



PROTECT

A COVID-19 National Core Study

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

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@PROTECT_NCS



Introduction

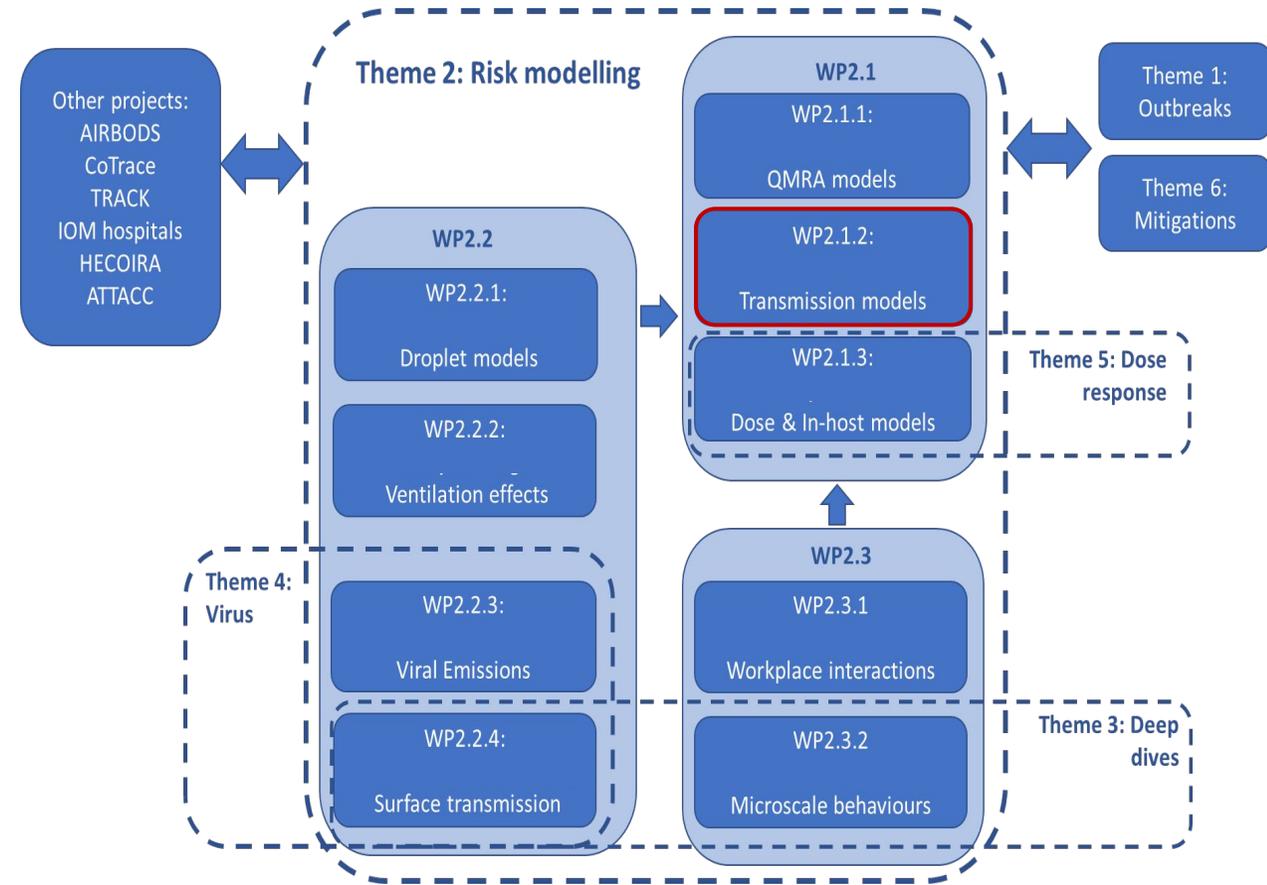


Aim: Develop and apply a mathematical model for virus transmission to improve understanding of how an outbreak propagates within a workplace and how this is influenced by workplace environmental factors, control strategies and human behaviour; link this model to higher-fidelity emission, dispersion and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



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); multiple micro environments within a workplace possible
 - Face coverings
 - Infectiousness of the individual

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)

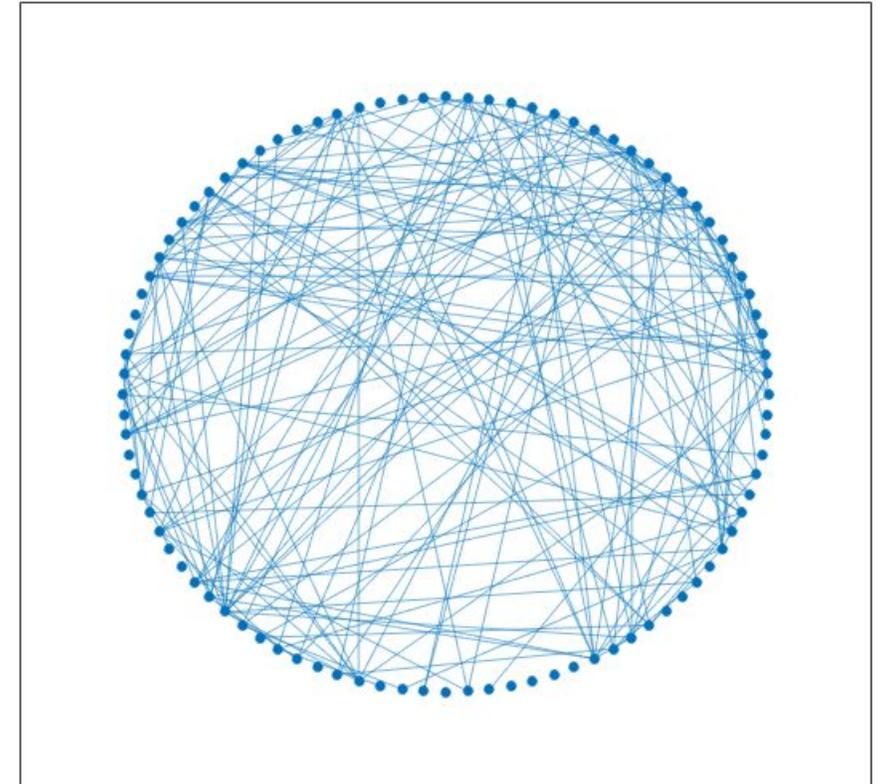
Weighted by cumulative daily duration of contact between pairs

Some but not all contacts repeat on consecutive days

Contacts can be assigned to different workplace micro-environments

Data sources:

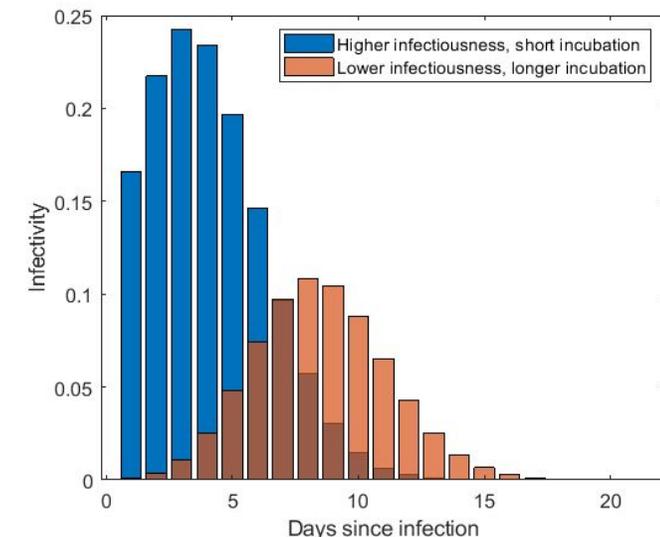
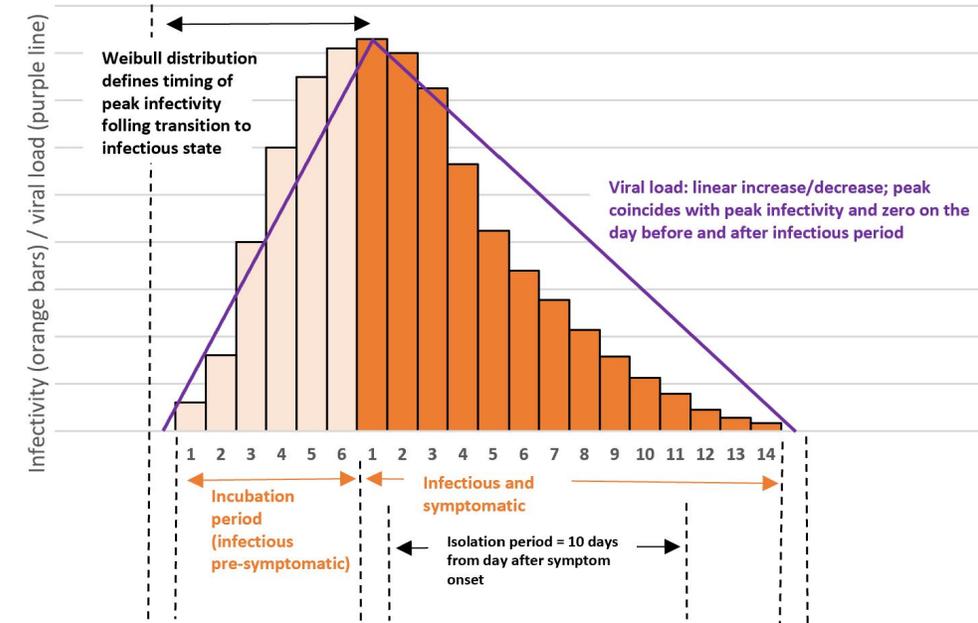
1. High resolution pre-pandemic office contact data generated by wearable tags: (short/face-to-face contact + proximity + duration, 10 days – ‘Lv13’ ‘Lv15’)
2. Limited UK data supplied by wearable technology providers (<2m only, tags fitted with proximity alerts)
3. Self-reported close contacts (diary 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 short contact network day 1

