# Mathematical Modeling for Cornell's Spring Semester

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Consistent with Cornell's commitment to respond quickly to new scientific and public health data, over the winter break, Cornell's pandemic modeling team updated a mathematical model of the spread of COVID-19 originally developed for the 2020 fall semester. The model was updated to incorporate newly available information: data from student and employee COVID-19 cases at Cornell during the fall semester; rising prevalence in the Southern Tier and the country as a whole; and the evolution of faster-spreading variants of SARS-CoV-2 from the United Kingdom, Brazil and South Africa. Based on this updated model, the team then identified likely scenarios for what might unfold over the spring semester and studied proposed modifications to Cornell's COVID-19 measures. This supported Cornell's preparation for the spring, with insights from the analysis resulting in modifications to interventions used in the fall.

While mathematical modeling of epidemics is inherently uncertain, with outputs being extremely sensitive to inputs and inputs having a significant amount of uncertainty, this work was able to identify the following insights:

- The new virus variants, COVID fatigue, elevated prevalence in the surrounding region that began after Thanksgiving, and a potential for elevated transmission during the winter all pose a significant challenge beyond the one we faced during the fall semester.
- New interventions being put into place are well-positioned to address this challenge. These interventions include 3x / week testing for varsity athletes, those students that live in group housing, and participate in social Greek-life organizations; measures to shorten results completion time in Cornell's testing program; measures to reduce travel during the semester; and new contact tracing and supplemental testing programs for employees.
- During the fall semester, travel outside the local area increased a student's risk of becoming infected by a factor of 8. Moreover, the risk of traveling may be larger in the spring than in the fall because of recent increases in national prevalence and increased transmissibility of new variants. Planned changes to how travel is reviewed and when surveillance tests are scheduled are important measures for reducing these risks.
- Based on national data and experiences at Cornell in the fall semester, most students are unlikely to experience severe symptoms if infected. Thus, we focus on infections as our primary health outcome rather than alternate measures.
- Fall data suggest that the number of cases in employees and the surrounding community are not influenced by prevalence in the student population, as transmission from students to non-student employees or community members was not observed during the fall semester. Thus, we do not include employee cases in the graphs we present below.
- Exposure to COVID-19 from family members and social gatherings away from campus, along with travel beyond Ithaca, together constitute the greatest risk to employees.

Together these two risk factors were the source of 75% of employee cases during the fall semester. Indeed, we see a strong correlation between infection rates in the counties surrounding Ithaca and infection rates in faculty and staff.

This document summarizes the analyses supporting these insights. The analysis presented here was prepared based on data from the fall and does not include data from recent cases during the spring semester. Its conclusions, however, are consistent with what we have seen so far during the early part of the spring semester.

The rest of the document has these sections. First, we consider students (section 1), then employees (section 2) and community members (section 3). Finally, we separately analyze the risk of travel among students (section 4).

# 1. Students

In the fall semester, we saw significant heterogeneity across student groups. In particular, undergraduate students participating in greek life and athletics were over-represented among those infected. To understand this, we analyze 3 groups of students:

| Student Group | Number of Students |
|---|---|
| 1: Undergraduates (UG) with greek or athletic affiliation | 3533 |
| 2: Other UG | 8434 |
| 3: Graduate and professional students | 6202 |

*Table 1: Sizes of the three student groups used in student calibration and projection.*

The results in Figure 1 below from the fall show extremely low case counts overall, but also indicate that Group 1 saw more infections than the other student groups. The percentage of students from Group 1 infected is even larger relative to other student groups since they are roughly half the size of each of the other two groups.

