PROTECT

A COVID-19 National Core Study

Agent-based modelling of workplace transmission of SARS-CoV-2

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HSE

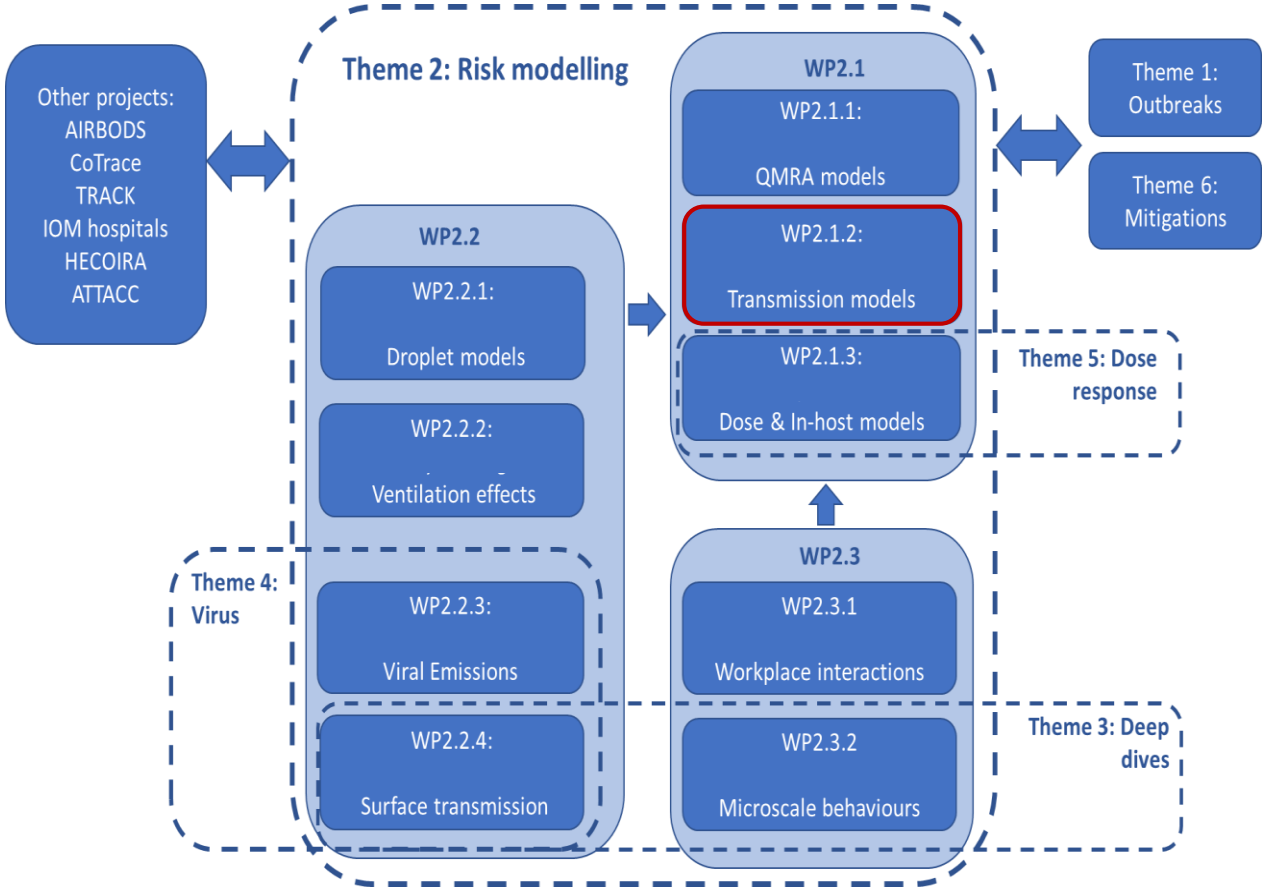
Introduction

Aim: Develop and apply a mathematical model for virus transmission to improve understanding of how an outbreak propagates within a workplace and how this is influenced by workplace environmental factors, control strategies and human behaviour; link this model to higher-fidelity emission, dispersion and in-host models

Scope: Enterprise level multi-generational transmission in 'closed' workplaces, i.e. workplaces without significant numbers of transient individuals

Includes: offices, manufacturing, food production, distribution and warehousing etc.

Excludes: retail, hospitality, education, hospitals, care homes, public transport



Model overview

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Susceptible-Infected-Recovered (SIR) model:

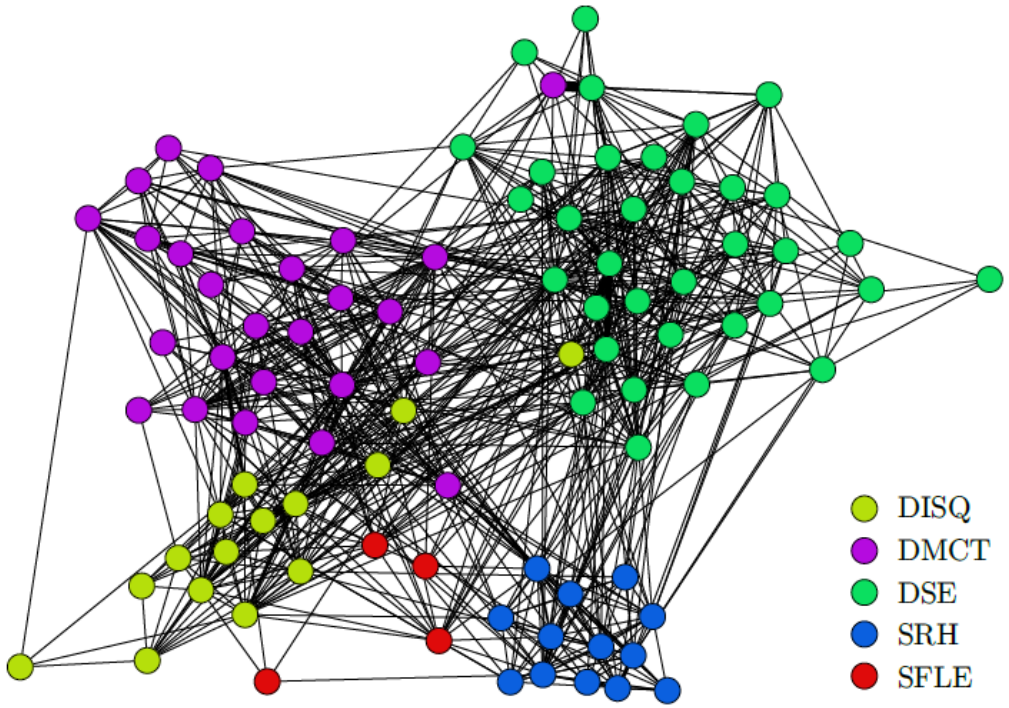
- Individual, stochastic, 24 hr time step
- Workplace contacts represented through a network
- Not considering severity of symptoms, hospitalisation or other outcomes from infection
- Transmission probability between pairs utilises an exponential dose-response and depends upon:
  - Duration and distance of contact
  - Workplace environment (especially ventilation)
  - Face coverings
  - Infectiousness of the individual
- Infectiousness of an individual is linked to their viral load - modelled using exponential proliferation and clearance phases
  - Varies over time and between individuals; to be extended to viral load-viral shedding-infectiousness

Workplace contact networks

Random sequence of 2x daily contact networks representing short (<2m, transmission predominantly via large droplets) and medium proximity contacts (2-5m, predominantly aerosols); weighted by cumulative daily duration of contact between pairs

Data sources:

1. High resolution pre-pandemic office contact data generated by wearable tags: (close contact + proximity + duration, 10 days – **'Lv13' 'Lv15'**)
2. Limited UK data supplied by wearable technology providers (<2m only, tags fitted with proximity alerts)
3. Self-reported close contacts (diary surveys)
4. PROTECT study using UWB wearables - high resolution (distance, duration, location), influence of worker attitudes and workplace controls (multiple workplaces, data not yet available)

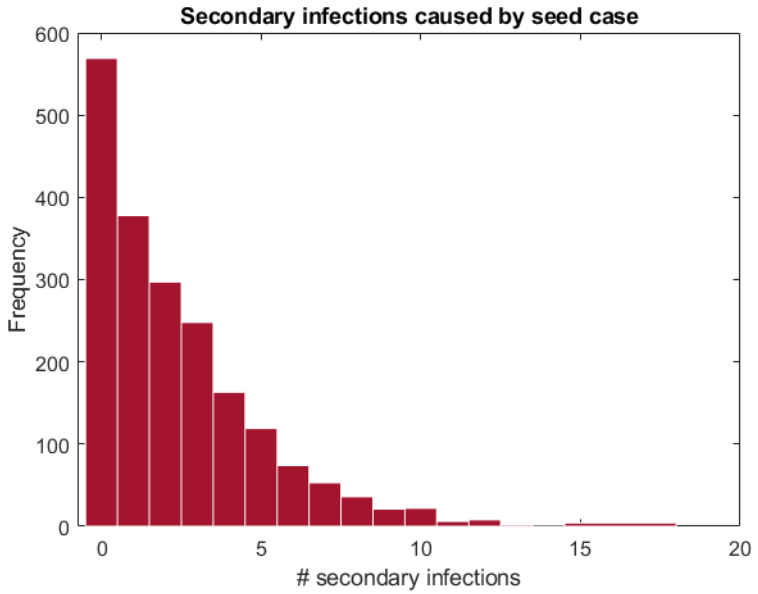


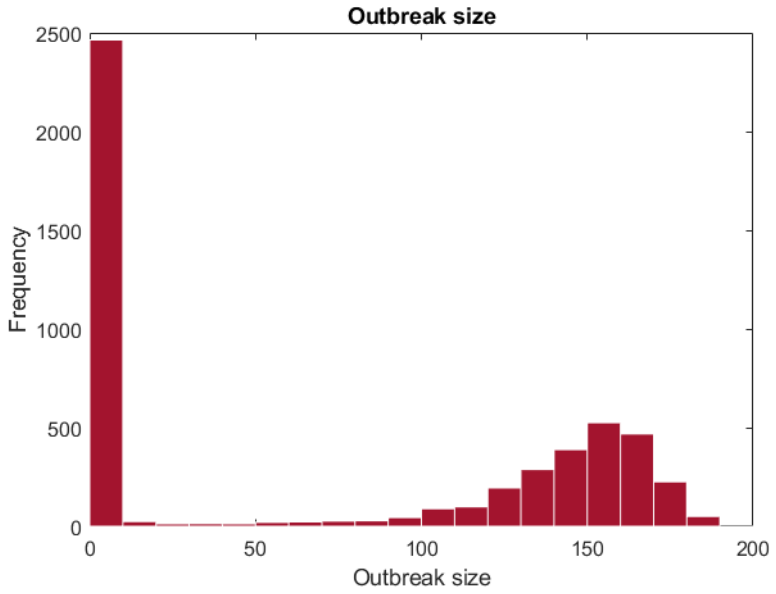
Lv13 contact network (face-to-face, aggregated over 2 weeks, colours represent departments)