Viral load and infectiousness

- Infectivity profile is derived from observed serial intervals (shifted Gamma distribution, Ashcroft correction to He *et al.*)
- Individuals' viral load modelled through exponential proliferation and clearance phases
- Distribution for peak viral load on day of symptom onset (or equivalent day for asymptomatic infections); Weibull incubation period
- Peak viral load determines an individual's relative infectiousness (based upon relationships between viral load and SARs in Lee *et al.* and Marks *et al.*), which is then applied to the overall profile of infectivity
- Individual daily viral loads only used to determine sensitivity of lateral flow testing, if applicable
- Intent is to replace the infectivity profile with a more comprehensive model of in-host viral dynamics – load, shedding and infectiousness, based upon individual longitudinal data



Transmission rates

Absolute levels of workplace transmission remain uncertain

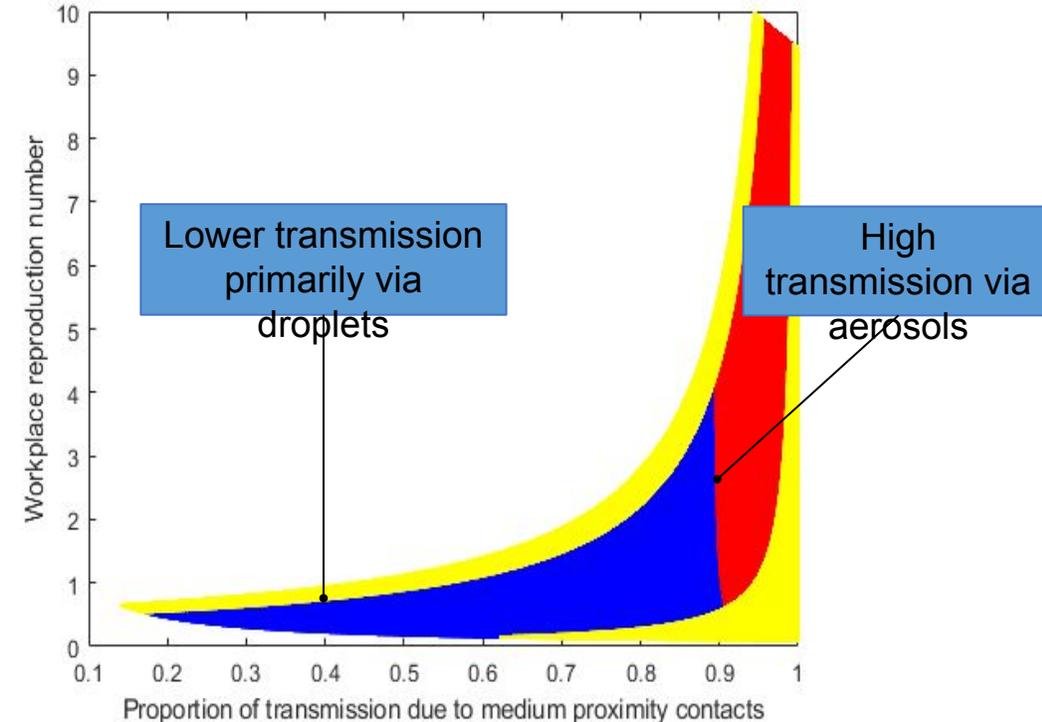
Two key model parameters determine the risk of transmission for short and medium proximity contacts per unit time

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:

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

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 ($\approx 5\%$ - 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)
		<i>Protective screens, air filtration</i>

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; 5 day working week

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

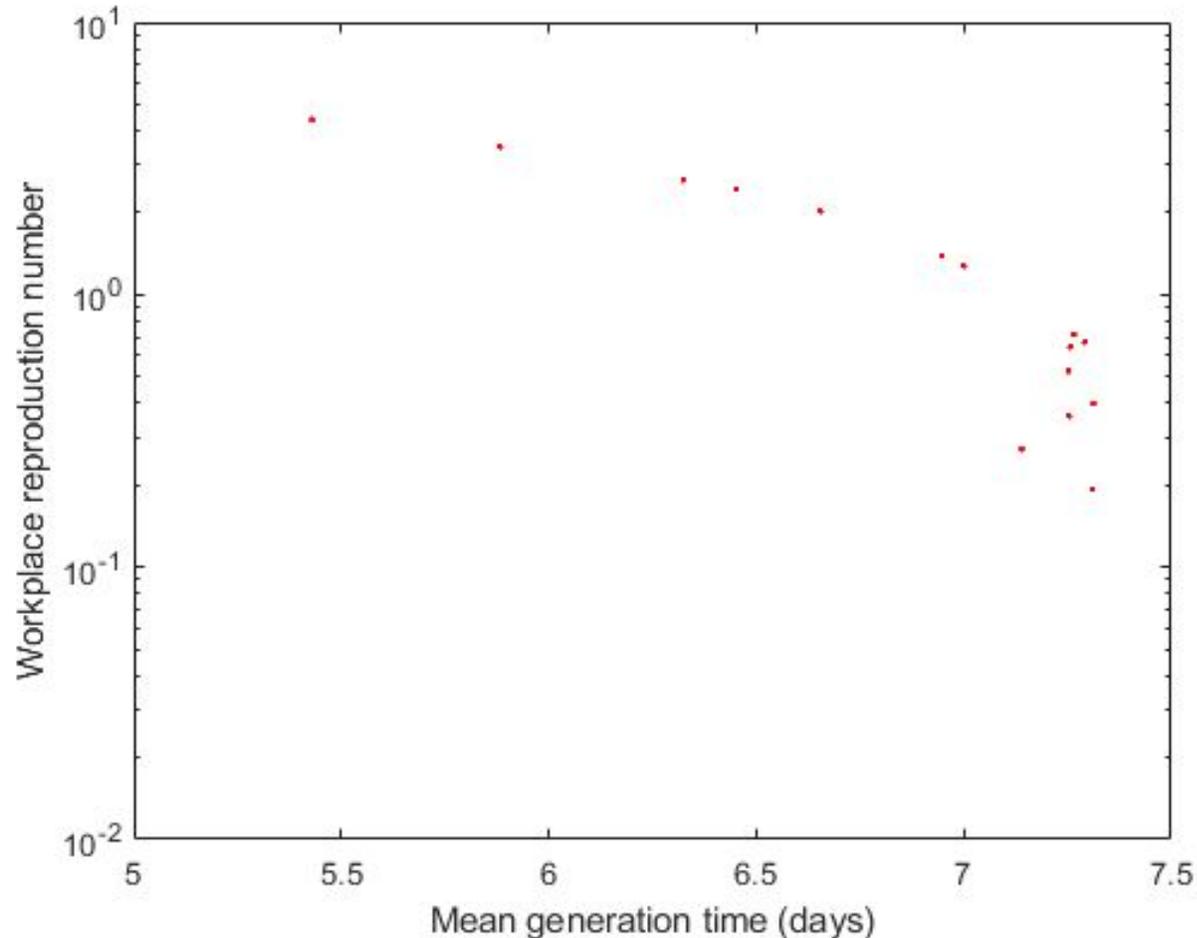
Social distancing:

- 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

Effect of workplace controls and mitigations



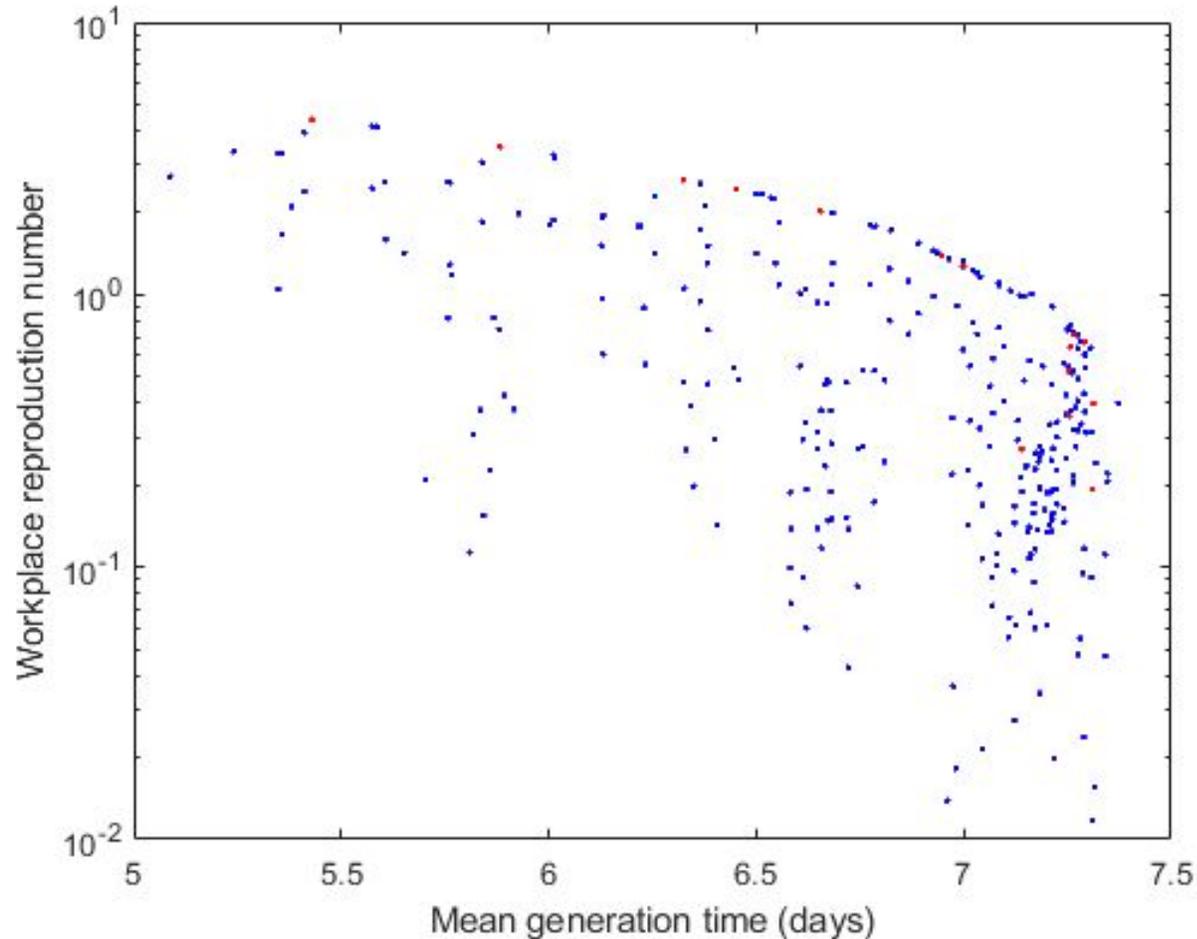
Baseline transmission scenarios; 25% symptomatic case isolation; no additional mitigations

Single seed case; 100% susceptible workforce

$R_{\text{workplace}}$ = mean workplace infections of seed case

Mean generation time over all workplace transmissions during simulated outbreak

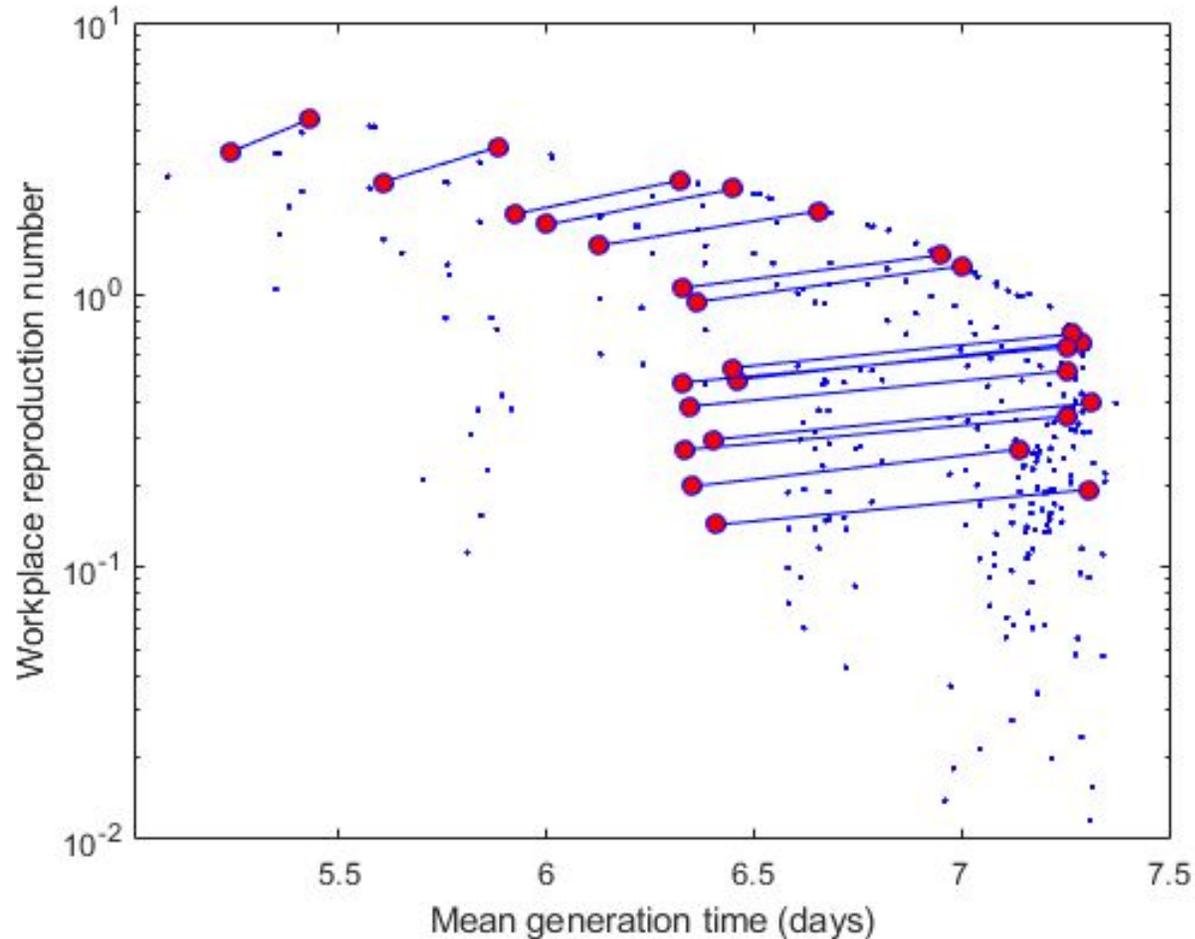
Effect of workplace controls and mitigations



20 control and mitigation scenarios x 15 pairs of transmission parameters

All utilise the same assumptions for viral dynamics and infectiousness

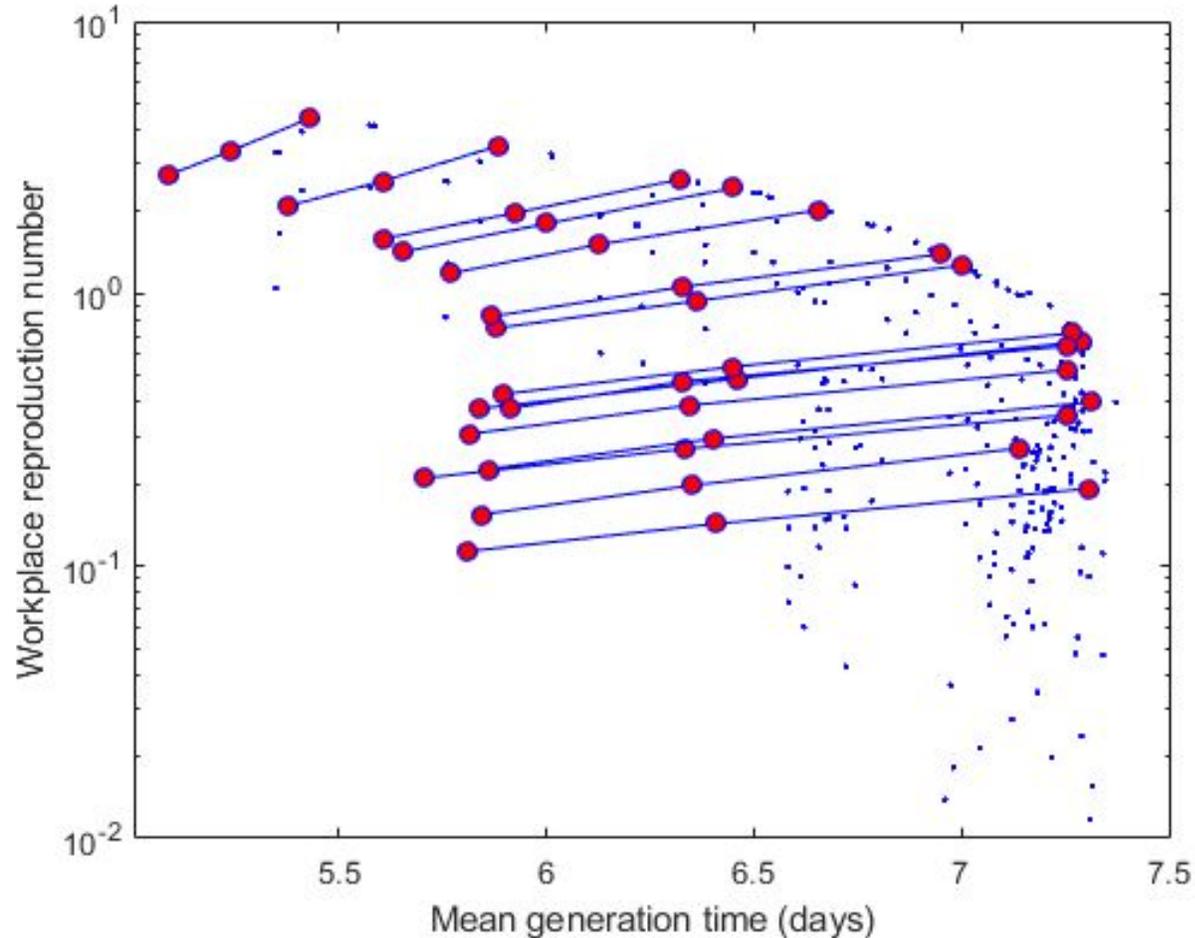
Effect of workplace controls and mitigations