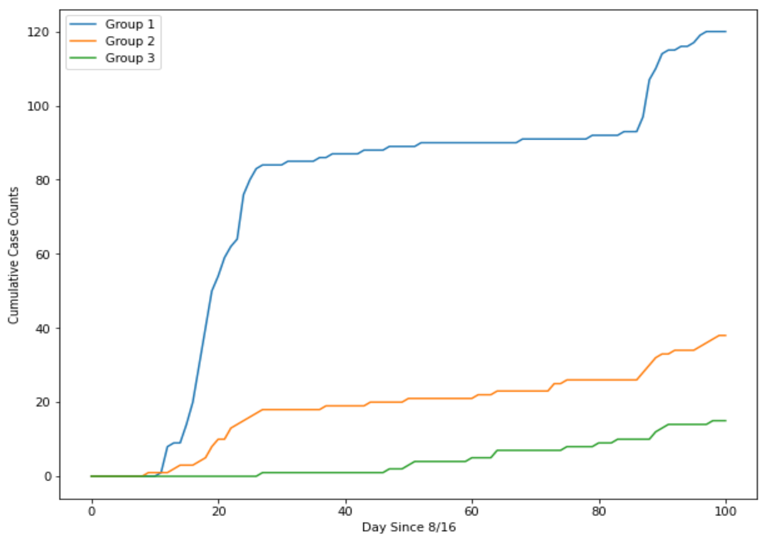


*Figure 1: We plot the cumulative case counts within each student group over the course of the fall semester, excluding those that tested positive on arrival to Ithaca. Day 0 corresponds to August 16, 2020. We see the effects of clusters at the start and end of the semester, with students of greek or athletic affiliation most heavily affected.*

<u>What explains the larger case count among Group 1 students?</u>
One small contributing factor is that Group 1 students are more likely than others to be infected during travel. Table 2 below shows that Group 1 students are twice as likely as Group 2 and Group 3 students to be infected by travel. In Group 1, across 10K students over a 10-day period, we see 1.4 new infections. Over the 100 days pictured in Figure 1, this corresponds to 5 imported cases in Group 1. While an imported case can create other student cases before it is contained, this is not enough to explain the full difference in outcomes across groups seen in Figure 1.

| Group | Rate of new student infections originating outside the campus community (# of new infections per- 10 days and 10K students) |
|---|---|
| 1 | 1.42 |
| 2 | 0.711 |
| 3 | 0.645 |

*Table 2: Rate of new student infections originating from outside the campus community during the fall semester, excluding positives from students who have just arrived to Ithaca. The rate is expressed as the number of new infections per 10 days and 10K students. The primary source of such infections is in-semester student travel outside of the Ithaca area, as contact tracing of positive cases shows extremely little physical contact between students and those outside the Cornell community in the local area.*

A larger contributing factor is that Group 1 students transmit more cases to other students, as shown below in Table 2. Indeed, each positive Group 1 student results in 0.764 additional student cases on average, which is 4 times larger than the number resulting from a positive Group 2 student, and 11 times larger than resulting from a positive Group 3 student. Thus, not only are Group 1 students more likely to be infected from outside of Cornell, on average they transmit the infection to more students than Group 2 or Group 3 students.

| | Source cases group (w/ # cases) | | |
|---|---|---|---|
| | Group 1 (125 cases, UG with Greek or Athletics Affiliation) | Group 2 (44 cases, Other UG) | Group 3 (15 cases, Graduate and Professional Students) |
| Average # positive contacts in Group 1 | 0.736 | 0.023 | 0 |
| Average # positive contacts in Group 2 | 0.028 | 0.148 | 0 |
| Average # positive contacts in Group 3 | 0 | 0.023 | 0.067 |
| Average # positive contacts in all groups | 0.764 | 0.194 | 0.067 |

*Table 3: Each column gives the average number of positive contacts (in each group) infected by one positive student. Each column gives these values for a different positive student source group. For example, a new Group 1 infection resulted in, on average, 0.736 new infections in Group 1 and 0.028 new infections in Group 2. These values are the results of averages from contact tracing and adaptive testing data.*

More than 96% of the additional cases created by a positive Group 1 case are among other Group 1 students. This creates larger case counts in the Group 1 population than in other groups, as we see in Figure 1, with almost all of these cases remaining restricted to this population.

<u>What does this mean for the spring?</u>

Over the summer, we developed a model to make projections for the fall. When this model was developed, much less was known about the virus, especially concerning its transmission in university populations. Over the winter break, we updated our model to reflect what we learned over the fall semester as well as anticipated changes to the situation on the ground during the spring semester: changes to prevalence in Ithaca, the nation, and the world; changes in transmission created by winter; and the rise of new variants of SARS-CoV-2.

As part of this update to our model, we used Table 3 above to determine the relative rates of transmission within and between groups, as observed through contact tracing and adaptive testing. We then performed an additional calibration step against fall data to estimate the rate at which infections are transmitted over time.