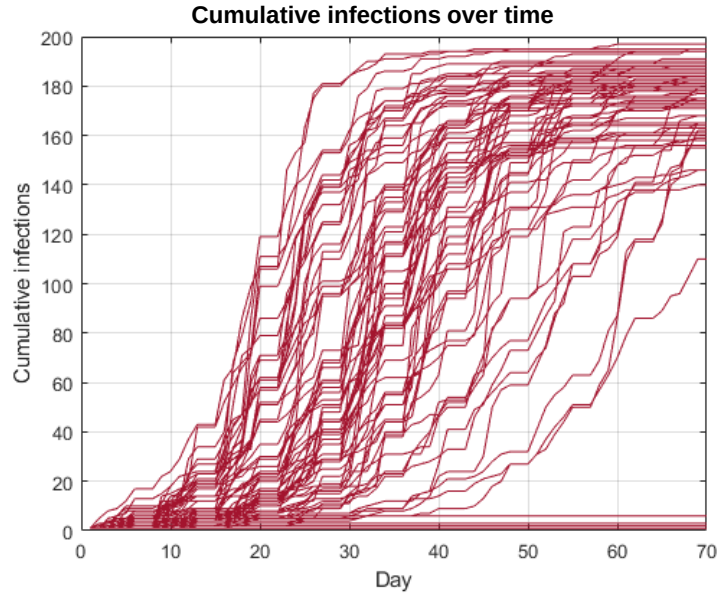
Model outputs

Wide variety of outputs can be extracted at both the workforce and individual level

- Transmission lineages for each simulated workplace outbreak – potential for use in conjunction with genomic sequencing data from Theme 1 outbreak investigations







'$R_{workplace}$' = Mean # secondary infections

Transmission rates

Absolute levels of workplace transmission remain uncertain

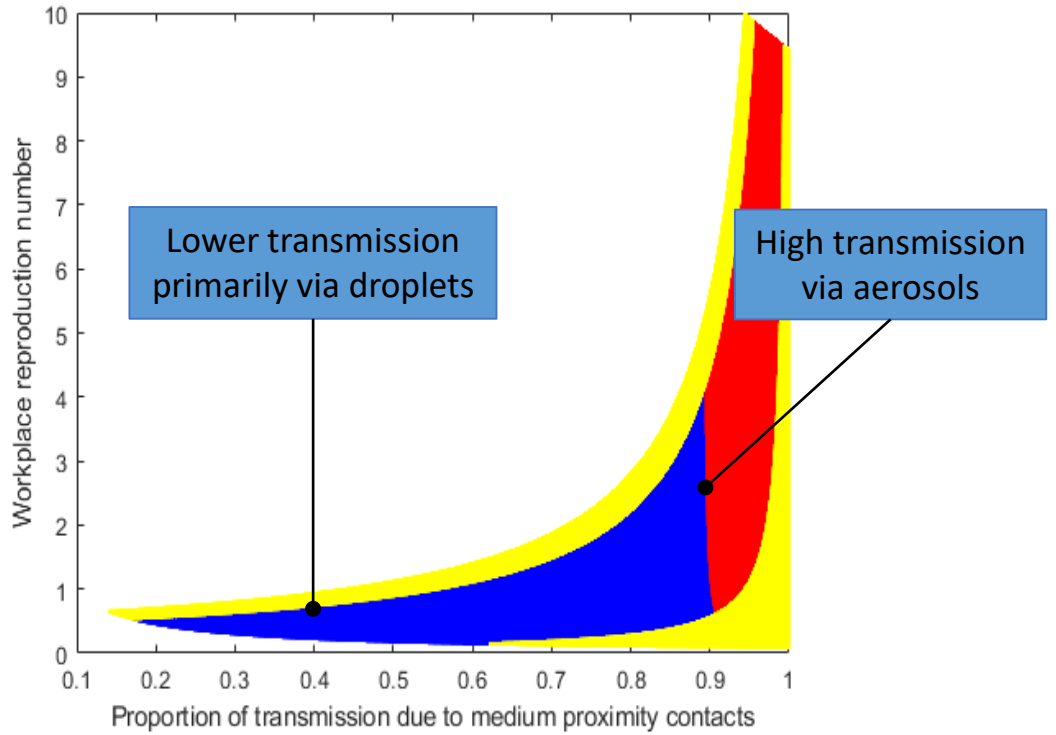
Two key model parameters determine the risk of transmission for short and medium proximity contacts per unit time

Credible ranges for these parameters, which are expected to vary considerably with the workplace environment, have been set via consideration of various evidence sources including:

- Epidemiological studies of the effect of distance on transmission risk
- SARs in specific outbreaks and settings (international)
- SARs for workplace contacts reported to Test and Trace

Will be refined further using higher-fidelity dispersion and risk modelling from PROTECT

Modelling of controls has mainly focussed upon looking at the relative reduction in transmission within this credible parameter space



Blue: credible transmission risks –used in evaluation of controls & mitigations

Red: insufficient reduction in transmission risk with distance

Yellow: predicted secondary attack rate for short proximity contacts (<2m for 15+ minutes) not compatible with Test & Trace (**≈5%** - analysis of workplace contacts from February 2021)

Workplace controls and mitigations

Baseline scenario: Lv15 contact network; five-day work pattern; 25% of symptomatic cases isolate; no other mitigations		
Keeping SARS-CoV-2 out of the workplace	**Workplace social distancing**	**Reducing transmission risks between individuals**
Once weekly LFD testing	60% building occupancy	Wearing face coverings during short proximity contacts
Twice weekly LFD testing	30% building occupancy	All day wearing of face coverings
Enhanced (50%) symptomatic case isolation	In workplace social distancing (75% reduction)	Increased workplace ventilation (x3 ACR)
Enhanced (80%) symptomatic case isolation	30% building occupancy + workplace social distancing	Increased workplace ventilation (x5 ACR)
Enhanced symptomatic case and workplace contact isolation		Vaccination (varying uptakes)
		Protective screens, air filtration