Once weekly lateral flow testing

Mean reduction in $R_{\text{workplace}} = 26\%$

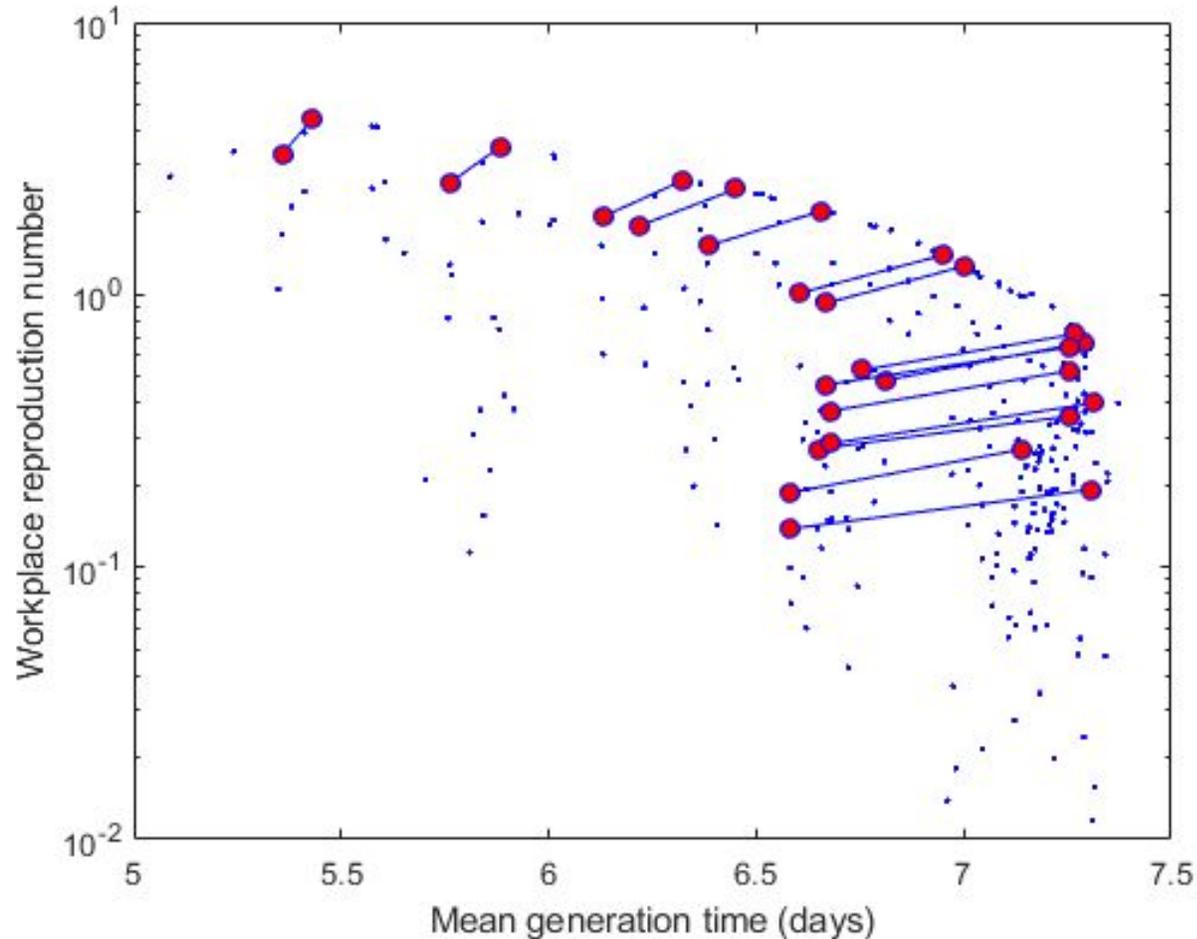
Effect of workplace controls and mitigations



Twice weekly lateral flow testing

Mean reduction in $R_{\text{workplace}} = 41\%$ –
insensitive to transmission parameters

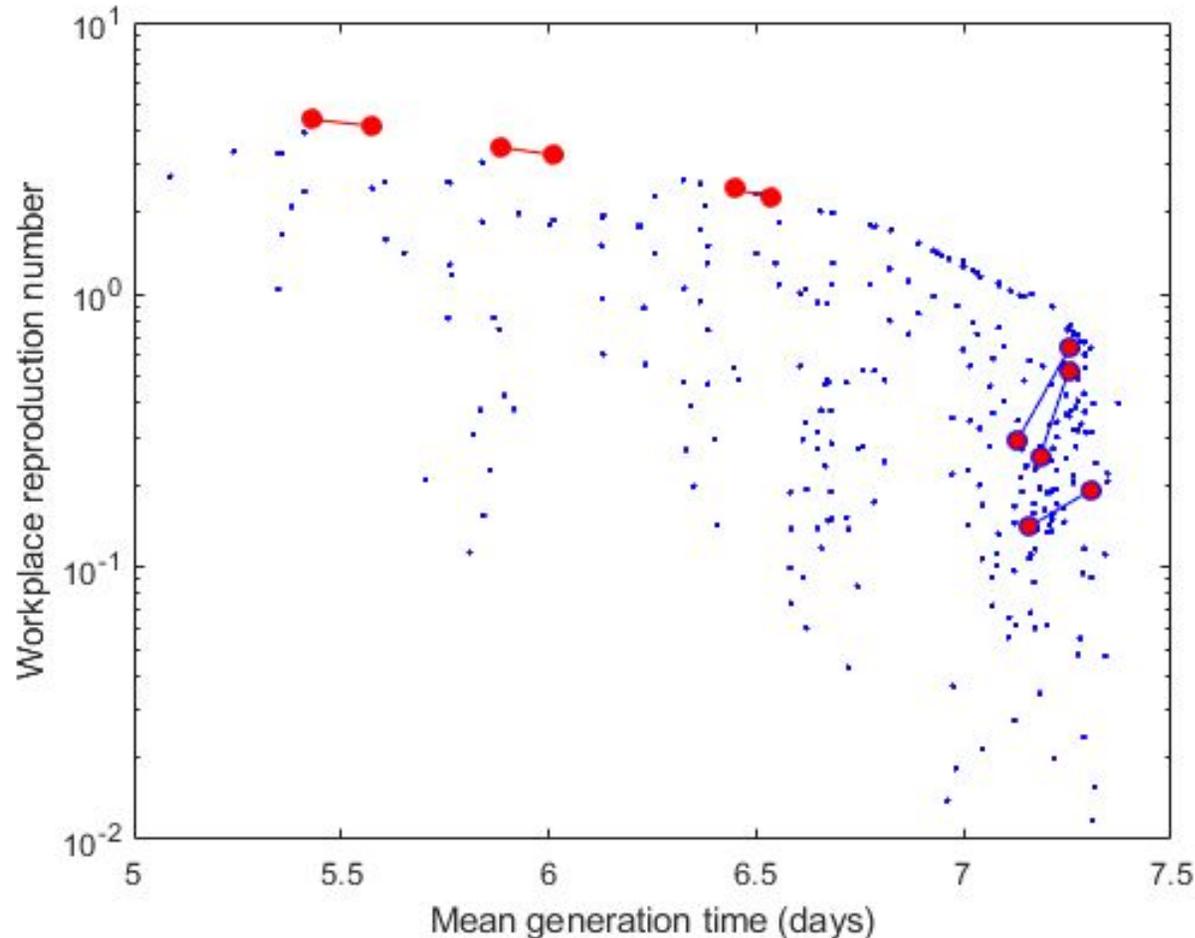
Effect of workplace controls and mitigations



