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PROFESSOR: So now let's synthesize all of our models of aerosol generation and dynamics in a well-mixed indoor space and epidemiological models of spreading and transfer of disease in that space and formulate a safety guideline for COVID-19 assuming indoor airborne transmission in a well-mixed room.

And so there's a number of ways we could go about this.

And the approach that I would like to propose is that we require that the indoor reproductive number is less than some tolerance.

So this epsilon here is the tolerance.

So typically something might be a lot less than 1 or maybe you get to allow it to be closer to 1.

And so that is essentially the probability of a transmission from one infector that enters the room at t equals 0 and stays for a time tau in the presence of a total number of n people in the room, which is the occupancy of the room.

So obviously, this doesn't handle every possible situation.

It is possible, if there is a very prevalent infection rate in the community that the room may find several infectors entering at once, in which case, we could certainly increase this number.

And then the 1 here would be replaced by i0 as we've seen before.

On the other hand, if you're interested in controlling the spread of the disease and you're not worried about a specific person, but you just want to say, I would like to make this room not contribute to spreading of the disease-- and imagine if everybody did that, then no rooms would contribute to spreading the disease-- so then this criteria would say that if two infectors came, they might infect two people, or three infectors, you're worried about three people.

Well we want to make sure is that the number of infectors is not growing.

So in other words, if there's one infector, they don't infect another one.

So the fact that there are more infectors gives a chance of at least some infection, but this seems like a more general and simpler criterion.

It's also a little bit like when the fire department looks at a room and decides on occupancy limit for an indoor space.

There's no fire going on.

They're not estimating what's the probability of a fire.

It's a conditional probability.

They're saying, if there's a fire, we want to make sure these people can get out.

And so they think about where the fire might start, where the smoke is, where are exits, and how many people can realistically get out of that room before the fire and the smoke reach a dangerous level.

So this indoor safety guideline has a similar flavor, where we're essentially defining here the number of people and also the amount of occupancy time that would be allowable.

So that it'd be unlikely for one infector to create a new infection and hence spread the disease.

So that is the basic thinking.

So this it's basically the conditional probability of spreading given this, that an infector enters at times 0 and stays for a time t.

So that's basically how we formulate the guideline.

And now let's think about-- already at this level without getting into the details of what goes into beta, which we've already talked about, there's a very important concept here, which is that if I define beta with brackets here to be the average transmission rate.

So the transmission rate may be changing in time, for example, as droplets are building up in the room as we've discussed.

But let's just think of kind of an average transmission rate.

Then this integral in time is just beta brackets, beta average times tau.

So if I put the beta bracket on the other side, I arrive at a very fundamental result, which is that the number of susceptibles in the room, which is roughly the occupancy-- although, if you're very low occupancy, it's everybody but the infected person, so it's n minus 1-- times the typical time spent in the room by the infected person is less than the tolerance divided by the average transmission rate.

This is very simple and very general relationship, which does not depend on the details of beta.

But what it's telling you is something which already you may recognize is very different than any of the existing official safety guidelines.

Official safety guidelines always limit one quantity.

For example, they might limit the number of people in a room.

They also can get a limit such as that from social distancing.

So you could take the area of the room, divide by a little six foot radius around each person-- or a three foot radius or a six foot separation-- and get at an occupancy.

So you fix n.

The problem with that is that time has to play a role.

If a certain number of people are in a room for a very short time, it's really unlikely to have any transmission.

But if the same number stays for a very long time, eventually some transmission must take place.

So time has to be important.

You will also find limits on time.

The CDC defines a contact where transmission is possible as being within six feet of an infectious person for more than 15 minutes.

So there is a time constraint there.

So it says that after 15 minutes, you should expect to be potentially infected.

But the problem is that that's not accounting for transmission rate factors, such as ventilation and all the things that we've discussed, and also the occupancy.

So how many people could you transmit it to?

If you're by yourself in a room or there's only two or three people in a very large space, are you really going to transmit in 15 minutes?

Not necessarily.

And anyway, so that is the problem with those kinds of criteria.

And it can be easily seen by plotting this relationship here.

So by the way, this quantity here, which is the product of n and t, or n minus one and t, is what I like to call the cumulative you exposure time.

So the time that you're exposed to the infected individual, tau, is multiplied by how many other people are in the room because that's how many people could get infected.

So the more people that there are, the more chance that one of them could be infected in a well-mixed room.

And so you really don't have a bound just on time.

It's really this product that's important.

And so let's plot what this looks like now.

So if we have here the time and here the occupancy, then this guideline is a bound that looks like this.

It saturates at one.

So basically, if you're below this guideline here, you're considered safe.

And up here is potentially unsafe.

Meaning that given the tolerance that you've chosen, you would expect that there could be a transmission with greater than that probability.

OK.

It saturates at one because it will never go below one.

Because only one person, you're not going to transmit to anybody.