All control scenarios evaluated for a range of short and medium proximity transmission risks (blue zone previous slide) with a single workplace seed case and fully susceptible workforce

Controls and mitigations – caveats & assumptions

General:

- Control scenarios evaluated singly in comparison to a baseline scenario with 25% symptomatic case isolation; single seed case; 100% susceptible workforce

Workforce testing:

- Lateral flow device (LFD) test sensitivity based on test day Ct value for Thermo Fisher TaqPath assay equivalent Ct units for the Innova device
- Half of the workforce tested on Monday and Wednesday, the other half on Tues and Thursday; positive cases isolate for 10 days from (and including) the day of LFD test

Ventilation:

- Medium proximity viral generation parameter β_m scales with ACR^{-1} (well-mixed assumption); short proximity transmission (β_s) is unaffected

Face-coverings:

- Workers are assigned as mask-wearers with probability P (compliance level) at the outset; mask wearers assumed to wear their mask for 100% of the time during close proximity contact with other workers
- For all day mask wearing all workers are assumed to be mask wearers for medium proximity contact but only wear them for 50% of the time; reduction is time weighted to take account of time when one but not the other of the pair are wearing masks, both or neither, assuming the wearing time is independent for each
- Three-ply face coverings reduce risk of transmission by 50% for both source and receptor for short and medium proximities with no account taken (yet) for differing contributions from droplet and aerosols at these different distances

Social distancing:

- Reduced building occupancy is implemented on a rotational but otherwise random basis; removal of network nodes representing individuals that are working remotely; no effect on contact patterns between pairs working onsite
- In workplace social distancing leads to a uniform reduction in all short proximity contact durations; medium proximity contacts unaffected

Vaccination

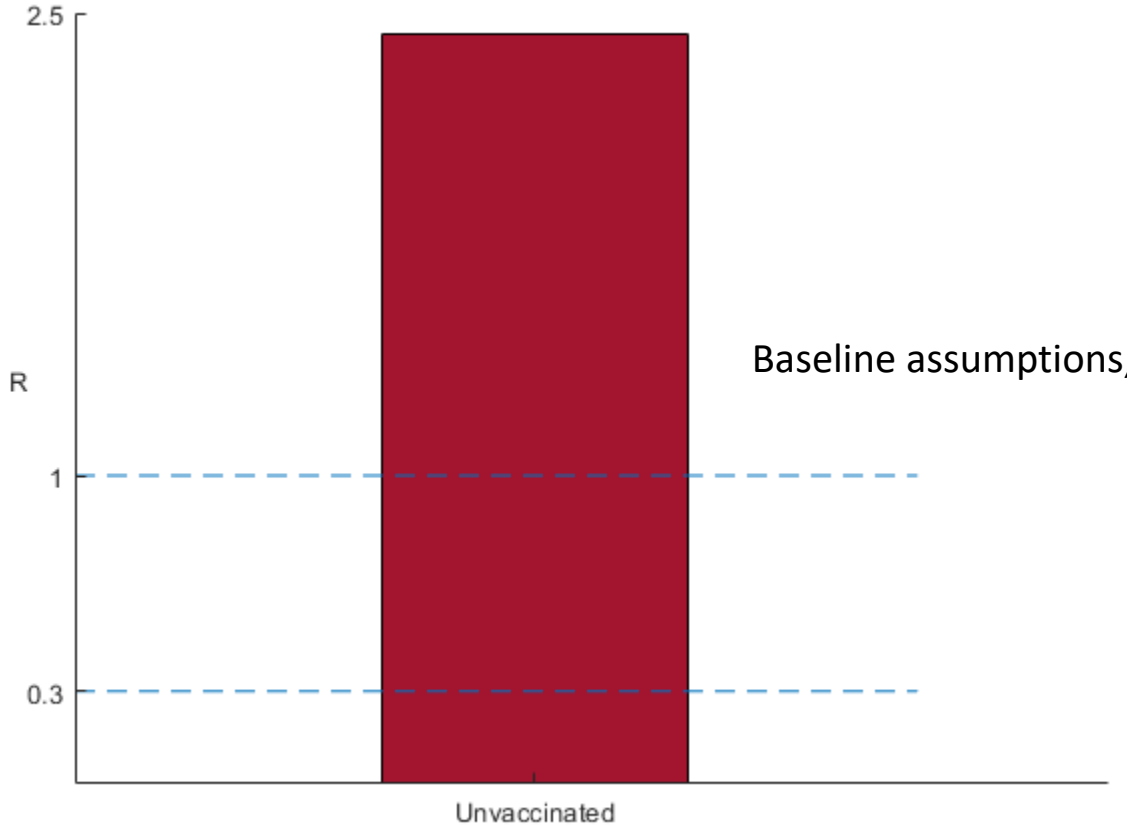
- Leaky and perfect vaccine assumptions with no waning of immunity
- After 2 doses: 75% reduction in risk of infection, 45% reduction in onwards transmission, no change to symptomatic proportion, incubation or infectious periods

