The effect of border controls on the risk of COVID-19 reincursion from international arrivals

Nicholas Steyn¹,³,⁴, Rachelle N. Binny²,⁴, Shaun C. Hendy³,⁴, Alex James¹,⁴, Audrey Lustig²,⁴, Michael J. Plank¹,⁴

¹. School of Mathematics and Statistics University of Canterbury, New Zealand.
². Manaaki Whenua, Lincoln, New Zealand.
³. Department of Physics, University of Auckland, New Zealand.
⁴. Te Pūnaha Matatini: the Centre for Complex Systems and Networks, New Zealand.

Abstract

In an attempt to maintain elimination of COVID-19, the New Zealand government has closed the border to everyone except citizens and residents. All arrivals are required to spend 14 days in government-managed isolation/quarantine and to be tested for COVID-19 on day 3 and on day 12 of their stay. We model the testing, isolation and potential transmission of COVID-19 within managed isolation facilities to estimate the risk of undetected cases and the risk of infectious cases being released into the community. We use a stochastic individual-based that includes a time-dependent probability of a false negative test result, complete isolation of confirmed and probable cases, and secondary transmission of COVID-19 between close contacts. We show that the combination of 14-day quarantine with day 3 and day 12 testing reduces risk of releasing an infectious case to around 0.1% per infected arrival. Shorter quarantine periods, or reliance on testing only with no quarantine, substantially increase this risk. It is important to avoid contacts between individuals staying in quarantine to minimise the risk of secondary transmission. We calculate the ratio of cases detected on day 3 to cases detected on day 12 in the model and show that this may be a useful indicator of the likelihood of secondary transmission occurring within quarantine. We do not explicitly model transmission of COVID-19 from individuals in quarantine to staff, but this is likely to present a significant risk. This needs to be minimised by strict infection control, use of personal protective equipment by staff at all times, and avoiding close contact between staff and hotel guests.

NOTE: This preprint reports new research that has not been certified by peer review and should not be used to guide clinical practice.
Introduction

Early in the COVID-19 outbreak New Zealand imposed strong border restrictions: the border has been closed to non-residents since 20 March and all arrivals have been required to spend 14 days in government-managed isolation/quarantine (MIQ) since 10 April. Together with very strong population-wide control measures imposed in late March, these restrictions have been successful in containing the virus and eliminating community transmission. As of 8 July 2020, there has been no reported transmission of COVID-19 outside government-managed quarantine facilities for more than six weeks and population-wide restrictions on domestic travel and large gatherings have been almost completely lifted. However, the strict border restrictions remain in place. In addition to the 14-day MIQ, travellers are checked for symptoms daily and are tested for COVID-19 on the 3rd and 12th days after arrival. Those that test positive and/or display symptoms are moved to a stricter MIQ facility until they recover. Individuals have the right to refuse to be tested; however, reports indicate this is rare, and those that do can be held in MIQ for up to an additional 14 days under the COVID-19 Public Health Response Act (New Zealand Government, 2020a).

Models of COVID-19 in New Zealand have so far not considered the rate of arrival of COVID-19 cases from overseas and the effect of various border measures in reducing the risk of these cases being released into the community. Assessment of the risk is critical because, now that domestic restrictions have been lifted, it is likely that any community transmission would grow into a large outbreak very rapidly, as seen recently in Melbourne for example. A model specifically designed for this purpose allows us to (a) determine which measurable variables may be useful to determine unmeasurable outcomes (e.g. whether there is transmission of COVID-19 within MIQ facilities) and (b) quantify the risk associated with different settings such as allowing special exemptions or better separating recent arrivals from those at the end of their stay.

In this study, we introduce a mathematical model of COVID-19 incubation, transmission and testing in border MIQ and explore the risk of releasing infectious individuals into the community under different scenarios. Key outcomes include: the probability of cases being undetected and the infectiousness of any undetected cases after being released from MIQ. We propose a metric that can be used to estimate the level of transmission occurring internally within MIQ facilities. We evaluate possible policy decisions and their potential outcomes, e.g. introducing special exemptions, cohort demarcation, and shortening the mandatory quarantine period. We only model the risk that international arrivals themselves pose, and do not consider the risks associated with immigration officers and MIQ workers coming into contact with recent international arrivals.

