Modelling of hospital and intensive care unit (ICU) requirements for Tasmania

Aims: to understand the health system surge requirements for Tasmania, in the event of a COVID-19 epidemic, once restrictions are lifted.

Methods: We used a deterministic SEIR mathematical model of COVID-19 based on a published and peer-reviewed model, updated for the age specific population structure of Tasmania, hospital capacity of Tasmania and specific Tasmanian targets for vaccination. The COVID-19 model parameters reflect the Delta variant, including R0 of 6 and an incubation period of 5 days. The model incorporates age-specific vaccination and vaccine protection at current rates of uptake (based on data provided from Tasmania). Vaccine effectiveness against Delta is assumed to be 31% following one dose for both vaccines, and 88% and 67% for Pfizer and AZ respectively after two doses. The vaccine effectiveness against hospitalisation, ICU and death is assumed to be >90% for both vaccines. Assumptions for face masks effectiveness were taken from a published, peer reviewed study of mask effectiveness during the Victorian second wave. The implementation of mandatory masks use has been estimated to be 28% (22-33%) effective in reducing transmissions while 70% were wearing masks. If mask coverage (70%) * mask effectiveness is 28%, then masks are estimated to be 40% effective.

The eligible population for vaccination in Tasmania is considered to be people 12 years and older. The vaccination rate was obtained from the publicly available data on first and second dose coverage over time in Tasmania. We modelled the vaccine roll out based on data provided, which expected 90% of the 16+ age group to be fully vaccinated by December first 2021, and 90% of the age group 12-15 having a first dose by middle/late December and 90% fully vaccinated by 17 of January 2022. The gap between first and second dose is considered to be 6 weeks.

Data from NSW was used for some COVID estimates, given Tasmania has no COVID-19 cases currently. Hospitalization, ICU and deaths rates were taken from NSW data and assumed to be 12% hospitalisation rate and 2% ICU admission overall, however Table 1 shows age-specific rates. Due to small numbers in NSW, the proportion of cases requiring ICU in unvaccinated children 0-11 was estimated from a large study in the US. Age-specific deaths rates were calculated using age-specific case incidence data from NSW and adjusted for vaccination rates by age groups, with 90% protection against these outcomes for fully vaccinated people. Median length of hospital stay and ICU stay was taken from a systematic review, which estimated a mean length of stay in ICU of 7 days. This is an optimistic scenario, based on reports from NSW that intubated patients have a considerably longer length of stay. The expected length of stay in Tasmania can be determined with discussion.

The contact matrix used is the one estimated for New Zealand rather than the average for Australia, to better reflect the lower population density in Tasmania. The model incorporates contacts tracing, testing and isolation of symptomatic people, while we model the necessity of masks and reduction in movements or mixing people.

We provide modelling of the requirements for ICU and hospital care for Tasmania under different vaccination scenarios (80-90%), different epidemic scenarios and different strategies for opening borders, to assist with planning for surge capacity and understanding the health system impact of policy decisions.

Initial conditions: The outbreak starts on December 1, and model runs from December 1, 2021, for 200 days, until June 2022. We start with 90% of the population 16 years old and over being fully vaccinated, while during the evolution of the outbreak, 90% coverage in 12-15 year olds is reached by mid January. We started with 10 initial infected cases at day 1 (December first), 2 symptomatic and 8 latent and untraced.

Scenario 1: No restrictions, varying contact tracing rates.

Scenario 2: Mandatory masks for people aged 10+, varying contact tracing rates.

Model description

We use a deterministic compartmental model for disease transmission, built using Matlab 2020. It is an expanded SEIR model based on a system of ordinary differential equations. The differential equations move the population through disease epidemiological stages and response stages. Once infected, the epidemiological stages in which people move through are being susceptible not vaccinated (S), vaccinated with one dose (V1) or two doses (V2), latent not infectious yet (E and Ev for vaccinated), latent infectious undiagnosed (E^u and E^{uv} for vaccinated), symptomatic infectious stages for undiagnosed (I1,I11 and I1v, I11v for vaccinated, where I1 and I1v last 1 day and is the first symptomatic day where an infectious person spreads more, while I11 and I11v represent the following 6 days of symptomatic period less infectious) and diagnosed (I2,I22 and I2v and I22v for vaccinated), recovered (R) or death (D), and public health response stages, as latent infectious diagnosed (E^t and E^{tv} for vaccinated) or isolated (Q and Qv for vaccinated), cases hospitalized (H) and requiring intensive care unit (ICU). We have two compartments for asymptomatic people who never develop symptoms, (A1 and A2). We assume they can infect others - A1 represents the peak of their infectiousness and A2 the 6 following days of gradually decreasing infectivity (A1v and A2v for vaccinated). Finally, the model has a compartment for uninfected contacts traced (C), which will stay home quarantine for 12 days before moving back to the susceptible compartment. Vaccinated people with one dose have 31% reduction in risk of infection, while people fully vaccinated have 88% (Pfizer) or 67% (AZ) reduction in risk of infection per contact, however both vaccine recipients once fully vaccinated have 90% reduction in hospitalization, ICU requirement and risk of death compared to no vaccinated people. Each of those compartments are age-specific (i) for 16 age groups, 5 years wide 0-74 years old and a 75+ last age group.