Effectiveness of controls and mitigations

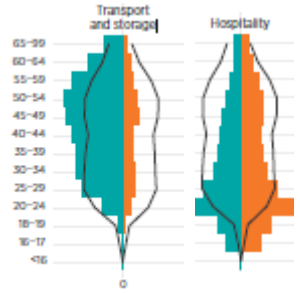
Control interventions	*High transmission predominantly via aerosols* 1 hr short-proximity transmission risk = 16.5% 1 hr medium proximity transmission risk = 8.6%		*Lower transmission primarily via droplets* 1 hr short proximity transmission risk = 30.2% 1 hr medium-proximity transmission risk = 0.44%	
	Mean reduction in R (baseline = 2.44)	**Mean reduction in outbreak size**	**Mean reduction in R (baseline = 0.64)**	**Mean reduction in outbreak size**
Twice-weekly lateral flow testing	42%	71%	41%	72%
Enhanced (80%) symptomatic case isolation	27%	34%	26%	50%
Wearing of face coverings (during short proximity contacts only)	7%	9%	54%	79%
Increased room ventilation (x3 ACR)	58%	88%	13%	28%
30% building occupancy	91%	>99%	91%	97%
Workplace social distancing (75% effective)	7%	10%	59%	83%
40% workforce vaccination	47%	65%	45%	69%
80% workforce vaccination	77%	97%	76%	91%

What does vaccination mean for other workplace mitigations?

Scenario: ‘High transmission predominantly via aerosols’



Baseline assumptions, no additional mitigations



Source: CIPD analysis of Annual Population Survey

51% double vaccinated based upon uptake to July 4th + overall demographic profile of UK workforce

Hospitality ≈40%, Transport ≈60%

Projected 2-dose overall workforce uptake: 80-90%

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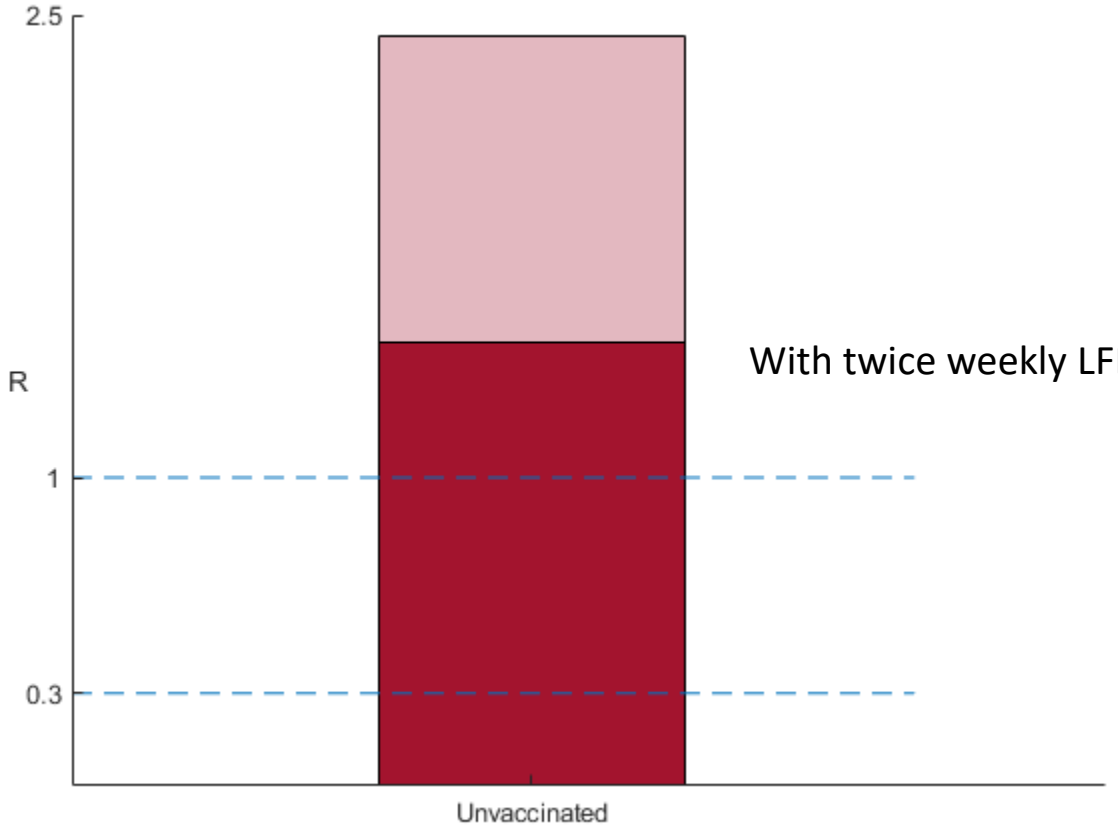
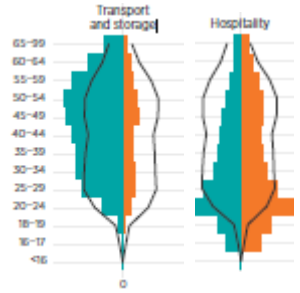