Then, to account for differences in transmission between the fall and the spring due to new virus variants, winter weather, and COVID fatigue, we identified 3 scenarios: optimistic, nominal, and pessimistic.

- The nominal scenario elevates transmission rates relative to the fall by a factor of 1.56x --- this assumes that faster-spreading variants recently will become predominant through the entirety of the spring semester with an increase in transmission using estimates from [Davies et al. 2020]. While this has not yet occurred and the CDC expects that it will be March before it does [Galloway et al. 2020], we also expect some elevation in transmission in February relative to the fall due to cold winter weather.
- The optimistic scenario elevates transmission relative to the fall by 1.25x, where the 25% increase is attributable to some elevation in transmission due to winter weather and COVID fatigue, and assumes that the UK and other faster-spreading variants do not become a significant fraction of cases until the spring semester ends.
- The pessimistic scenario uses a higher elevation of 1.96x, which includes both the 56% elevation due to faster-spreading variants and a 25% elevation due to winter weather and COVID fatigue, for the full duration of the semester.

None of the scenarios include the effect of immunity developed through past infections, since the fraction of students who have been infected is low. In addition, none of the scenarios include the effect of vaccinations, since few students will be vaccinated during the spring semester.

We then simulated what might happen over the course of the spring semester in the student population under these scenarios. The two panels in Figure 2 show results, picturing the percentage of each group infected on the y-axis and spring virus transmission relative to the fall semester on the x-axis. The left panel shows results under the fall's testing strategy: 2x per week for undergraduates, 1x per week for graduate and professional students. The right panel shows results under a new testing strategy: elevating testing frequency to 3x / week for students in Group 1, while continuing to test other undergraduates (Group 2) 2x / week and graduate and professional students (Group 3) 1x / week. This new strategy is being implemented by Cornell for the spring, based in part on the results pictured.

Our simulations show that if we test all student groups at the rate we used in the fall, as shown in the left-hand panel of Figure 2, then infections remain at a low level under the optimistic scenario, moderate under the nominal, and quite high under pessimistic. Many of these infections are in Group 1 in these scenarios with few infections propagating outside of this group, consistent with our observation in Table 3 from the fall that most secondary infections resulting from Group 1 infections stay within that group.

The right panel of Figure 2 then considers the new testing strategy being implemented, which tests Group 1 3x / week. This results in substantially better infection control, with most of the benefit coming from a reduction in infections in Group 1 itself. This is consistent with this offer of additional testing providing a substantial benefit directly to the students in that group.

