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Rapid Review: Modelling of COVID-19 Responses in Australia

Question

We were asked to: (1) Review mathematical models of COVID-19 responses in Australia or by Australia groups; (2) comment on the limitations of the models

Executive summary

Available models

As at 4 April 2020, we have identified seven modelling studies of COVID-19 by Australian groups through literature search (5 pre-print publication, 1 media report) and our networks (1) with characteristics summarised in table 1 (next page).

The approaches and assumptions in these models are reasonable and appropriate given the narrow scope of the question each sought to answer and the rapidity of their development. However, the trade-off is that all models lacked complexity with the exception of Study 1 (University of Sydney – ACEMod), which incorporated a detailed analysis of assumptions and interventions assessed via a suitable model design/methodology.

- All models considered the available evidence and/or made reasonable assumptions for model parameters based on our current understanding of the epidemiology of COVID-19.
- Six models assessed transmission (spread), 2 assessed intensive care (ICU) demand and 3 assessed mortality.
- Six models assessed the impact of social distancing and one on the international travel bans.
- A major gap common to all models was the lack of inclusion of the potential impact of asymptomatic and pre-symptomatic transmission on the epidemic – only Study 1 considered this but as a conservative estimate.
- None of the models comprehensively explored the impact of the full suite of available public health and policy interventions either in the short, medium or long term.

Limitations

The collective limitation of these models for informing national and sub-national responses to COVID-19 relates to aspects that have NOT been included in the models reviewed. These include the:

- Parametrisation of asymptomatic and pre-symptomatic transmission and its potential impact on the epidemic (except study 1). This has been recognised by the US CDC as a major issue and potential issue to monitor by WHO.
- Impact of interventions and strategies currently being employed or likely to be employed in the immediate or near term including:
- Case detection: screening and diagnostics strategies (contact screening, diagnostic criteria, application of broader screening approaches including in high-risk groups and to address asymptomatic and transmission)
- Coverage of interventions (particularly case detection and isolation) and the impact of adherence/non-adherence
- Novel or emerging tools or strategies (point of care diagnostics, treatments, post-exposure prophylaxis, social strategies for improved adherence to public health messaging and interventions)
- Enhanced targeted interventions to geographic hotspots with high case burden and/or confirmed or suspected community transmission
- Impacts of health and other resources allocation and the impacts of health system constraints
- Direct and indirect costs and/or cost-effectiveness of particular interventions
- Longer term "exit strategy" approaches such as a step-wise release of social distancing interventions and the rapid application of tools to mitigate disease resurgence – all the models consider the interventions to be held in place until a vaccine is available or that the epidemic will rebound once intervention strategies are lifted

Recommendations

1. Future modelling could be undertaken that provides guidance on exiting the lockdown without having disease resurgence, including how this might be achieved without availability of a vaccine (or effective treatments).
2. Key considerations for future model design (interventions) include:
   - Re-adjusting assumptions as empirical evidence emerges - for example, the duration of viral shedding, the role of age groups in transmission, the importance of asymptomatic and mild cases in diseases transmission
   - A focus on applying existing tools in the best possible way – for example, assessing the impact of coverage of contact screening, compliance with and expansion of the diagnostic algorithm, adherence to physical and social distancing measures
   - Maximising the benefits of novel tools that have been implemented in other settings, are under trial or are in the pipeline – for example, biomedical tools such as point of care testing, screening strategies, treatments and prophylaxis, and socio-behavioural interventions, like m-health, patient support and legal measures to improve adherence to social distancing / quarantine
   - Modelling the impact of resource allocation decisions to optimise resources where they are limited – for example, consumables, personal protective equipment, medical equipment, health workforce, and financial resources
3. Given the expertise of Australian and international mathematical modelling groups, consideration could be given to a transparent consortium-based approach, where several groups may independently model the same question

Key findings

- The actual international travel bans implemented are likely to have delayed the occurrence of local transmission (Study 4, 5)
- A combination of self-isolation, social distancing with at least 80-90% compliance over a duration of 90 days can flatten the curve and a total lockdown can suppress all infections after 49 days (Study 1, 5, 7).
- Social distancing with >70% compliance is required to control the epidemic (Study 1, 3)
- School closures are unlikely to have a major impact on the epidemic* (1, 3)
- Once intervention strategies are lifted then the epidemic is likely to rebound in the absence of additional public health interventions (see limitations above) (1)