With twice weekly LFD testing



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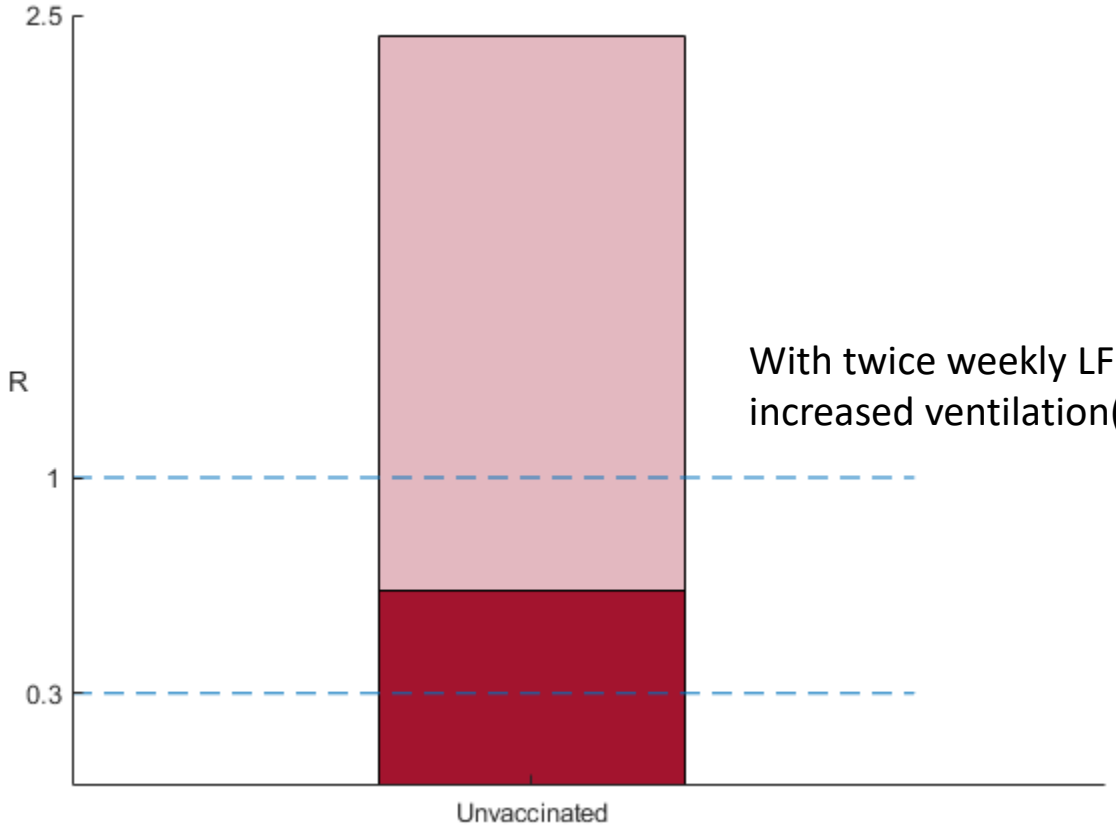
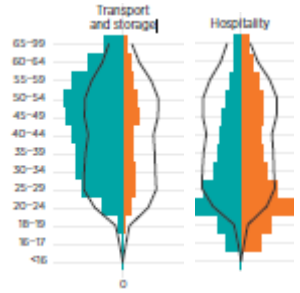


With twice weekly LFD testing + increased ventilation(x3)



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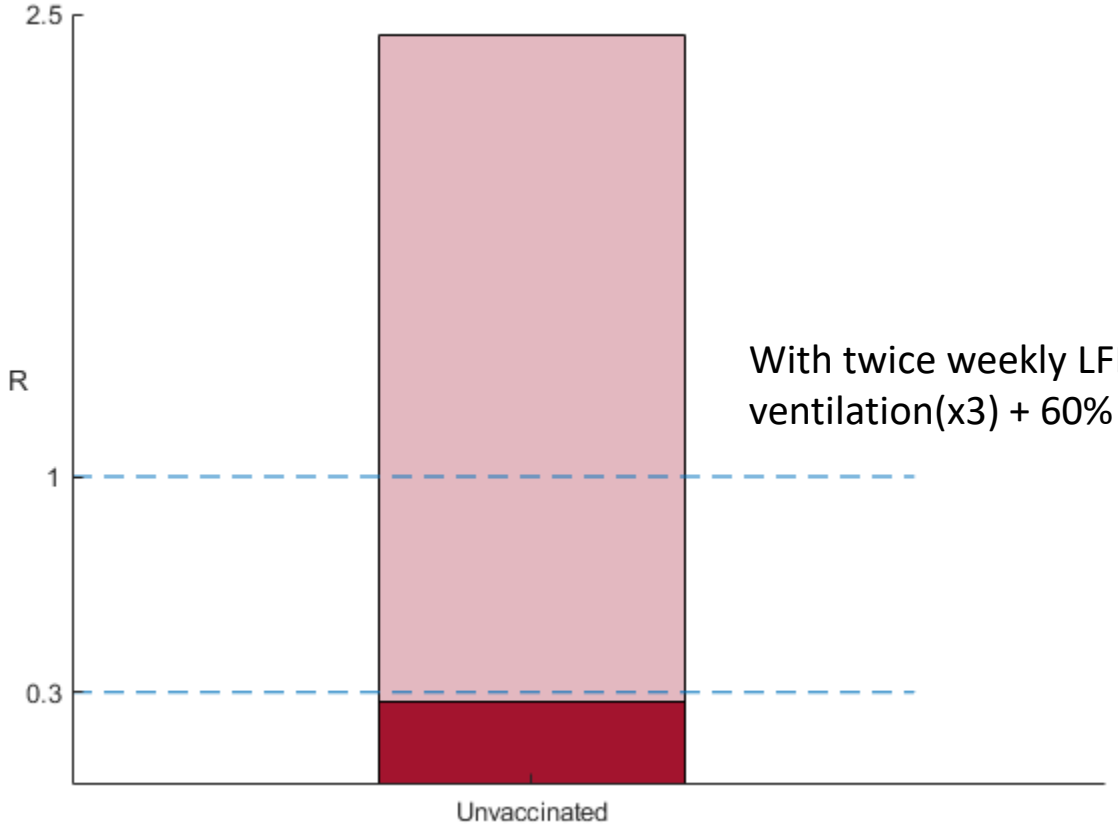
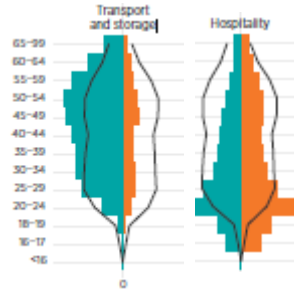