Table 1: Data/parameters used

Symbol	**Definition**	**Value**
$R0$	Basic reproductive number	6
θ	Percentage of symptomatic people isolated	90%
ρ	Percentages of contacts traced and home quarantined	80%-50%
q_1	Duration of quarantine for contacts traced isolation for symptomatic	12
d_1	Latent duration not infectious	3.2 days
d_2	Pre symptomatic infectious duration	2 days
d_3	Symptomatic infectious duration	7 days
v_1	Vaccine effectiveness against infection following dose 1	31%
v_2	Vaccine effectiveness against infection following dose 2	88% Pfizer and 67% AZ (People over 60 are considered to have had mostly AZ)
N	Total population	542,000
g	Asymptomatic	35%
μ	Age-specific case fatality rate	0-9 0% 10-29 0.02% 30-49 0.08% 50-59 0.24% 60-69 1% 70+ 9.14%
μv	Age-specific case fatality rate for vaccinated people	90% reduction from **μ**
ICU	Hospitalization rates	0-4 4% 5-9 2% 10-19 3% 20-29 8% 30-49 12% 50-59 19% 60-69 26%

		70+ 50%
ICU	ICU rates	0-9 0.009% 10-19 0.0046% 20-49 1% 50-59 4% 60-69 7% 70+ 10%
HV and ICUV	Hospitalizations and ICU for vaccinated people	90% reduction of rates above
dh	Duration in hospital	5 days
dicu	Duration in ICU	7 days
ICU maximum capacity		114 beds
m	Masks effectiveness in infection reduction	20% (considered to be wear only indoor)
mr	Movement restriction	Varied from 0, 10, 30 and 60%.
adr	Asymptomatic detection rate	Those results are plotted for worse case of 0%

Differential equations

$$dS_i/dt = -\lambda * S_i - \rho * \lambda 2 * S_i + C_i/q_1 - doses$$

$$dE_i/dt = \lambda * S_i + (1 - v1) * \lambda * V1_i - E_i/d_0$$
$$dEv_i/dt = (1 - v2) * \lambda * V2_i - Ev_i/d_0$$

$$dE_i^u/dt = (1 - \rho) * E_i/d_0 - E_i^u/d_1$$
$$dE_i^t/dt = \rho * E_i/d_0 - E_i^t/d_1$$
$$dEv_i^u/dt = (1 - \rho) * Ev_i/d_0 - Ev_i^u/d_1$$
$$dEv_i^t/dt = \rho * Ev_i/d_0 - Ev_i^t/d_1$$

$$dC_i/dt = \rho * \lambda 2 * S_i - C_i/q_1$$

$$dI_i^1/dt = (1 - g) * E_i^u/d_1 - I_i^1/d$$
$$dI_i^2/dt = (1 - g) * E_i^t/d_1 - I_i^2/d$$
$$dIv_i^1/dt = (1 - g) * Ev_i^u/d_1 - Iv_i^1/d$$
$$dIv_i^2/dt = (1 - g) * E_i^t/d_1 - I_i^2/d$$
$$dA_i^1/dt = g * (E_i^u/d_1 + E_i^t/d_1) - A_i^1/d$$
$$dAv_i^1/dt = g * (Ev_i^u/d_1 + Ev_i^t/d_1) - Av_i^1/d$$

$$dI_i^{11}/dt = I_i^1/d - \theta * I_i^{11}/d_4 - (1 - \theta) * I_i^{11}/d_6$$
$$dI_i^{22}/dt = I_i^2/d - I_i^{22}/d$$
$$dIv_i^{11}/dt = Iv_i^1/d - \theta * Iv_i^{11}/d_4 - (1 - \theta) * Iv_i^{11}/d_6$$
$$dIv_i^{22}/dt = Iv_i^2/d - Iv_i^{22}/d$$
$$dA_i^2/dt = (1 - adr) * A_i^1/d - A_i^2/d_6$$