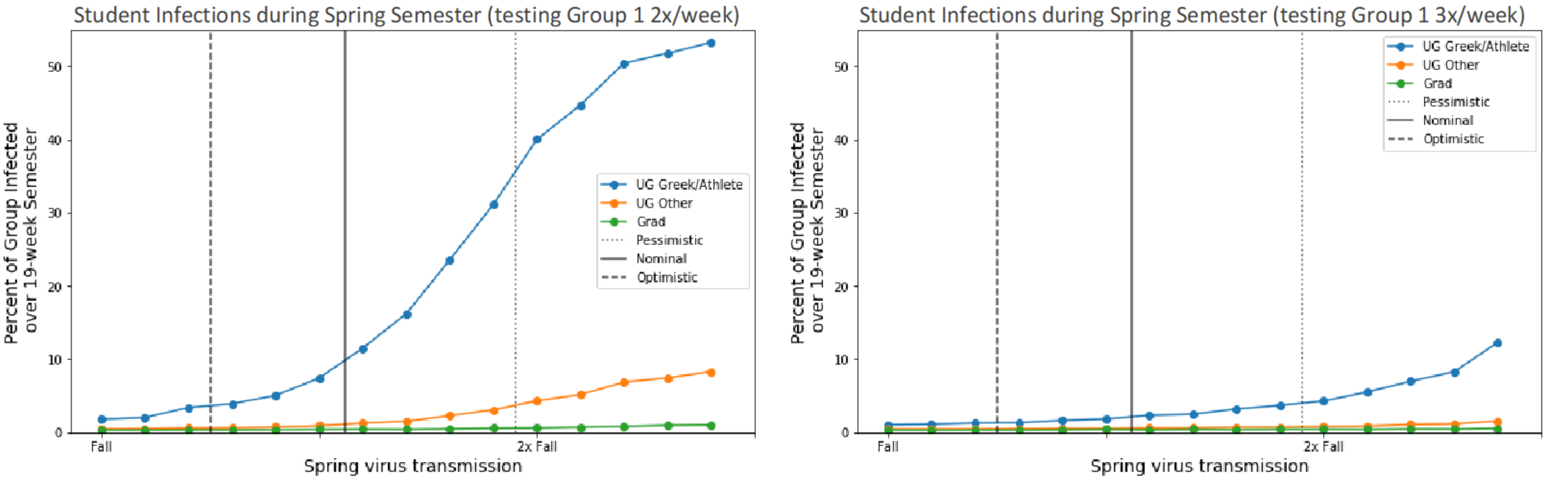


*Figure 2: Testing Group 1 students twice (left) per week or three times (right) per week. Each curve represents one group of students. The horizontal axis gives the elevation in spring transmission rates relative to the fall, while the vertical axis gives the average percentage of students infected over the course of the entire semester within the indicated group. The nominal scenario has this elevation at 1.56*x*, while the pessimistic scenario has it at 1.95*x *(almost twice the transmission rate seen in the fall). Note that the horizontal axis does* ***not*** *represent time, but rather the transmissibility of the virus.*

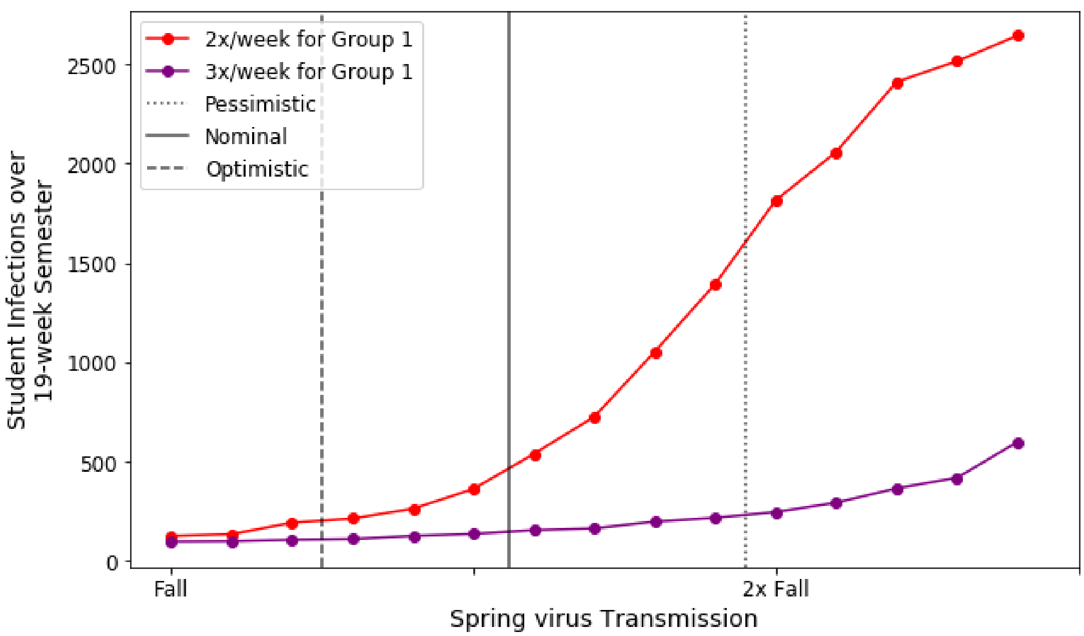


*Figure 3: The red curve represents testing Group 1 students twice per week; the purple curve represents testing Group 1 students three times per week. Group 2 and 3 students are tested twice per week and once per week, respectively. The horizontal axis gives the elevation in spring transmission rates relative to the fall, while the vertical axis gives the average total number of student infections over the 19-week spring semester across stochastic simulation outcomes. The nominal scenario has this elevation at 1.56*x*, while the pessimistic scenario has it at 1.95*x *(almost*

