PROFESSOR: So now that we've discussed prevalence and risk scenarios, we come to a very important topic, which is, when should you impose the guideline?

Obviously, when the epidemic is raging at a very high rate, it feels out of control, it's spreading, we want to impose the guideline that we've discussed, which limits the indoor reproductive number for each space within some tolerance.

And that would, for example, give us some number N1 from the safety guideline, R N less than epsilon, which is going to be smaller than the normal occupancy of that room for a given time and all the other factors that we've been discussing.

But what happens as the prevalence of infection goes down.

Generically, there must be some curve like this.

And we'd like to understand what is the simplest reasonable model we can come up with that can tell us how to relax the approximation?

So for example, let's think of a school or a business, where we typically have a lot of the same people there every day, but some others are coming and going, or maybe going home and getting infected and coming in.

So the rate of infection is low.

So we expect typically the number of infected people is zero or occasionally one.

And as the prevalence goes down, then we start to see that the situation is getting safer and safer.

So that at a certain point P1, where we start to say, you know what we can actually increase the occupancy of the space with everything else held fixed while still wearing masks.

And then we hit the normal occupancy.

And you might call that the new normal, where we're going about our business, the room is filled with the typical number of people.

Let's say, the classroom is back to its normal size.

We don't have any remote teaching going on.

But we're wearing masks or taking other factors into account, such as higher ventilation rates, let's say, open windows.

But then we continue lowering the prevalence.

There's a certain point where we get rid of those other precautions.

So extra open your windows.

Or more importantly, the dominant effect is the removal of the mask because we know that's a significant factor.

And then you might call that back to the real normal, actually, not the new normal.

Where we are back to full occupancy and really not taking any precautions.

That's going to happen at a rather low prevalence.

But we hope that that time will eventually come and hopefully not so far in the future.

And I mention here a very important point we've not talked about yet in this class but we should keep in the back of our minds.

When I talk about occupancy I'm really talking about the number of susceptible people.

We just saw that in the last couple of boards.

But the number of susceptible people are really only those that are not immune to the disease, for example, by vaccination.

So as more and more people become vaccinated, then this occupancy number might-- for example, let's say, as a typical occupancy will be at 25 people in a class.

As more and more people are vaccinated, the number that we plug in this formula here might actually be lower when we just make decisions because there are fewer and fewer susceptible people that are left.

So that's another very important factor to keep in mind.

Of course, also, vaccination has the indirect effect of lowering the prevalence that is seen in the population as we start to stamp out the epidemics.

So we also have that effect.

So I won't talk about that any further now but come back to this calculation based on the risk scenario, the second one that I talked about last time, where we take into account prevalence So let's look at the three different cases here.

So the first one is where we have restricted occupancy.

This is where we've decided there's an N1, which is epsilon over average beta tau.

So all the physical parameters are buried in there.

And this is going to be something less than the normal occupancy, N0.

Now what is the tau we want to think about?

Well, if we have a school or a business, this would be the cumulative time that people spend together to the point where the number of days they spend together is, let's say, on the order of a week would be a reasonable number to think about.

Because if we write tau is the typical hours per day.

Time is some kind of maximum number of days.

This maximum number of days could be set by, for example, the testing frequency.

For example, here at MIT, we are testing our entire population at least once a week in order for anyone, including myself, to be admitted to the campus.

And so we are definitely testing within a week and catching new infections at that rate.

It could also be motivated by the incubation time, which is the time to show symptoms.

And most people will remove themselves.

And we know that's around 5.5 days, a typically reported value.

So again, on the order of a week.

And there's also, of course, other ways that people are removed or they recover.

So there's removal and recovery, which is another way that if you start to go more than, let's say, two weeks, we start to think an infected person that didn't get removed then end up in the hospital has probably recovered.

So if we think of a certain number of days and hours per day, that gives a tau that is going to go into this formula.

And actually, I should also mention that for simplicity here, technically this should be N1 minus 1.

And I can either include that or not when I do this calculation.

But I'm generally thinking of N1, which is going to be bigger than 1.

So think of an occupancy of 10 people in a classroom, or something, might be a limit that we would be interested in considering.

But certainly we can put the 1 in there if we want to.

So now let's ask ourselves, how would we start to reopen the space once we've decided on a safe occupancy during the greatest level of restrictions?

So that would then lead us into a phase of relaxing restrictions.

And this would still be with masks.

So keeping in mind that masks are an essential part of achieving a reasonable occupancy when the pandemic is high and there's a lot of prevalence.

And that we would only start to relax occupancy first before we take away the suggestion to wear masks.

And that would be then the last step.

So for relaxing restrictions, we're then going to be interested in the indoor reproductive number being less than now a rescaled value, which would be epsilon over P i Q i N. And the indoor reproductive number, remember, is N minus 1.

But it's approximately N times beta tau.

So I've replaced again N minus 1 with N just to get a simpler formula.

And so notice now here, N is in both sides of the equation.

If I want to solve for the value N2, which is this yellow curve here, I'm actually going to have to put the N's on one side and take a square root.

So my N2 then would be the square root of epsilon over beta tau times P i times Q i.

And remember also, another approximation here is that P i is definitely much less than 1.

We're looking to limit a very low prevalence.

And so also therefore, Q i is basically tending to 1 because it's 1 minus P i.

And so that factor is really not that important.

And notice also, epsilon over beta tau, that's N1.

So N3 is approximately related to N1 by the square root of N1 divided by P i.

That's this number here.