$$dAv_i^2/dt = (1 - adr) * Av_i^1/d - Av_i^2/d_6$$

$$dQ_i/dt = adr * A_i^1/d + I_i^{22}/d + \theta * I_i^{11}/d_4 - (1 - (h + icu + \mu)) * Q_i/q_1 - (h + icu + \mu) * Q_i/d_5$$

$$dQv_i/dt = adr * Av_i^1/d + Iv_i^{22}/d + \theta * Iv_i^{11}/d_4 - (1 - (hv + icuv + \mu v)) * Qv_i/q_1 - (hv + icuv + \mu v) * Qv_i/d_5$$

$$dH_i/dt = h * Q_i/d_5 + hv * Qv_i/d_5 - H_i/dh$$

$$dICU_i/dt = icu * Q_i/d_5 + icuv * Qv_i/d_5 - ICU_i/icu$$

$$dR_i/dt = (1 - \mu_i) * (1 - \theta) * I_i^{11}/d_6 + (1 - \mu v_i) * (1 - \theta) * Iv_i^{11}/d_6 + A_i^2/d_6 + Av_i^2/d_6 + (1 - (h + icu + \mu)) * Q_i/q_1 + (1 - (hv + icuv + \mu v)) * Qv_i/q_1 + H_i/dh + ICU_i/icu$$

$$dD_i/dt = \mu_i * (1 - \theta) * I_i^{11}/d_6 + \mu v_i * (1 - \theta) * Iv_i^{11}/d_6 + \mu_i * Q_i/d_5 + +\mu v_i * Qv_i/d_5$$

$$dV1_i/dt = doses - V1_i/d_7 - (1 - v1) * \lambda * V1_i$$

$$dV2_i/dt = V1_i/d_7 - (1 - v2) * \lambda * V2_i$$

The force of infection is described as

$$\lambda_i = \sum_{j=1}^{18} \frac{\beta_1 * c_{i,j} * (E_j^u + Ev_j^u)}{N} + \sum_{j=1}^{18} \frac{\beta_2 * c_{i,j} * (E_j^t + Ev_j^t)}{N} + \sum_{j=1}^{18} \frac{\beta_3 * c_{i,j} * (I_j^1 + I_j^2 + A_j^1 + Iv_j^1 + Iv_j^2 + Av_j^1)}{N} + \sum_{j=1}^{18} \frac{\beta_4 * c_{i,j} * (I_j^{11} + I_j^{22} + A_j^2 + Iv_j^{11} + Iv_j^{22} + Av_j^2)}{N}$$

Where $\beta_1 = 1.32$ for latent undiagnosed contacts, $\beta_2 = \frac{\beta_1}{2}$ for latent diagnosed and home quarantined (50% reduction in R0), $\beta_3 = 2.16$ for the first day of symptoms and $\beta_4 = 0.2$ for the following 6 days of symptoms, to reproduce an overall R0=6 without interventions. $c_{i,j}$ is the age-specific contact matrix adapted from NZ, and *N* is the total population. Then we added the reduction in transmission by mask use (multiplied λ_i by $1 - m_i$) where m_i is a combination of proportion of the population wearing it and mask effectiveness to reduce the force of infection.

Results

With the vaccine rollout and the expected 90% vaccination coverage in the 12+ years old just after 47 days from the start of the epidemic, we modelled two scenarios, without any restriction and with indoor masks use in people 12 years and older. For those scenarios, we started with the best case of 80% contacts traced and quarantined while in latency period and then decreased the proportion of contacts traced.

The results show that in the case of no restrictions, a minimum of 80% contacts need to be traced, while the use of masks indoors for the age group 10+ even if contact tracing is reduced to 50%, can mitigate the impact of lower contact tracing.

An important observation is that when looking at age specific results, cases are mostly in the unvaccinated age groups (including children). Cumulative results by age groups are showed after 50 days (January 19), when is assumed 90% 12+ are fully vaccinated. A limitation is that hospitalization and ICU data comes from NSW when the vaccination coverage was low at the start of the outbreak, and cases spreading over the older population, therefore when we calculated those rates in the youngest age groups the sample was small and icu and deaths rates in 0-9 years old are 0%. This highlights the need to update the data in the future. Figures to follow:

Scenario 1: No restrictions

Figure 1.1: Cumulative cases, no restrictions

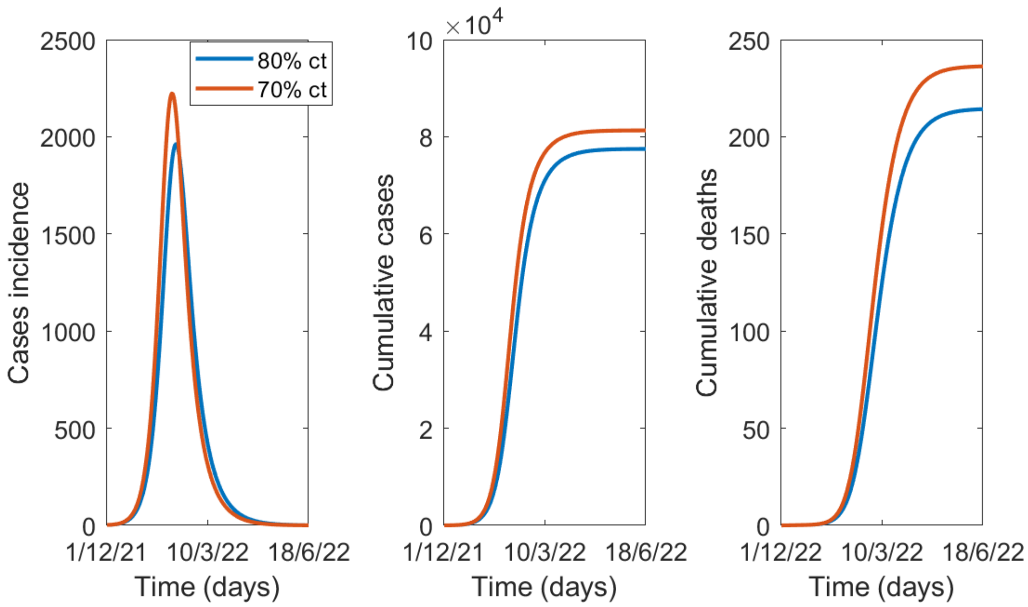

Table 1.1: Cumulative cases at 200 days with 70-80% contact tracing

CT	cases	deaths
80%	77492	214
70%	81305	236

Figure 1.2: Hospital and ICU bed requirements, no restrictions (line represents the code black threshold)

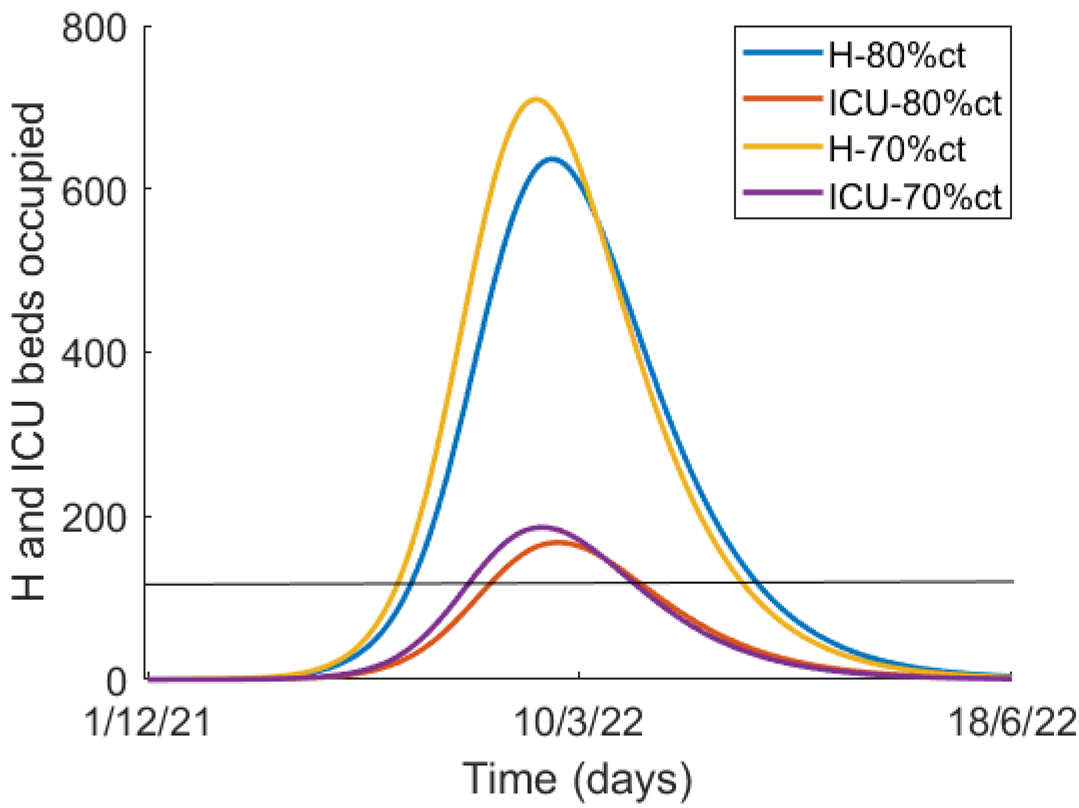

Table 1.2 Peak hospital and ICU beds required in a single day

	CT	Date	Peak daily usage
H	80%	March 4	636
	70%	February 28	709
ICU	80%	March 5	168
	70%	March 2	186