Enhanced isolation of symptomatic cases
(75%)

Mean reduction in $R_{\text{workplace}} = 27\%$ –
insensitive to transmission parameters

Effect of workplace controls and mitigations

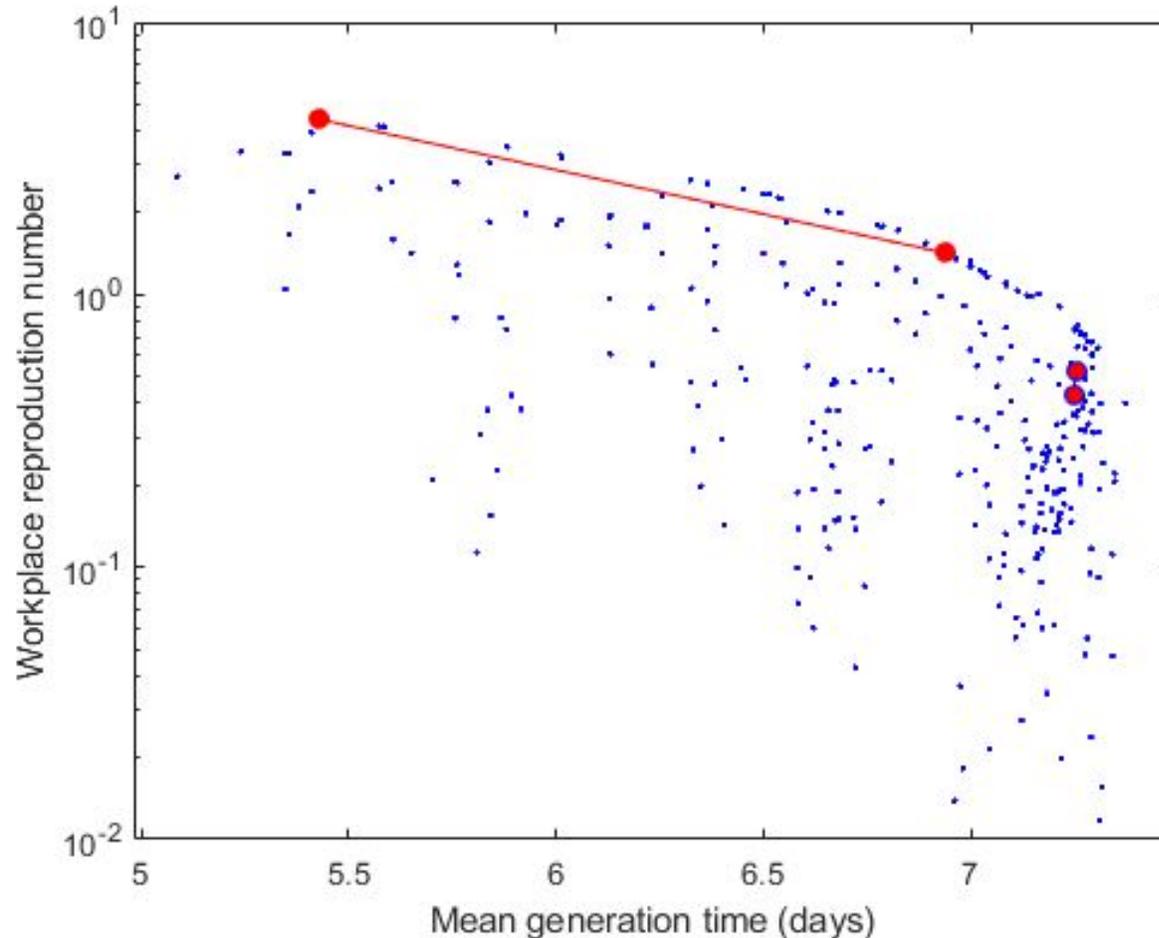


Face coverings worn during short proximity contacts (90% compliance)

Transmission primarily through short proximity contact (large droplets) 44% reduction in $R_{\text{workplace}}$

Transmission primarily through medium proximity contact (aerosols) 6% reduction in $R_{\text{workplace}}$

Effect of workplace controls and mitigations

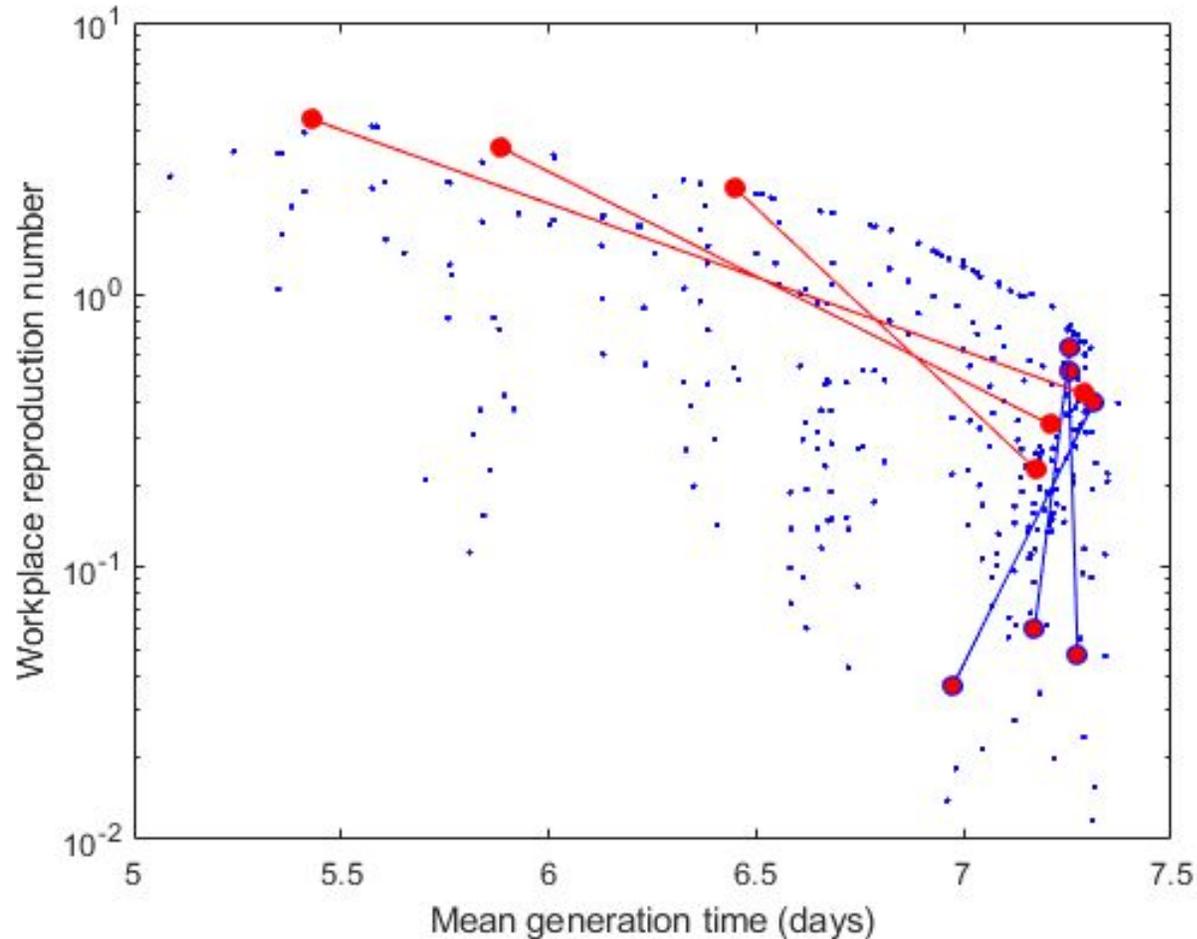


Increased ventilation (x5 ACR)

High transmission via medium proximity contacts vs. lower transmission predominantly via short proximity contacts

15%-72% reduction in $R_{\text{workplace}}$ depending upon importance of short vs. medium proximity contacts