Methods

Infected arrivals have a probability of being subclinical $p_{sub} = 42.5\%$ (Lavezzo et al, 2020). All individuals are tested on specified days and interviews are conducted daily in which symptomatic individuals have a $p_{detectSymptoms} = 33\%$ chance of meeting the case definition, with the results being returned and actioned on the following day. Detected cases are moved to a stricter MIQ facility, which is assumed to have no risk of discharging an infected case. Individuals that do not test positive or meet the case definition are released $LOS = 14$ days after arrival. The case definition is the required level of symptoms to be considered a suspect case, and thus be moved to a stricter facility. The model is run in discrete time steps of one day.

When enabled, individuals interact with each other within MIQ and each interaction has a probability of transmitting the virus. The assumption of Poisson distributed contacts ignores the possibility of superspreaders or superspreading events, which are very unlikely within the strictly controlled MIQ environment (though see Discussion). Individuals travelling together are not explicitly modelled. Transmission between family members or other travelling companions staying in the same hotel room is
expected to occur, although we expect that such contacts will be detected so they pose very little risk. This needs to be considered when comparing model results with observed data.

Key assumptions:

- The secondary attack rate is proportional to the distribution of generation times (Feretti et al, 2020), scaled and peaks at 0.7%, the average found in Cheng et al. (2020). This assumes individuals in close contact in isolation facilities are likely to be more careful than the general public and to have limited opportunity for high-risk contacts, such as gathering in large groups or socialising in crowded spaces (Leclerc et al, 2020). Small variations in this parameter have little influence on the relative effects of different policies.
- All individuals are assigned randomly distributed incubation periods (i.e. time from infection to symptom onset) with distribution $\sim \Gamma(\mu = 5.5 \text{ days}, \sigma = 2.3)$ (Lauer et al, 2020). For subclinical cases this is interpreted as the date of peak infectiousness.
- Infected arrivals are randomly assigned infection dates between 0 and 9 days prior to arrival $\sim U(0,9)$. This means that on average symptom onset occurs 1 day after arrival, consistent with NZ data. Infected individuals displaying symptoms before departure have a $p_{\text{Detect Symptoms}}$ chance of not travelling. This parameter is also used as the probability that a symptomatic individual within MIQ is detected on any given day.
- Test sensitivity is a function of time since exposure, a linear interpolation of the false negative rates reported in Kucirka et al. (2020), scaled to give a peak sensitivity of 94.3% (Wikramaratna et al, 2020) three days after symptom onset (Kucirka et al, 2020). This assumes testing is more sensitive than suggested in Kucirka et al. (2020), as the tests are administered by trained nurses rather than volunteers.
- Subclinical individuals are assumed to be less infectious than clinical individuals by a factor of $relInf = 0.50$ (Davies et al, 2020) and have a lower test sensitivity, $relSens = 80\%$.
- Each infected individual has a Poisson number of contacts: $C \sim \text{Poisson}(\text{meanContacts})$, resulting in a binomial number of secondary infections: $\sim \text{Binomial}(C, SAR)$, where SAR is the relevant secondary attack rate. These secondary infections are chosen randomly from all individuals in the simulated MIQ.
- The effective reproduction number $R_{eff}$, i.e. the expected number of secondary cases caused by a single infected arrival if they were in MIQ, for the full duration of their infectious period:

$$R_{eff} = \text{meanContacts} \left[ (1 - p_{\text{sub}}) + relInf \times p_{\text{sub}} \right] \sum_{i=1}^{t_{\text{max}}} \text{SAR}(t_i)$$

For the default parameter values, $R_{eff} = 0.143$. Testing, symptom monitoring and removal of confirmed and probable cases from the quarantine facility will reduce the effective reproduction number below this value.

Model Outputs

Three key metrics are considered: (1) the number of undetected cases as a proportion of the number of infected arrivals; (2) the number of significantly infectious cases released into the community as a proportion of the number of infected arrivals; and (3) the ratio of cases detected in the second week after arrival to cases detected in the first week after arrival. We define “significantly infectious” as being within the first three days since symptom onset (or equivalent time for asymptomatic cases). This is when individuals are assumed to have passed 93% of their total infectiousness. When enabled, transmission within MIQ may theoretically increase the values of (1) and (2) above 100% if there is sufficient transmission within MIQ, so that more infected individuals are released than arrive. The ratio of cases detected in the second week to cases detected
in the first week was chosen as a measurable indicator of transmission within MIQ. Parameter values are shown in Table 1.