Scenario 2: Contact tracing fixed at 80%, everyone 10+ wearing masks indoors compared to 5+ wearing masks indoors

Figure 2.1: Cumulative cases, universal masking 10+ and 5+

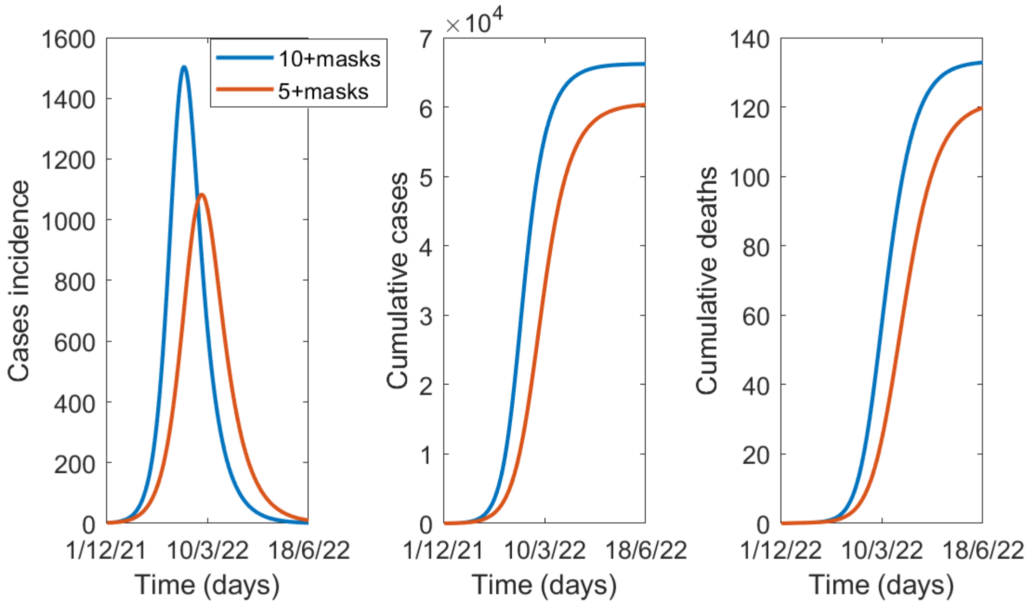

Table 2.1: Cumulative cases and deaths after 200 days

Universal masking	cases	deaths
10+	66196	132
5+	60333	120

Figure 2.2: Hospital and ICU bed requirements, mask guidelines for 10+ and 5+ (line represents the code black threshold)