With twice weekly LFD testing + increased ventilation(x3) + 60% occupancy



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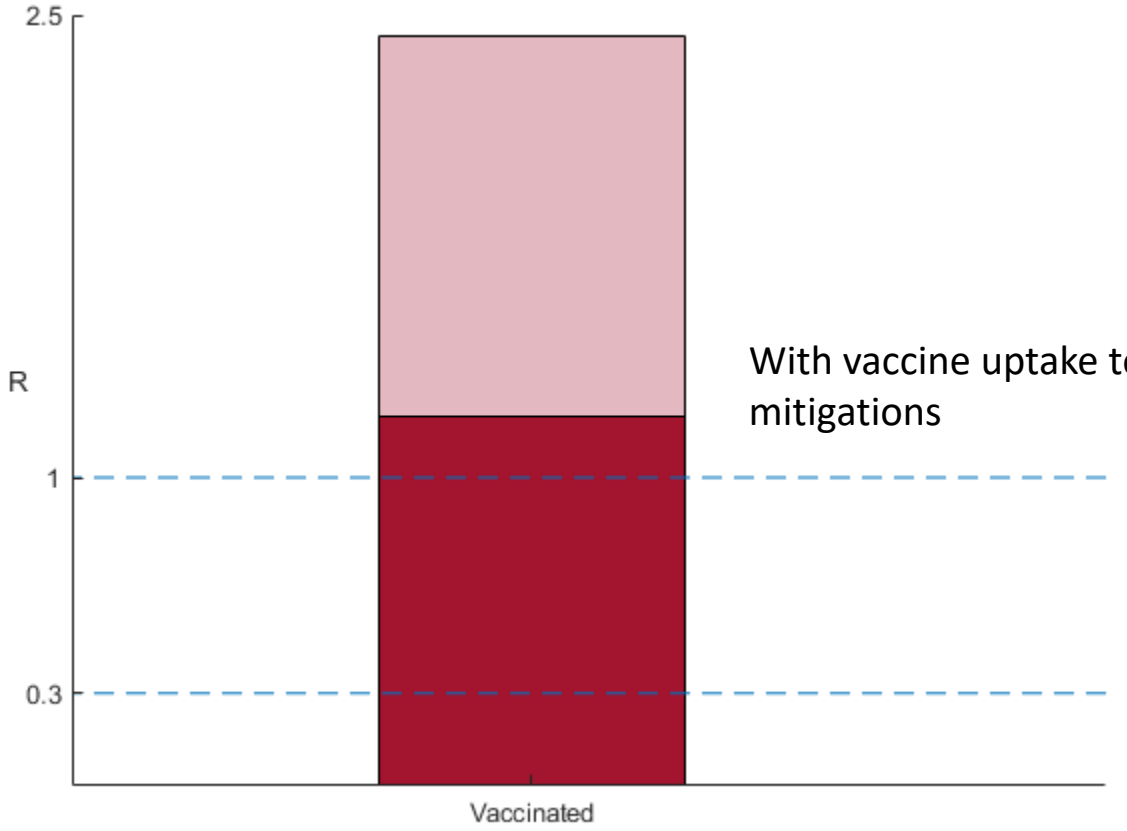
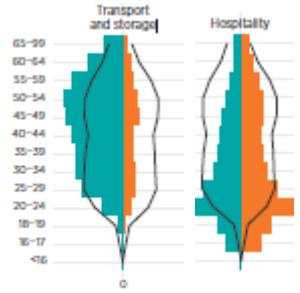


With vaccine uptake to July 4th, no other mitigations



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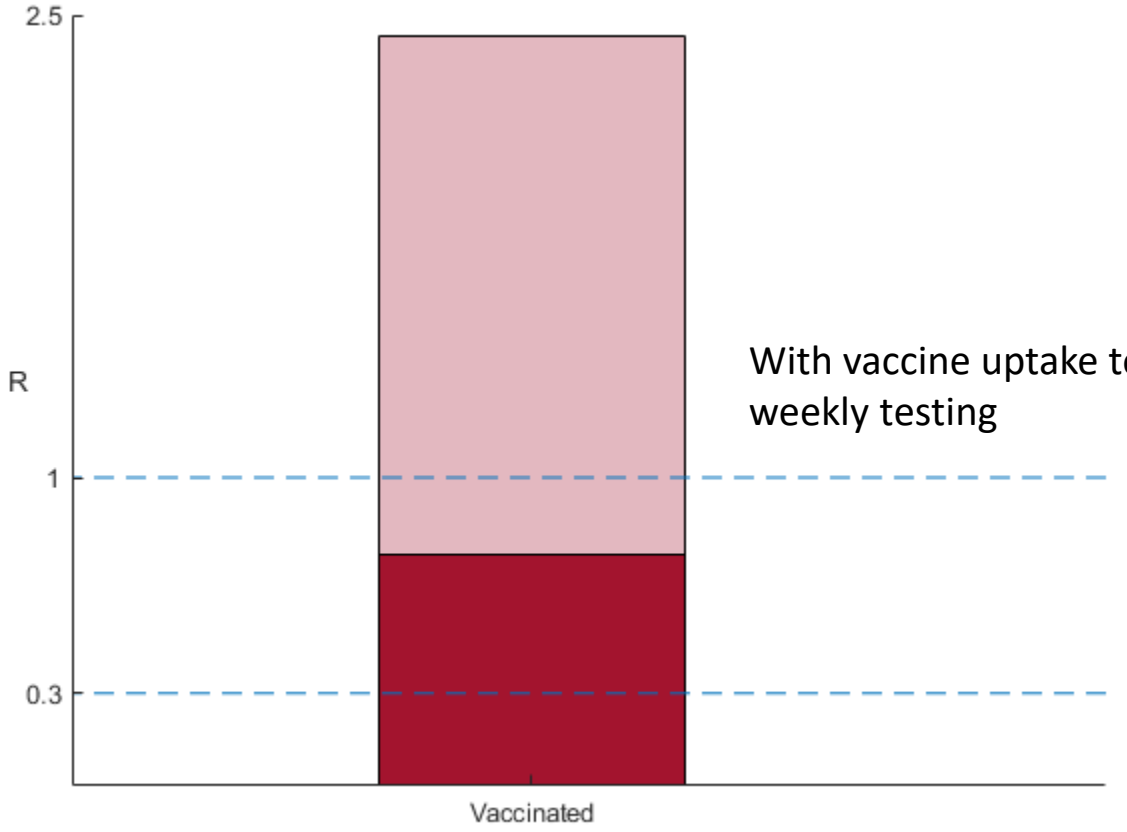
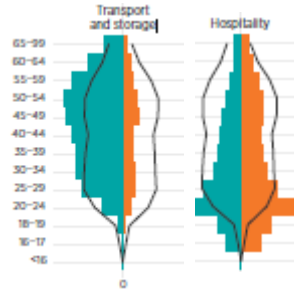