| Name             | Description                                              | Default Value | Source                        |
|------------------|----------------------------------------------------------|---------------|-------------------------------|
| pSub             | Proportion that are asymptomatic                         | 42.5%         | Lavezzo et al. (2020)         |
| relInf           | Relative infectiousness of subclinical individuals        | 50%           | Davies et al. (2020)          |
| relSens          | Relative sensitivity of test of subclinical individuals   | 80%           | Assumption                    |
| pDetectSymptoms  | Probability a symptomatic individual's symptoms are detected | 33%           | NZ Estimate                   |
| LOS              | Length of stay                                           | 14 days       | NZ Policy                     |
| testDays         | When tests administered, days since arrival              | [3, 12]       | NZ Policy                     |
| peakSAR          | Peak secondary attack rate                               | 0.7%          | Cheng et al. (2020)           |
| Generation time  | Distribution of generation times, used to calculate SAR(t), the function of secondary attack rates. | Weibull (5.67, 2.83) days | Feretti et al. (2020)         |
| meanContacts     | Mean number of contacts each individual has               | 0 (no transmission), 5 (moderate transmission) | NZ Estimate                   |
| Onset distribution | Distribution of time from exposure to symptom onset | Γ(5.8, 0.95) days | Lauer et al. (2020)           |

Table 1. Parameter descriptions and default values.

Results

Observed Data

From 9th June 2020, arrivals in New Zealand MIQ facilities have been tested twice, once around day 3 and once around day 12 (Ministry of Health, 2020). We consider the two-week period between 23rd June and 6th July, during which all individuals have been subject to these requirements for their entire stay. During this time, 21 cases of COVID-19 were reported in MIQ facilities. Table 2 gives a breakdown of these arrivals.

For comparison, 1,000 trials of the model were run for the same period. The number of daily arrivals was taken from NZ international arrival count data from StatsNZ. The probability of an arrival being infected was assumed to be 0.5%. This value was chosen so that the model (under the assumption of no transmission within MIQ) detected a similar number of cases as were reported. The model was also run with a moderate level of transmission in MIQ. Results are shown in Table 2.

In the model with no internal transmission, there were an average of 0.086 (0.046, 0.13) cases detected in the second week for every case detected in the first week. When a moderate amount of internal transmission was introduced, this increased to 0.12 (0.059, 0.18). Ignoring the two cases that were known close contacts of other cases, we observed a ratio of 0.12 in the data (2/17), within the range of plausible values for both no transmission and moderate transmission.

Two of the total observed cases, both detected in the second week, were each confirmed to be travelling and isolating with another case. We are not explicitly modelling these so they are ignored when comparing results.
Table 2. Observed and modelled quarantine case detection for the period 23rd June to 4th July 2020. The model allows for a single case to be detected in multiple ways (e.g. if they declare their symptoms on the same day as a test), so totals may not match. 1st and 3rd quartile simulated values are given in parenthesis. Undetected cases may not be infectious when they leave.

The model consistently over-predicts the number of clinical cases and under-predicts the number of subclinical cases. There are at least three factors that might contribute to this: (1) international arrivals are typically younger so are more likely to be asymptomatic than the general population, and (2) clinical cases that have not developed symptoms on the day of testing may be listed as asymptomatic, with their status not updated when symptoms develop; (3) prevention or disinclination of symptomatic cases from traveling may be stronger than assumed in the model.

Scenarios

We consider seven scenarios. These are run both without transmission in MIQ and with a moderate level of transmission in MIQ, equivalent to each individual having 5 contacts per day on average.

Scenario 1 – Test on Arrival Only
- Each individual is tested once on arrival and held until the results are ready.
- As in the full model, symptomatic individuals have a 33% chance of meeting the clinical definition and being detected.
- No exemptions permitted.

Scenario 2 – Test on Departure and Arrival
- Each individual is tested once before departure and once on arrival. They are held until the results are ready. The test before departure is assumed to be of the same quality as a domestic test.
- As in the full model, symptomatic individuals have a 33% chance of meeting the clinical definition and being detected.
- No exemptions permitted.

Scenario 3 – Five Day Quarantine
- Individuals are required to stay in a government managed quarantine facility for five days.
- Individuals are tested twice: once on arrival, and once on day four.
- No exemptions permitted.

Scenario 4 – 10 Day Quarantine
- Individuals are required to stay in a government managed quarantine facility for 10 days.
- Individuals are tested twice: once on day three, and once on day 8.
- No exemptions permitted

**Scenario 5 – 14 Day Quarantine (Current)**
- Individuals are required to stay in a government managed quarantine facility for 14 days.
- Individuals are tested twice: once on day three, and once on day 12.
- No exemptions permitted

**Scenario 6 – Exemptions Allowed**
- Individuals are required to stay in a government managed quarantine facility for 14 days.
- Individuals are tested twice: once on day three, and once on day 12.
- Exemptions are permitted at any time. Each individual has a 5% chance of being granted an exemption and is tested the day before their release.