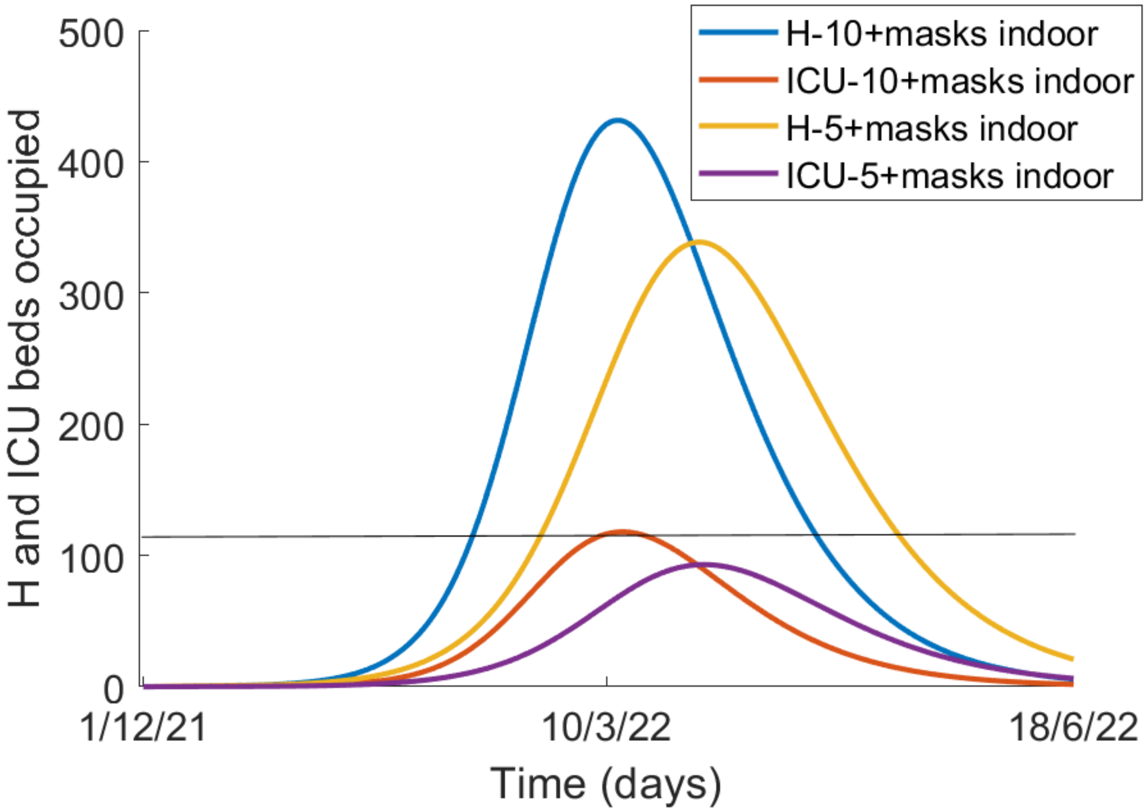

Table 2.2: Peak hospital and ICU beds required in a single day by age group by mask guidelines

	Masks	Date of peak	Max daily usage
H	10+	March 12	431
	5+	March 30	339
ICU	10+	March 14	118
	5+	April 1	93

SCENARIO 3: Fixed contact tracing 80%, mask use indoors for 12+ and varying movement restriction (mr) - 10%, 30% and 60%

Figure 3.1: Cumulative cases, varied movement restrictions

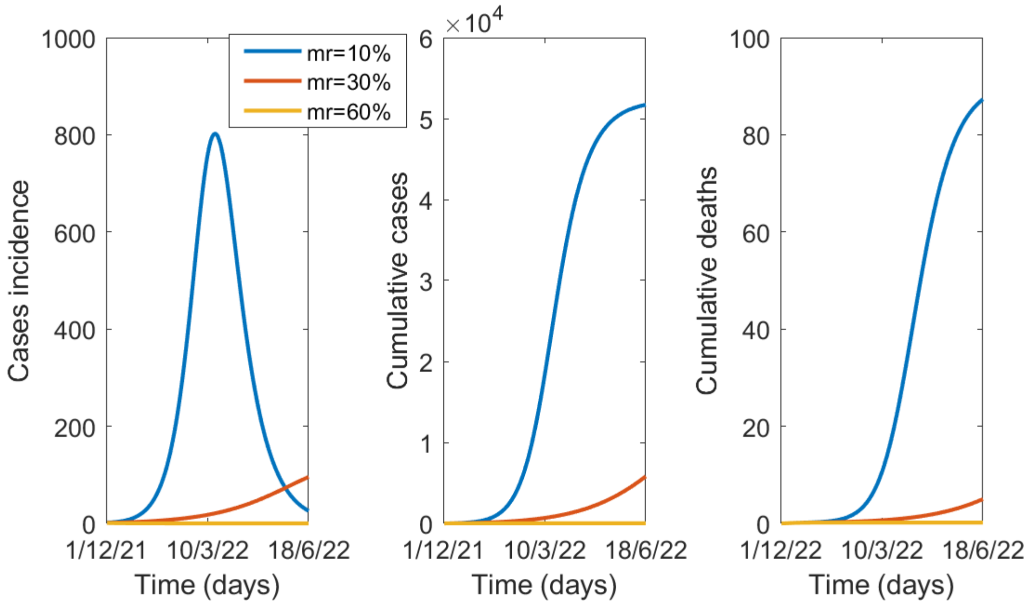

Table 3.1: Cumulative cases and deaths, varied movement restrictions

Movement restriction with masks for 12+ and 80% contact tracing	cases	deaths
10%	51699	87
30%	5804	5
60%	15	0

Figure 3.2: Hospital and ICU bed requirements, varying movement restrictions (line represents the code black threshold)