*twice the transmission rate seen in the fall). Note that the horizontal axis does **not** represent time, but rather the transmissibility of the virus.*

Results from the two plots in Figure 2 are summarized for the entire student population in Figure 3. This shows the total number of infections (not the percentage) under the strategy of continuing with 2x/week testing for all undergraduates (in red) vs. moving to 3x / week testing for Group 1 (in purple). As noted above, we see a substantial reduction in infections from testing Group 1 more often, especially in scenarios where spring virus transmission is more elevated relative to the fall. This supports the benefit of changing test frequencies for Group 1 to 3x / week, especially in terms of building robustness to the possibility that the new variants arrive early or combine with other factors to create a large increase in transmission rate relative to the rate seen in the fall.

Additional observations:

- Fall data suggest that the number of cases in employees and the surrounding community are not influenced by prevalence in the student population, as transmission from students to non-student employees was not observed during the fall semester. Thus, we do not include employee cases in the above graphs.
- Based on national data and experiences at Cornell in the fall semester, most students are unlikely to experience severe symptoms. Thus we focus on infections as our primary health outcome rather than alternate measures.

## 2. Employees (faculty and staff):

Data from the fall semester suggests that exposure to COVID-19 from family members and social gatherings away from campus, along with travel beyond Ithaca, together constitute the greatest risk to employees. Together these two risk factors were the source of 75% of employee cases during the fall semester. Indeed, we see a strong correlation between infection rates in the counties surrounding Ithaca and infection rates in faculty and staff in Figure 4 below.

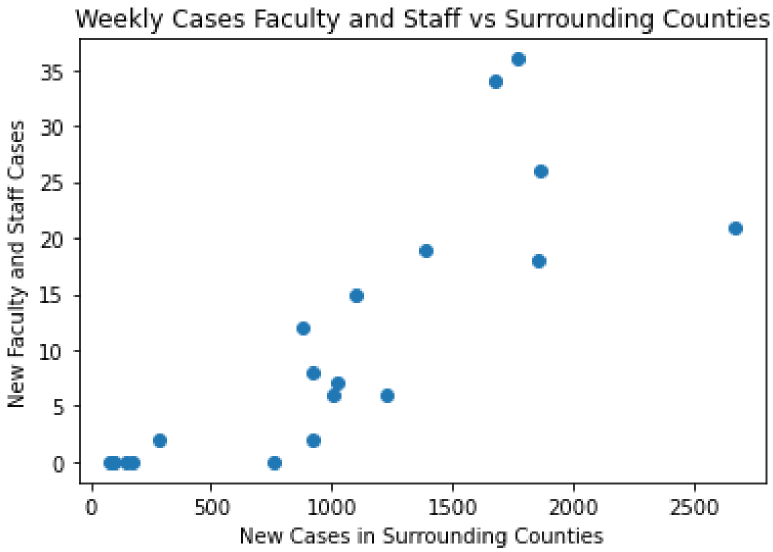


*Figure 4: Weekly new employee cases at Cornell plotted versus the number of new weekly cases summed across all counties adjacent to Tompkins County. Many of the employees that tested positive during the fall semester live outside Tompkins County where prevalence is higher. During this period, case counts in Tompkins county were low and a plot of faculty/staff case counts against case counts in Tompkins + surrounding counties shows a similar correlation.*

Meanwhile, transmission from on-campus contacts appears to have played a much smaller role, though some on-campus transmission took place. Employees appear to be much more compartmentalized within their social groups than is the case with students, which helps contain any potential on-campus spread. No employee infections were observed due to student infections during the fall semester, so it seems that our social distancing measures from the fall were effective and students are unlikely to be a significant source of risk for employees in the spring semester.

This is evident in Figure 5 below, which shows cumulative case counts for employees over the fall semester. Case counts are low through September (including at the start of September, when there was a cluster in the student population) and the middle of October. They then rose through November as prevalence in the surrounding local area rose. They reached their greatest rate of increase after Thanksgiving and in December and January, after the in-person fall semester had ended and students had left. Employee cases have since subsided in late January and early February, coincident with the end of the holiday season and the return of students to Ithaca. This is consistent with employee case counts being the result of infections acquired at home and in the local community, where prevalence was high due to holiday gatherings.