**Scenario 7 – Late Exemptions Allowed**
- Individuals are required to stay in a government managed quarantine facility for 14 days.
- Individuals are tested twice: once on day three, and once on day 12.
- Exemptions are permitted in the second week only. Each individual has a 5% chance of being granted an exemption and is tested the day before their release.

![Figure 1](https://doi.org/10.1101/2020.07.15.20154955)

**Figure 1.** Relying on repeated testing and having no MIQ would significantly increase the risk of missed cases. Number of undetected cases as a percentage of infected arrivals. Vertical bars give the interquartile range for fortnightly values using the observed June NZ arrival and prevalence rates, and the wider horizontal line gives the expected value. Red bars are the results with no transmission in MIQ, and blue bars are the results with moderate transmission in MIQ.
Figure 2. A shorter quarantine period would significantly increase the chance of a highly infectious individual entering the community. Number of significantly infectious cases released into the community as a percentage of the number of infected arrivals. The vertical bars give the interquartile range for fortnightly values (same duration as observed data), and the wider horizontal line gives the expected value. Red bars are the results with no transmission in MIQ, and blue bars are the results with moderate transmission in MIQ.

Figure 3. Number of significantly infectious cases released into the community as a percentage of the number of infected arrivals. This is cropped to highlight the differences resulting from exemptions. The vertical bars give the interquartile range for possible values over one week, and the wider horizontal lines give the expected value. In these scenarios, the 1st and 3rd quartile values are sometimes zero, while the mean is >0, so there may be no vertical lines. Red bars are the results with no transmission in MIQ, and blue bars are the results with moderate transmission in MIQ.
Figure 4. Ratio of cases detected in week 2 to week 1 under the current scenario (14-day quarantine). Four levels of transmission in MIQ are modelled: none, low (2 contacts on average), moderate (5 contacts on average) and high (10 contacts on average). These correspond to effective reproduction numbers of 0, 0.018, 0.052 and 0.104 respectively. The vertical bars give the interquartile range for possible values over a fortnight, and the wider horizontal line gives the expected value. The red bar is the results with no transmission in MIQ, and the blue bars are the results with moderate transmission in MIQ.

| Scenario          | Transmission in MIQ | % of All Cases | Median Value | First Quartile Value | Third Quartile Value |
|-------------------|---------------------|---------------|--------------|----------------------|---------------------|
| Test on Arrival   | None                | 47%           | 47%          | 39%                  | 54%                 |
|                   | Moderate            | 47%           | 48%          | 39%                  | 55%                 |
| Test Departure & Arrival | None         | 36%           | 36%          | 29%                  | 43%                 |
|                   | Moderate            | 37%           | 37%          | 30%                  | 45%                 |
| Five Day Quarantine| None                | 9.4%          | 8.7%         | 4.8%                 | 14%                 |
|                   | Moderate            | 12%           | 11%          | 7.4%                 | 17%                 |
| 10-Day Quarantine | None                | 6.0%          | 5.3%         | 0.0%                 | 9.1%                |
|                   | Moderate            | 8.9%          | 8.3%         | 4.5%                 | 13%                 |
| 14-Day Quarantine | None                | 7.7%          | 6.9%         | 4.0%                 | 11%                 |
|                   | Moderate            | 10%           | 10%          | 5.3%                 | 14%                 |
| Exemptions Allowed| None                | 8.4%          | 7.7%         | 4.3%                 | 12%                 |
|                   | Moderate            | 11%           | 11%          | 5.9%                 | 15%                 |
| Late Exemptions Allowed| None            | 7.9%          | 7.1%         | 3.8%                 | 12%                 |
|                   | Moderate            | 11%           | 10%          | 5.0%                 | 14%                 |

Table 3. Number of undetected cases as a percentage of infected arrivals. The numerator includes undetected cases that acquired their infection during their stay. Median and quartiles are estimated from fortnightly windows.
Testing on arrival, or testing on departure and arrival, only detect around 53% and 64% of arriving infected cases respectively. This could be improved if more accurate tests are developed but would always be the least recommended strategy.