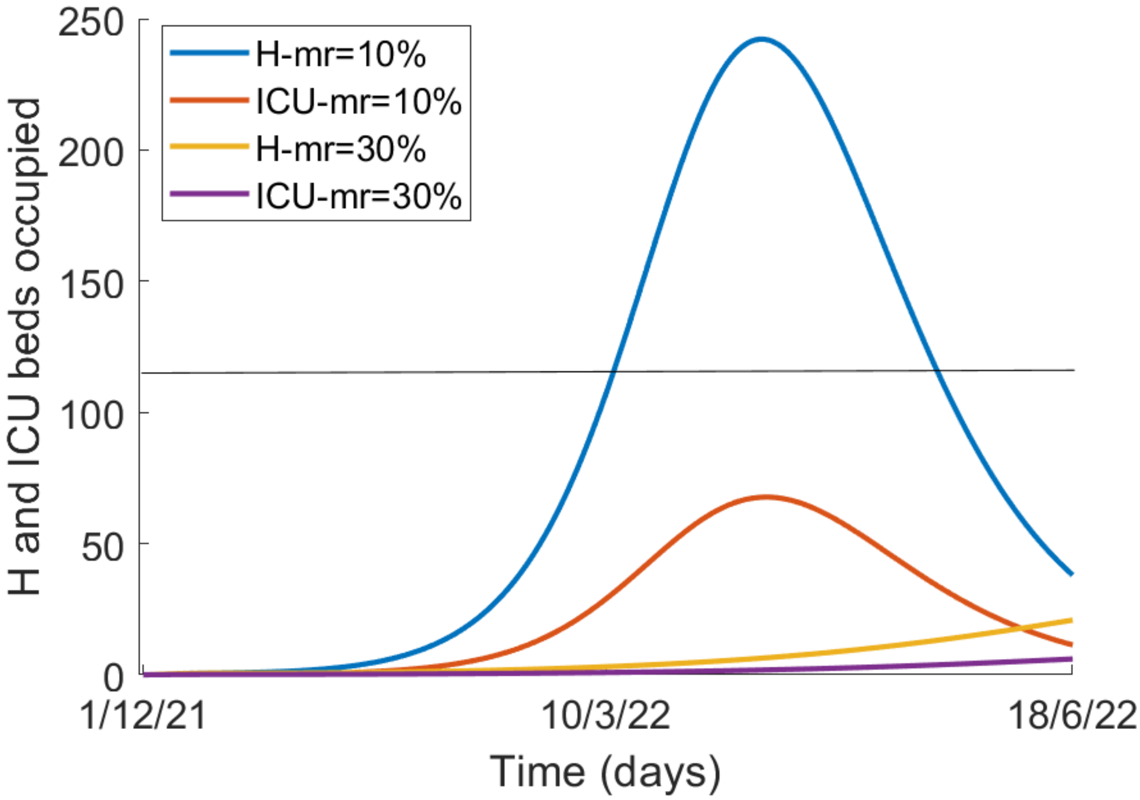

Table 3.2: Peak hospital and ICU beds required in a single day (masks plus movement restriction)

	Movement restriction	**Date**	**Max usage**
H	10%	April 12	242
	30%	June 18	20
ICU	10%	April 13	68
	30%	June 18	6

SCENARIO 4: Masks indoor for 12+ (80%), reduction of contacts tracing to 50% and varying movement restriction by 10%, 30% and 60%.

Figure 4.1: Cumulative cases, 80% masks, 50% contact tracing, varied movement restrictions