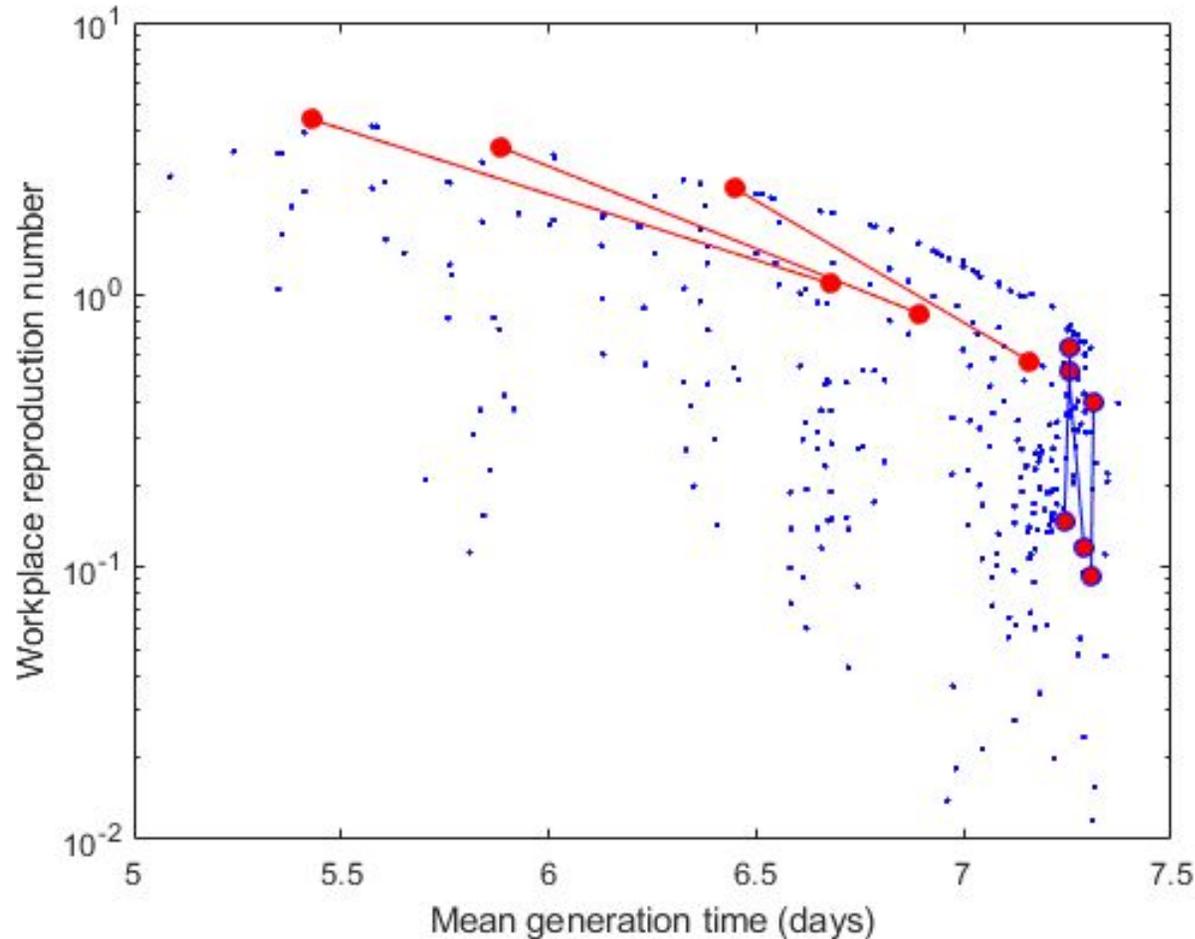
Effect of workplace controls and mitigations



30% building occupancy (whole workforce remote working on a rotational basis)

91% reduction in $R_{\text{workplace}}$ – insensitive to transmission parameters

Effect of workplace controls and mitigations

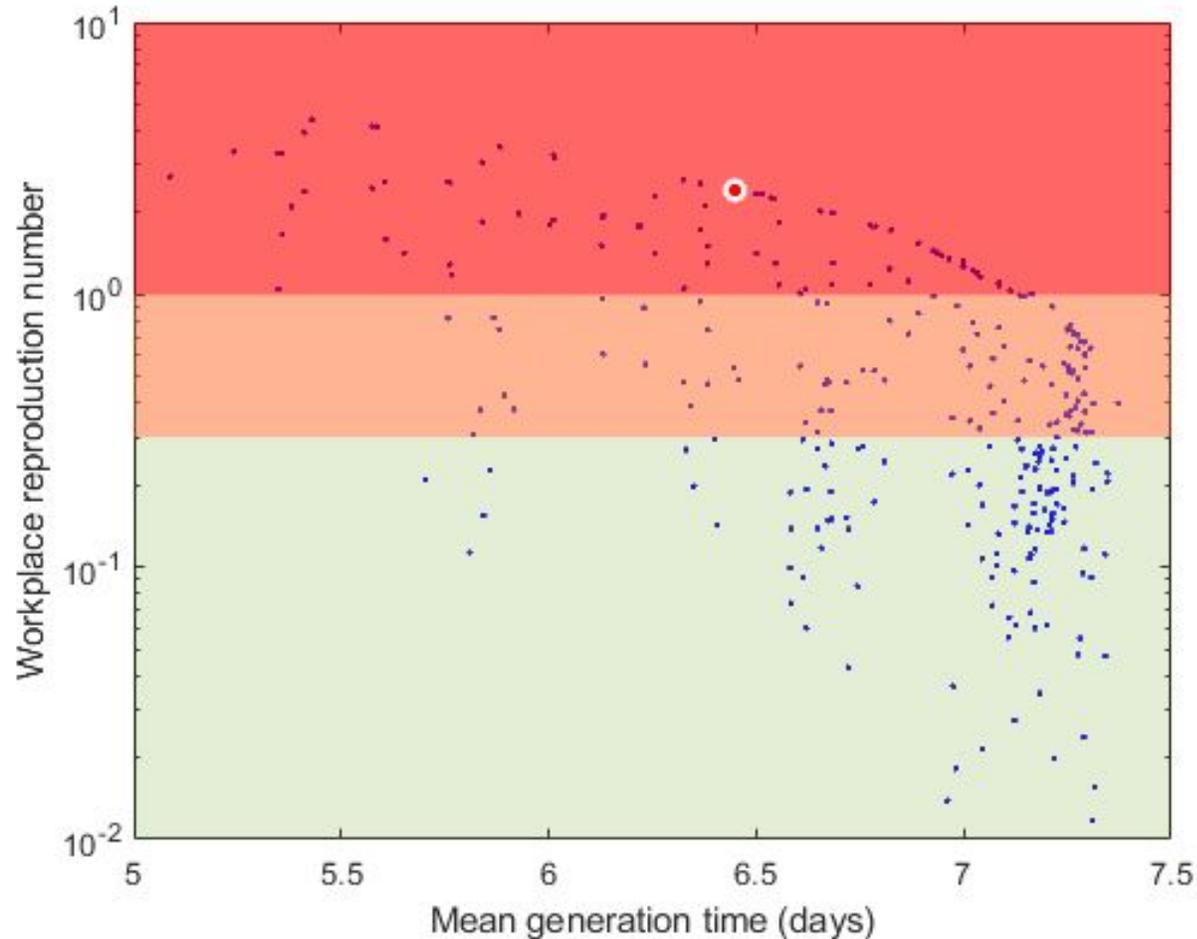


80% workforce vaccination (2-doses, leaky)