With vaccine uptake to July 4th + twice weekly testing



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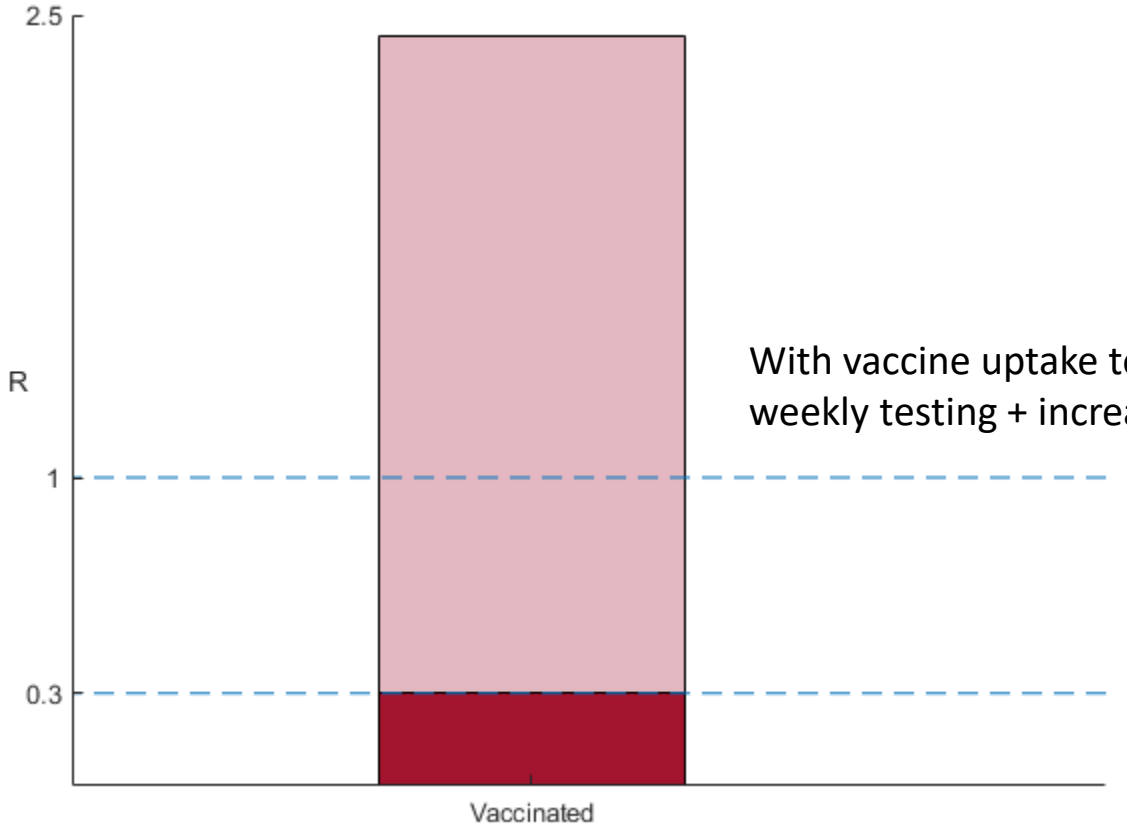
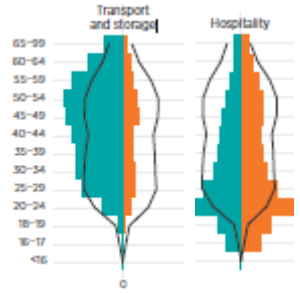


With vaccine uptake to July 4th + twice weekly testing + increased ventilation



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Summary

A model for workplace transmission of SARS-CoV-2 has been developed that relates transmission to worker contact patterns, the workplace environment and control measures. Findings from the model include:

- Outcomes an enterprise level are highly variable/ stochastic
- With pre-pandemic office contact patterns large scale outbreaks are highly unlikely through close contacts alone. Modelling suggests a majority of transmission over greater distances (or via fomites) is necessary for such outbreaks to occur.
- Effectiveness and practicality of controls is context specific and is influenced by the predominant routes of transmission
- Current levels of workforce vaccination can reduce the necessity of other workplace controls and mitigations but many workplaces will require additional controls if outbreaks are to be prevented

Acknowledgements

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Thank you

Nick Warren

sites.manchester.ac.uk/covid19-national-project

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