A 5-day quarantine period detects as many cases as the full 14-day period but is not as effective in preventing highly infectious cases reaching the community. Under a 5-day quarantine period, around 6.8% of infected arrivals are released while highly infectious. With recent arrival rates (assuming no transmission in MIQ) this equates to an infectious case being released into the community every 9 days on average. The 10-day period reduces this to an infectious case being released every 100 days on average, and the 14-day period (the current scenario) reduces this even further to approximately 600 days.

Under the current 14 day quarantine scenario, a moderate level of transmission in MIQ (where each individual has contact with an assumed 5 others daily), increases the risk of a highly infectious case reaching the community rises from one every 600 days (no transmission) to one every 27 days. With a higher level of transmission in MIQ (equivalent to an average of 10 contacts per day) this risk increases even further. This highlights the importance of minimising contacts within MIQ facilities.

Table 4. Number of significantly infectious cases released into the community as a percentage of the number of infected arrivals. The numerator includes undetected cases that acquired their infection during their stay. Median and quartiles are estimated from fortnightly windows.

| Scenario          | Transmission in MIQ | % of All Cases | Median Value | First Quartile Value | Third Quartile Value |
|-------------------|---------------------|----------------|--------------|----------------------|----------------------|
| Test on Arrival   | None                | 45%            | 45%          | 38%                  | 52%                  |
| Only              | Moderate            | 46%            | 45%          | 38%                  | 54%                  |
| Test Departure & Arrival | None               | 35%            | 35%          | 29%                  | 42%                  |
|                   | Moderate            | 37%            | 36%          | 29%                  | 44%                  |
| Five Day Quarantine | None               | 6.8%           | 5.9%         | 3.3%                 | 10%                  |
|                   | Moderate            | 10%            | 9.1%         | 4.8%                 | 13%                  |
| 10-Day Quarantine | None                | 0.5%           | 0.0%         | 0.0%                 | 0.0%                 |
|                   | Moderate            | 3.3%           | 3.3%         | 0.0%                 | 5.3%                 |
| 14-Day Quarantine | None                | 0.1%           | 0.0%         | 0.0%                 | 0.0%                 |
|                   | Moderate            | 2.2%           | 0.0%         | 0.0%                 | 4.5%                 |
| Exemptions Allowed | None               | 0.5%           | 0.0%         | 0.0%                 | 0.0%                 |
|                   | Moderate            | 3.0%           | 0.0%         | 0.0%                 | 5.0%                 |
| Late Exemptions   | None                | 0.1%           | 0.0%         | 0.0%                 | 0.0%                 |
| Allowed           | Moderate            | 2.4%           | 0.0%         | 0.0%                 | 4.3%                 |

Table 5. Effective reproduction number and ratio of cases detected in the second week to cases detected in the first week under various levels of transmission in MIQ. Low transmission is equivalent to 2 contacts per day, moderate transmission is equivalent to 5 contacts per day, and high transmission is equivalent to 10 contacts per day. Median and quartiles are estimated from fortnightly windows.

| Scenario | Transmission in MIQ | Effective Reproduction Number | Overall Ratio | Median Value | First Quartile Value | Third Quartile Value |
|----------|---------------------|-------------------------------|---------------|--------------|----------------------|----------------------|
| 14 Day   | None                | 0                             | 0.122         | 0.111        | 0.056                | 0.176                |
|          | Low                 | 0.018                         | 0.139         | 0.132        | 0.066                | 0.211                |
|          | Moderate            | 0.052                         | 0.164         | 0.154        | 0.091                | 0.231                |
|          | High                | 0.104                         | 0.203         | 0.190        | 0.118                | 0.286                |
Despite the additional test, exemptions do pose a small amount of additional risk. This can be mostly mitigated by restricting exemptions to the second week only.

The ratio of the number of cases detected in the second week to cases detected in the first week increases as internal transmission increases. This is an observable quantity that can be easily calculated. Although, it is noisy tracking this value over time should give some insight into the level of transmission in MIQ. If this ratio increases substantially, then internal procedures should be evaluated.

Other Scenarios
Cohort demarcation, as suggested by the review into MIQ (NZ Government, 2020b), is another policy option being considered. This is where recent arrivals are kept separate from those nearing the end of their stay. While somewhat useful in reducing risk when there was transmission in MIQ, especially when exemptions were allowed, it was not as effective as simply reducing transmission in MIQ. Furthermore, although it wasn’t explicitly modelled, the act of moving people during their stay likely increases their contacts. This would increase risk, possibly by more than the reduction obtained by the separation. We also modelled a small number of testing refusals, although provided these individuals were kept for an additional 14 days and well isolated from other guests, there was no significant change in risk.