76% reduction in $R_{\text{workplace}}$ - insensitive to transition parameters

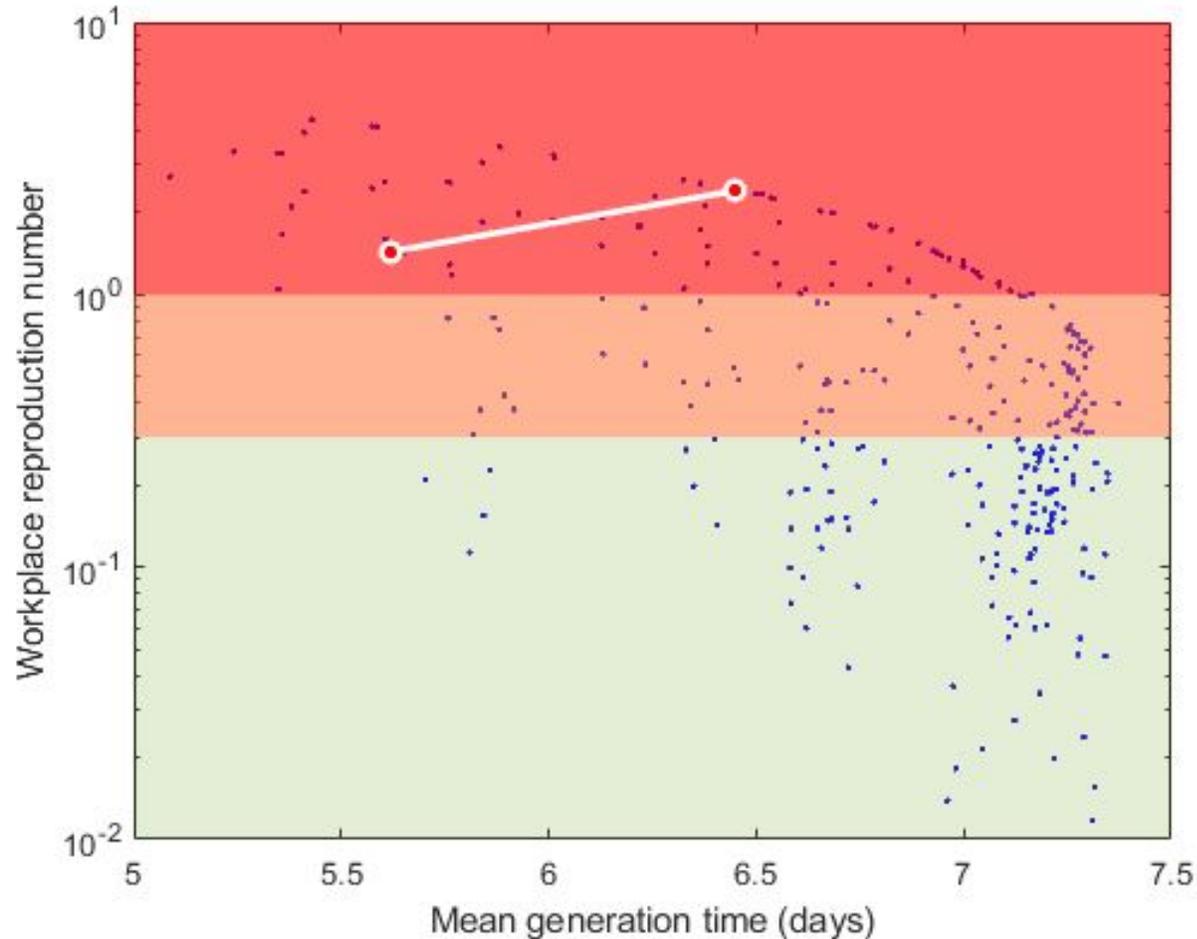
Impact upon generation times differs

Achieving COVID-Secure workplaces



High transmission predominantly via aerosols
1 hr short-proximity transmission risk = 16.5%
1 hr medium proximity transmission risk = 8.6%

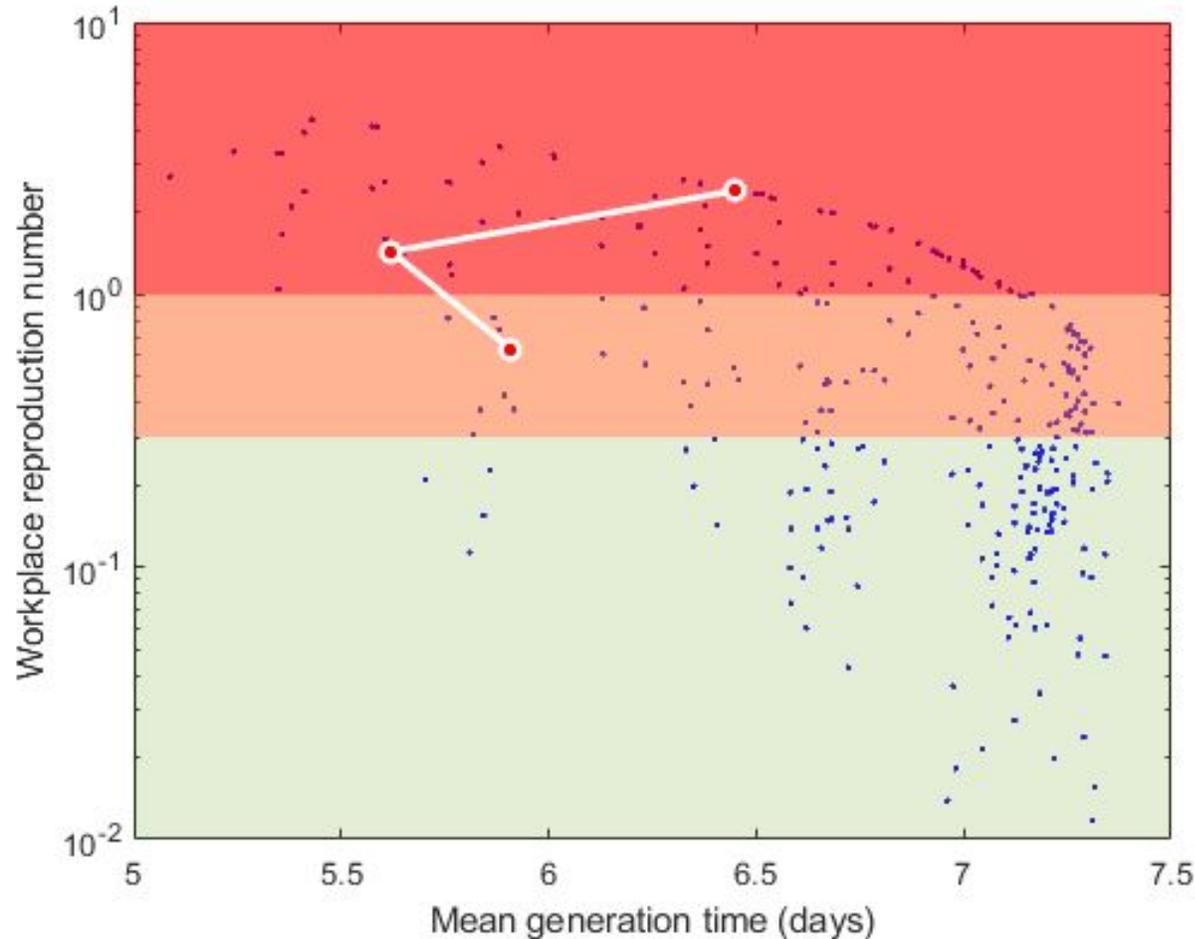
Achieving COVID-Secure workplaces



High transmission predominantly via aerosols
1 hr short-proximity transmission risk = 16.5%
1 hr medium proximity transmission risk = 8.6%

With twice weekly LFD testing

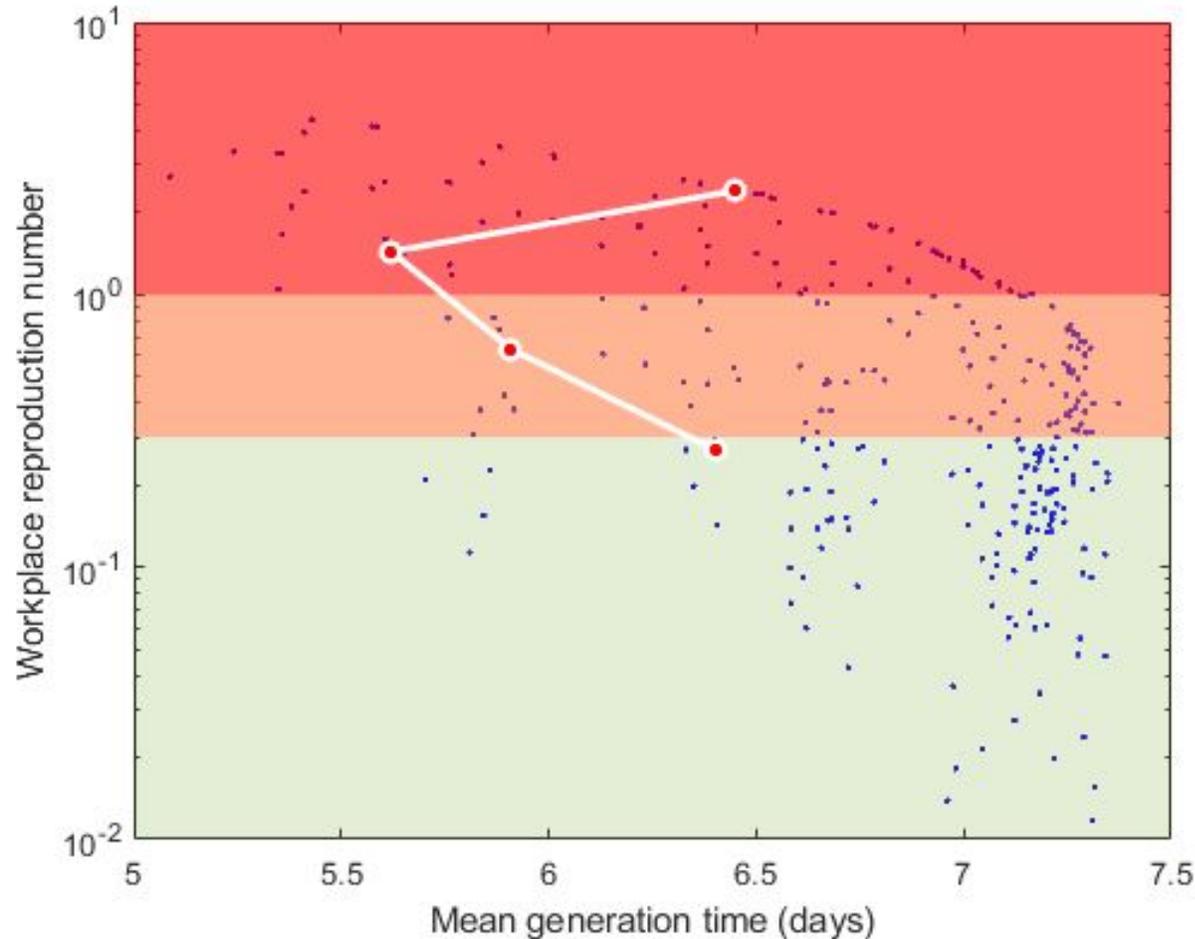
Achieving COVID-Secure workplaces



High transmission predominantly via aerosols
1 hr short-proximity transmission risk = 16.5%
1 hr medium proximity transmission risk = 8.6%

