards of masks, sanitizing, and social distancing can protect us in meaningful and understandable ways.

The numbers show that we should take these defenses seriously. Stay six feet apart (not four!), wear masks, sanitize religiously — and don't touch your face!

. . .

I hope to write this model up in proper LaTeX sometime soon, but, I have finite time. If you'd like to pitch in, or want to start a conversation of any kind, shoot me a response :)

Coronavirus Risk Quarantine Mathematics Data Science