So it's OK.

So an occupancy of one is OK, except in a building where perhaps other people have come and gone from that room or ventilation is bringing particles from other rooms.

And we'll come back to that.

But just at the simple level of analyzing one room, obviously one is fine.

And here you see a very fundamental problem that I was just alluding to, which is that if I put the standard guidelines on-- for example, a limit on number of people.

So this could be fixed occupancy.

And in fact, in Massachusetts, for example, right now there is a guideline which says n is less than 25.

No more than 25 persons can congregate in a room.

In fact, I'm teaching class right now which we have 51 people, and I was able to split into two rooms.

And then this rule came along, and then we had to start doing three, remotely broadcasting between those rooms because we have a 25 person rule.

The problem with that rule is it doesn't take into account time.

What if my class is only five minutes long?

Or let's say it's one-hour long, OK.

In that time, if I don't have an expectation transmission, I should be OK.

On the other hand, if those 20 people sit in the classroom for several weeks, it's pretty likely that if an infected person is among them, there will be a transmission.

So time has to come in.

And that you see very clearly here from the crossing of the fixed occupancy with the safety guideline.

So for a short amount of time, the fixed occupancy, which is telling you should be under this-- so basically you should only have a lower occupancy.

So this is a fixed occupancy bound.

For example, the one in Massachusetts.

At first, this is too conservative.

So you are telling people they cannot be in the space, but until this amount of time has passed, it's very unlikely that anybody would transmit.

Imagine this time as one minute.

It's pretty unlikely that you're going to have a transmission.

On the other hand, if you keep waiting, you always cross the yellow line.

And over here it's too risky and too dangerous, basically.

Because you're allowing people to think that they're safe because there's only 25.

But let's say this crossover happens after one hour, and the people are in the room for five hours, there's a very high risk of transmission.

So just putting out a number like 25 doesn't really protect you because these lines always cross.

You will always cross the safety guideline at a certain time.

That's the safe time.

OK.

Similarly, so basically-- so let me just kind of stress that here.

So this is basically, what we're really concerned is this.

We're very concerned about situations where a guideline is giving people the sense of protection, and in fact they're at high-risk.

We're also concerned about this case here.

Because for example, as in the case of my class, we might be causing some damage to people's education or to their businesses or to the economy by shutting down a certain space or imposing a limit that doesn't have really a strong scientific basis because we don't expect transmission to happen under those circumstances.

So we're concerned about both.

But I'm particularly concerned about the overly risky case because that is contributing to transmission of the disease, and potentially loss of life.

Now, if we look in the other direction, we have the same kind of issue.

So if we have a time limit-- for example, let's say here.

You know, this could be like this.

So this would be a fixed time.

For example, 15 minutes from the CDC is the time they recommend for contact.

So that's a pretty short time.

OK, and what a guideline like that says is that if you're in the presence of an infected person-- sufficiently close-- for 15 minutes, then here you're safe, but over here you're unsafe.

But again, you have the same phenomena.

Now, 15 minutes is a pretty short time, so that's typically going to be safe.

But again, in this region it's too conservative.

So the blue here is still too conservative.

But now, when you get up here, even the 15-minute rule eventually becomes unsafe.

Because if there's a very large amount people in a room and they also can interact with each other through well-mixed space-- so I'm not talking about a really, really big room.

I'm talking about a small enough room that you could expect air to be transmitted between the people in that space-- then if I keep increasing occupancy, again I cross that line.

There's always a crossing.

So you cannot have a guideline only based on time or only based on occupancy.

If you think of this limit-- for example, how about we take for the 15-minute rule, what if I put 15 people or maybe 20 people into a small tent-- just let's say a little bit bigger in the size of this board-- and everybody's standing close together.

We might pass the infection in much less time than 15 minutes because we have a chance to infect each other, and if I keep going up, I'm going to cross that line.

And the tent also has a very small volume, poor ventilation, and this yellow curve is very low.

OK, so this concept of the cumulative exposure time is really important to understand because it's very general.

It really isn't so tied to the details of the model.

And it just shows you that any bound on one parameter such as occupancy, time, and I should mention also social distance.

Because that's the big one which is happening right now.

Social distance guidelines-- so this would be that the distance, d, is greater than six feet.

And that's a CDC guideline in the United States.

It can be greater than one meter, which is 3 feet, and that's from the World Health Organization.

So about half the distance.

That leads to a guideline where there's still a maximum occupancy, which is the area of the room divided by d squared, or by some other factor depending how you think people are going to be arranged.

But basically, you go into the room, you map out that spacing, and you arrive at a fixed occupancy.

This is being done everywhere, including here at MIT right now.

And that still leads to fixed occupancy.

So regardless of how it was derived, you still have a fixed occupancy, which is too conservative at first, and eventually is too risky.

And you must know where is that crossover point because occupancy and time are linked.