With twice weekly LFD testing + increased ventilation (x3 ACR)

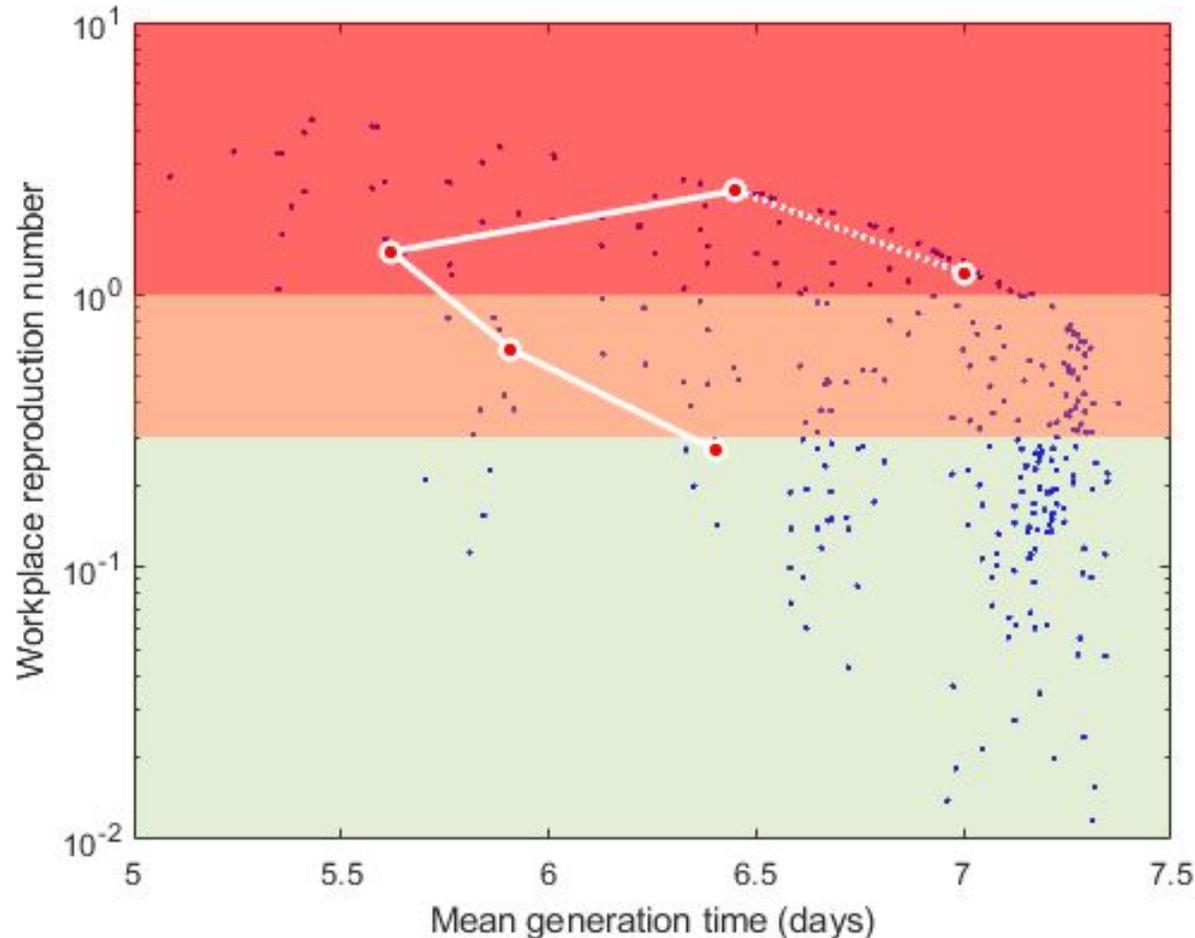
Achieving COVID-Secure workplaces



High transmission predominantly via aerosols
1 hr short-proximity transmission risk = 16.5%
1 hr medium proximity transmission risk = 8.6%

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

Achieving COVID-Secure workplaces



High transmission predominantly via aerosols

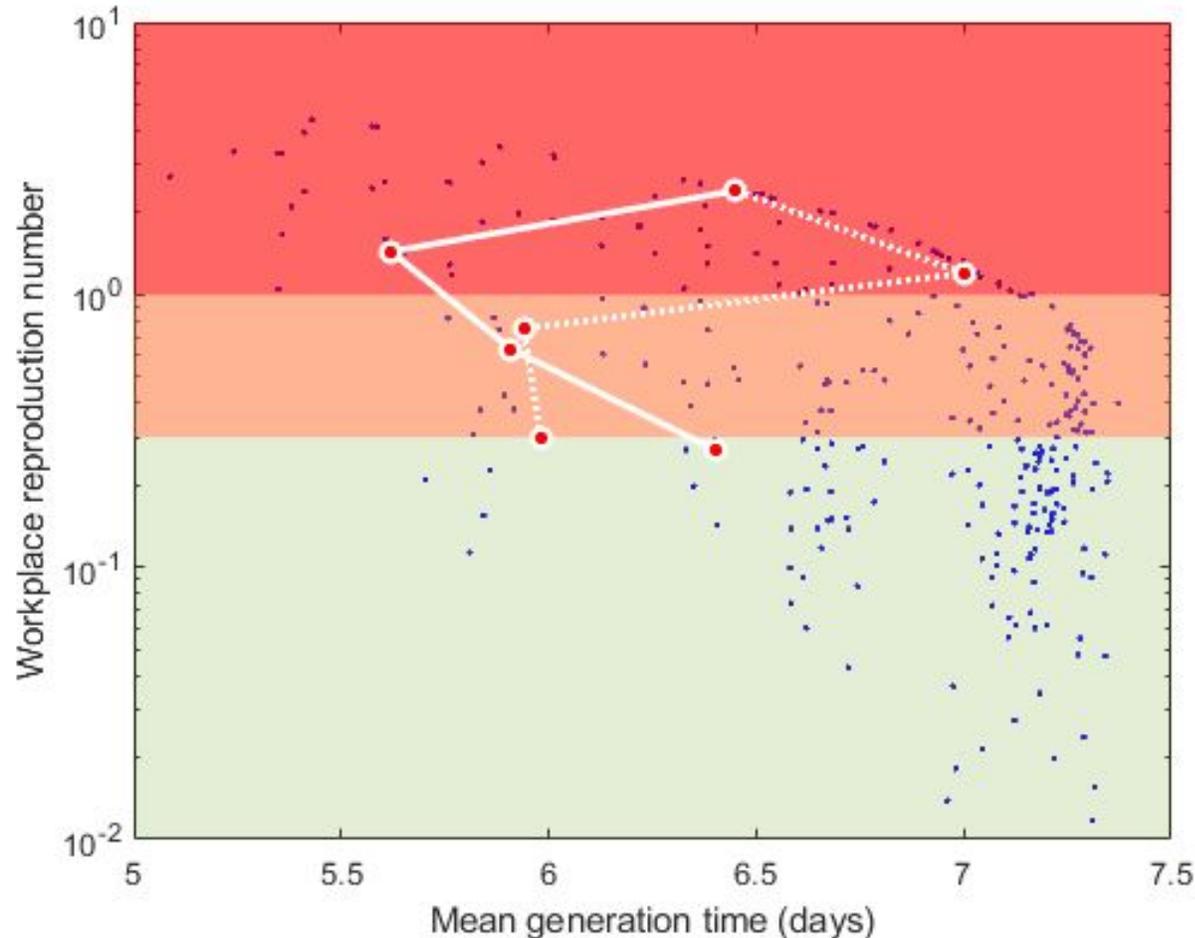
1 hr short-proximity transmission risk = 16.5%

1 hr medium proximity transmission risk = 8.6%

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

With 2-dose workforce vaccination levels based upon demographic profile and uptake rates by age to July 4th (51% overall)

Achieving COVID-Secure workplaces



High transmission predominantly via aerosols

1 hr short-proximity transmission risk = 16.5%

1 hr medium proximity transmission risk = 8.6%

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

With 2-dose workforce vaccine based upon demographic profile and uptake rates by age to July 4th (51% overall) + twice weekly testing + increased ventilation (x3 ACR)

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:

- 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 route of transmission
- In addition to contact patterns, workplace controls and environmental conditions (especially ventilation) influence the generation times for workplace transmission
 - These factors can both shorten and lengthen generation times and for some controls the effect depends upon the levels and relative importance of the different routes of transmission

Acknowledgements

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Thank you

Nick Warren

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

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