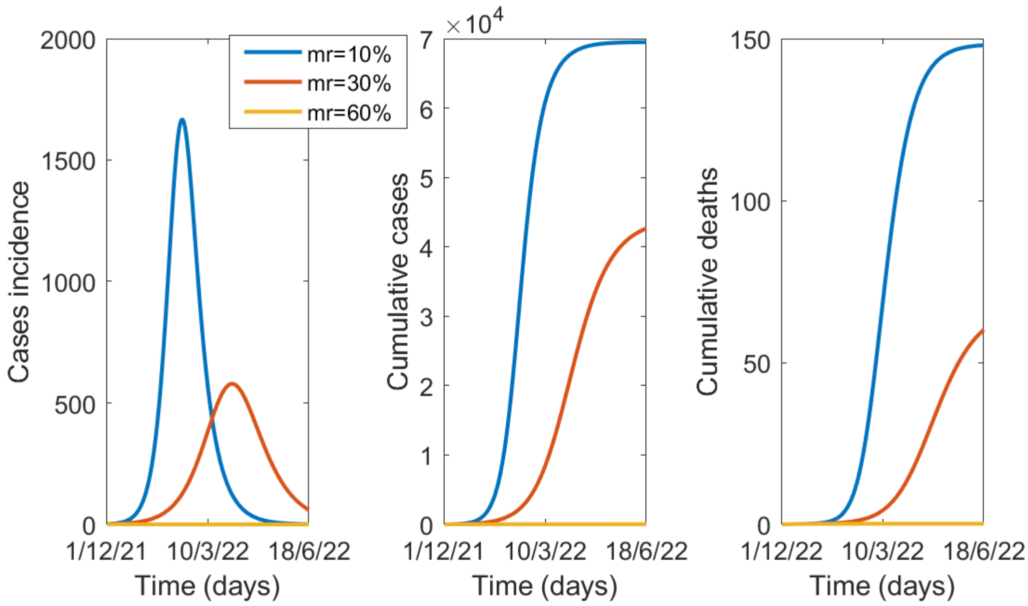

Table 4.1: Cumulative cases and deaths at 200 days, 80% masks, 50% contact tracing, varied movement restrictions

Movement restriction	**cases**	**deaths**
10%	69493	148
30%	42642	60
60%	30	0

Figure 4.2: Hospital and ICU bed requirements, 80% mask use, varying movement restrictions (line represents the code black threshold) and 50% contact tracing.

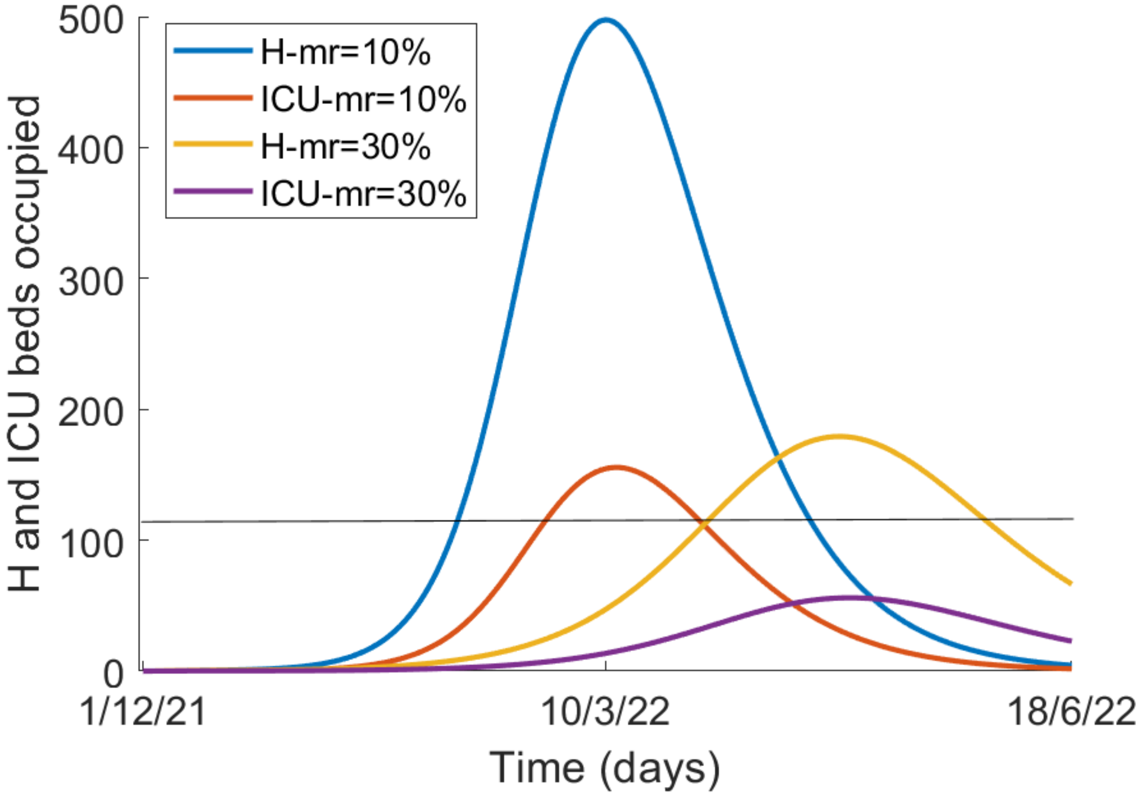

Table 4.2: Peak hospital and ICU beds required in a single day by age group, 80% mask use, varying movement restrictions and 50% contact tracing

	Movement restriction	Date of peak	Max daily usage
H	10%	March 10	397
	30%	April 29	179
ICU	10%	March 13	155
	30%	May 2	56