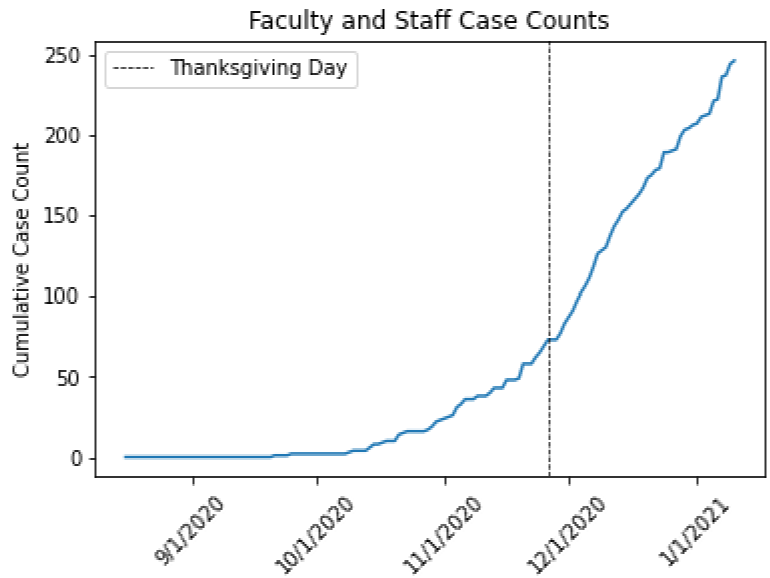


*Figure 5: Cumulative case counts in employees over the fall semester.*

Data from the fall suggest that transmission within the employee population is, unfortunately, difficult to model using the modeling team's current simulation framework. Employees are protected through a strong natural "pod" structure further augmented by social distancing measures. Compared with students, there are many more degrees of separation between two employees working in different roles in different parts of the campus. In contrast, our simulation structure assumes that individuals are "well-mixed" within each of a small number of groups --- fall data suggests this is a reasonable assumption for students, but not for employees. Moreover, because employee infections are driven significantly by prevalence in the local area and on-campus interventions have little ability to address infections acquired away from work, implying there would be less directly actionable information from a COVID-19 model for employees.

For these reasons, we do not provide quantitative projections for infections and employees and instead hypothesize that employee cases will continue to be strongly correlated with prevalence in the surrounding area. While we do support the recent launch of new employee contact tracing and supplemental testing programs, employees are likely to continue to face increased prevalence in the surrounding area, which Cornell cannot control.

## 3. Community:

- During the fall semester, we did not see evidence of transmission from students to the community, and saw little transmission from the broader community into the student population. While the return of students to Ithaca College (IC) does create a greater potential for Cornell-IC student interaction in the spring semester, IC students are being tested on arrival and twice weekly afterward [Ithaca College, 2020] and frequent testing of both Cornell and IC students is likely to limit the impact of these interactions.
- Employees interact with the broader non-Cornell community, especially with family members living in the same household, and also with others. It is unfortunately likely that employees will infect non-Cornell-affiliated individuals. The bulk of these infections,

however, are likely to be the consequence of other community interactions. In this context, Cornell's surveillance testing and contact tracing program for employees are likely to reduce transmission originating from employees below what it would be if campus were closed and these programs were not in operation.

## 4. Travel:

In the fall semester, we saw a substantial fraction of the positive cases among students associated with travel. Out of the 86 student positive cases reported during the semester, more than 10% were found immediately after a return from travel, even after excluding positives from first-time arrivals. In addition, more positive cases may have been travel-related but not revealed as such by contact tracing.

While this does suggest that travel is risky, quantifying this risk requires controlling for other risk factors. Indeed, it may be that people with other risky behavior also happen to travel more.

Thus, we conducted a statistical analysis to address this possibility by including other factors that were seen to differentially influence whether a student tests positive: social Greek-life organization membership, varsity athletic participation, student degree program and housing. We estimated the probability that a student would test positive (from a non-arrival test) in a particular week, based on these factors and also whether the student traveled in the previous two weeks.

After controlling for these factors, we found that a student who traveled in the past 2 weeks had **8x higher odds of testing positive** than if they did not travel. Measures to reduce non-essential travel will reduce the number of infections brought to campus through this source.

## References

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