So the function prevalence, this yellow curve, is 1 over square root of prevalence.

And one nice thing about writing it this way is that I can decide on a reopening protocol without actually redoing my calculation with all those complicated variables, including the risk tolerance epsilon, and all the factors that go into beta because I've lumped them into N1.

What I'm saying here is that we've already done a calculation and decided to impose a certain occupancy restriction on certain space based on principles that we've been discussing in this course.

But now as prevalence goes down, according to the simple formula, whenever N2 is bigger than 1-- we would use this if N2 is bigger than N1.

So basically, when these two curves cross, as you get a lower prevalence, you now switch to two and you'll start increasing.

And you will do that until you get to N0.

This is the relaxing restrictions.

So basically, when N2 is bigger, than we allow this until N2 equals N1.

And that's this time here, P, P2.

So basically, we start imposing restrictions at P1.

So basically, we start relaxing restrictions when the prevalence equals P1.

That would be when N2 is equal to N1.

And so that would be when P1 is 1 over N1.

So essentially, that's when you expect to find one infected person.

So this is approximately 1 over N1.

Up here, when you go below this, you're saying, well, it's actually unlikely that during the time tau we'll even get one infected person.

And that's when we start to relax.

So that's the first crossover point.

And there's a second crossover point when this is equal to P2-- sorry, is equal to N0.

That's [INAUDIBLE] P2 is.

And so basically, P2, which is when we would hit the saturation point and that's when we've reopened in some sense to the full normal situation, that would be when N2 is equal to N0.

Wait, sorry.

I wrote here N2 equals N1.

Sorry, I meant when N2 equals N0.

Sorry.

That's the time P2 here, when N2 is equal to N0, that's when we cut off.

So this is N0.

And we solve for P i.

You can see that we get N1 over N0 squared.

So that is the place where I then switch.

And now I'm going to cap the occupancy at N0.

So maybe to summarize here, what I would say is that the occupancy should be less than or equal to N1 for P i greater than P1.

It'll be N2, which depends on P i for P i between P1 or P2 and P1.

And then as the prevalence gets lower, we go to full occupancy, N0, when P i is less than P2.

So this is basically this full curve of reopening.

And then the final decision to make is, when do we return completely to normal and take away certain restrictions we've done?

So here I mentioned masks.

We could also include in this calculation relaxing other restrictions, such as maybe not having the ventilation on quite so high.

So that would be when we finally go back to no restrictions of any kind.

We're back to normal.

So this means no masks, no other precautions, full occupancy.

So in this case, R N is going to be less than epsilon over-- well, let's see here.

It's the same as before.

We have this P i, N that we just looked at.

Or technically. times Q i.

But now we have another factor, P M squared.

Because compared to the case with no masks, we know the bound in the guidelines.

So the effect of beta just gets rescaled by P M squared.

So technically that's in R N here.

But now we have this extra factor.

You think of it like a rescaling of epsilon.

And so what that's going to do for us then is that there's another curve that goes like this, which is just like this one but it's shifted by a factor P M cubed-- or P M squared, sorry.

Which is like the case where you had-- so this is like no masks.

It's like the N2 with no masks.

And the other curve is with masks.

And there's a rescaling factor, which really has to do with the remediation that you've done.

And in this case, P3 would then just be P M squared times P2.

So if our P M is a factor of 10%, let's say, masks are letting 10% of infectious droplets get through, the P M squared might be a factor of 100.

So then we would wait to the prevalence is 100 times smaller before we finally allow people to remove masks and be at full occupancy.

And you could make a similar calculation for other types of restrictions.

And in fact, you can calculate such a curve for a given room, given scenario of human behavior and interventions, such as filtration or ventilation.

And what the theory allows you to do is to, of course, recalculate N1.

And then you can recalculate N2 as well.

And so you can say, well, I don't like this curve.

I would like to try to reopen my school sooner.

How would I do that?

Well, I know that if I make various interventions, I can raise the pink curve.

So I could end up somewhere here, let's just say.

This might be with safety interventions.

Actually, one such intervention, by the way, is masks themselves.

Because if I follow this curve all the way down here, there's some curve down here, which is no masks, which is the safety guideline with no masks.

And if I turn on masks, I go up.

But when I make that intervention, also P2, notice, scales also like N1.

And so that's actually moving in this direction.

And so I essentially move this yellow curve.

And so I'm now going to say, well, with a different set of interventions I can make the room safer.

And what that does, it gives me more people in the room.

But it also means that I change when I make the decision to reopen.

And in particular, I can get myself to full occupancy at a higher prevalence because the room is actually now made safer.

So I note it.

But on the other hand, this switch here was at 1 over N1.

So this part shrinks a little bit as this ultimately goes up to full occupancy.

So basically, I think compared to the current situation or the typical situation where policymakers are making decisions based on something like the six-foot rule and a somewhat arbitrary feeling about what is a high prevalence-- is it 1%, is 0.1%-- and we decide, OK, now we can close our schools or reopen our schools or set the occupancy at half, the guideline tells you how to set occupancy for of the worst case scenario, when the pandemic is very prevalent in society.

But now also, through these kinds of calculations, we can make rational decisions about how to reopen.

I'm not advocating necessarily for the exact formulas we find on the board here.

But the principles I'm showing you could lead to quantitative and scientifically justifiable ways of taking a specific space and a specific usage of that space and deciding how to close, as prevalence goes up, and reopen, as prevalence goes down, including ultimately returning to normal and removing masks and all other forms of precaution as the epidemic disappears.