Although not well documented, it is possible that some infected individuals may be super-shedders, meaning they are significantly more infectious than average. To test the effect of individual heterogeneity in infectiousness, we assigned each case an individual value for the peak secondary attack rate, drawn from a gamma distribution with mean 0.007 (which is the default assumption) and shape parameter 3. Any effects of this were not discernible even with a high number of contacts.

Sensitivity Analysis
Sensitivity analysis of the main model outputs was performed to key model parameters for the scenario of 14-day quarantine with two tests. We tested sensitivity to a time offset (Table 6) or a scaling (Table 7) of either the secondary attack rate function or the test sensitivity function. We also tested sensitivity to the probability of detecting symptoms, the proportion of infections that are subclinical, and the distribution of pre-arrival exposure dates (Table 8).

The ratio of cases detected in the 2nd week to cases detected in the 1st week was sensitive to all assumptions. The proportion of cases missed, and the proportion released while significantly infectious, was somewhat sensitive to a shifting of test sensitivity and moderately sensitive to scaling of the same assumption. They were both also sensitive to the distribution of pre-arrival exposure dates, although only the former was sensitive to the proportion of cases that were subclinical.

| Function            | Shift       | Percentage Missed | Percentage Released While Significantly Infectious | Ratio of Cases Detected in 2nd Week to 1st Week |
|---------------------|-------------|-------------------|-----------------------------------------------|-------------------------------------------------|
|                     |             | No Transmission   | Moderate Transmission                          | No Transmission                                | Moderate Transmission                           |
|                     |             |                   |                                               |                                                 |                                                 |
| Secondary Attack Rate| 1-day earlier| 7.8%              | 11%                                           | 0.08%                                          | 2.4%                                            | 0.121                                          | 0.164                                         |
|                     | Current value| 8.1%              | 10%                                           | 0.05%                                          | 2.3%                                            | 0.122                                          | 0.162                                         |
|                     | 1-day later  | 7.7%              | 10%                                           | 0.09%                                          | 2.1%                                            | 0.123                                          | 0.157                                         |
| Test sensitivity    | 1-day earlier| 8.0%              | 11%                                           | 0.06%                                          | 2.0%                                            | 0.099                                          | 0.128                                         |
|                     | Current value| 8.0%              | 11%                                           | 0.04%                                          | 2.5%                                            | 0.124                                          | 0.160                                         |
|                     | 1-day later  | 8.1%              | 11%                                           | 0.1%                                           | 2.6%                                            | 0.174                                          | 0.208                                         |

Table 6. Sensitivity to shifts in the secondary attack rate as a function of time from symptom onset and test sensitivity as a function of time since exposure. There is a moderate level of sensitivity to these shifts, however, the relative effects of various policies remain very similar.
In recent weeks the number of arrivals has increased, and the prevalence of COVID-19 overseas is also rising. Both of these factors lead to increased risk over time. This risk may be amplified if lower-quality MIQ...
facilities are used. The triaging of arrivals into “high-risk” and “low-risk” facilities is one possible solution to minimising risk and should be included in future modelling work.

There are other sources of risk associated with the border such as flight crew, immigration officers, and hotel workers. We have not explicitly modelled the risk of transmission from an infected hotel guest to a staff member because of a lack of data about the number of contacts between guests and staff and the associated secondary attack rate. It is possible this risk is comparable to or greater than the risk of releasing an imported case into the community. For example, recent community outbreaks in Melbourne are thought to have been seeded as a result of hotel staff being infected by people in quarantine facilities. Contacts between hotel guests and staff should be minimised and physical distancing and proper use of personal protective equipment by hotel staff at all times.

We did not model superspreaders or superspreading events as these are unlikely to occur within MIQ. It is possible that communal spaces and surfaces (such as buses, elevators, reception areas, door handles) could provide an avenue for environmental transmission. This would effectively correspond to an increase in the mean number of contacts parameter in the model, but is unlikely to cause superspreading events given the restrictions on individual movements. Nevertheless, communal spaces and surfaces should be regularly cleaned and good hand hygiene encouraged to minimise the possibility of environmental transmission. Supershedders (individual heterogeneity in infectiousness) can increase the risk of release an infectious case, but this effect is small providing existing procedures are followed. We did not explicitly model families or other groups travelling together. It is possible that these will increase the number of cases detected in the second week because of transmission between people staying in the same room, but for the purposes of measuring widespread transmission in MIQ should not be considered in the ratio calculation.

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