Table 1: Summary of available Australian models

Model	Question and Population	Interventions modelled	Outcomes assessed
Model 1 University of Sydney - ACEMod	Spread Australia	Case isolation, restriction on international travel, social distancing and school closures	Incidence and prevalence
Model 2 University of Sydney - SEIR Model	Spread NSW	Social isolation policies	Hospitalised cases and ICU cases
Model 3 University of Western Australia	Spread Newcastle	School closure, workplace non-attendance, increased case isolation and community contact reduction	Number of cases
Model 4 James Cook University	Spread Australia	Social isolation policies	Number of cases
Model 5 University of New South Wales	Spread, mortality Global / no setting	Self-isolation and social distancing	Total number of cases and length of the epidemic
Model 6 University of New South Wales (Kirby)	ICU demand Australia	Full and partial travel bans	Number of cases and deaths
Model 6 University of Tasmania	Spread, mortality, ICU demand Tasmania	Closing schools, case isolation, household quarantine, social distancing of >70 year olds	Number of cases and deaths

Background

Mathematical models are useful tools for comparing the potential impact of different policies or interventions before they are implemented. There are different model types that can be used, each with strengths and limitations.

To properly interpret models and make policy and practice decisions based on models, care must be taken to ensure the modelling approach is aligned with the **question being asked**, the **data available** and that the **assumptions** (unknowns) are clear.

Infection disease and COVID-19 models can be broadly classified according to **WHO** they model, **HOW** they model and **WHAT** they model.

WHO

Whether they model individuals and their characteristics ("agent-based models") or use population averages ("population-based models")

- Agent-based models capture individual behaviours and on occasions social networks, more realistically, but they require significantly more detailed data for adequate parameterisation.

HOW

Whether the model incorporates randomness ("stochastic" models) or does not incorporate randomness ("deterministic" models)

- Stochastic models are better for analysing the early stages of an epidemic when random events can significantly change the epidemic trajectory (e.g. one infectious person going to a crowded place).
- For questions about established epidemics, both model types produce similar results.

The assumptions the model makes about biological disease states

- Models classify people into a set of distinct disease states such as susceptible (S), exposed (E) and infected (I) or recovered (R).
- Different model structures (e.g. "SIR", "SEIR", "SEEIIR") represent different assumptions about the biological stages of the disease.

Whether the model incorporates population stratifications

- Models may sub-divide the population according to risk factors such as age, comorbidities, access to services, or disease severity (for people infected) or behavioural factors (compliance with social distancing).
- These factors are modelled if they impact outcomes (e.g. age) or are being assessed for intervention (e.g. risk groups to be tested).

WHAT

Interventions or scenarios

Models can consider a variety of questions, for example:

- Forecast possible epidemic trajectories and the impact of different policies and interventions on these trajectories
- Calculate the cost and cost-effectiveness of different policy choices or interventions strategies
- Define how to optimise limited resources (e.g. financial, human resource, or consumables/equipment)
- Assess the best way(s) to implement particular interventions (e.g. risk groups for prioritisation)
- Determine which new technologies would have the greatest impact (e.g. how much effort to invest in discovery of new treatments vs new tests vs vaccine).

Key limitations of COVID-19 Models

- COVID-19 is a novel infectious pathogen and our understanding of its transmission is developing and incomplete.
- The model "parameters" or assumptions such as incubation period, basic reproduction number (R0) and proportion of asymptomatic cases are based on data and research that is currently available.
- Human behavioural patterns play a major role in transmission dynamics - because these differ across settings, data (and assumptions) from one country/state may not apply elsewhere

Study 1: Modelling transmission and control of the COVID-19 pandemic in Australia: University of Sydney

Key Question

- What is the impact of intervention strategies (primarily social distancing) on the COVID-19 pandemic spread in Australia?

Methodology

- Stochastic agent-based model for all of Australia
- Age stratification (with a focus on older adults and children) and social mixing in different contexts (i.e. households, workplaces etc.) are considered
- Symptomatic and asymptomatic cases are considered
- Model was simulated over a period of 28 weeks

Intervention strategies considered

- Case isolation
- Restriction on international travel
- Social distancing
- School closures

Assumptions

- R0 value was calibrated to be 2.27 and the mean incubation time was taken to be 5 days
- Asymptomatic cases are assumed to be 30% as infectious as symptomatic cases. 67% of adult cases were assumed to be symptomatic while 13.4% of cases in children were assumed to be symptomatic
- School closures were assumed to eliminate school contacts but increase contacts at home

Main findings

- School closures are not found to have any significant benefits
- Social distancing with less than 70% compliance of any duration had no effect on controlling the disease spread, while social distancing with 80-90% compliance controlled the disease within 13-14 weeks
- Resurgence in the number of cases occurred after social distancing measures were lifted at 13 weeks

Limitations

- A significant number of parameters (including incubation period, infectivity of asymptomatic vs. symptomatic individuals, infectivity of children vs. adults and daily contact rates) need to be calibrated/estimated for the model. These may change as more information/research becomes available
- No long term projections and long term interventions were considered (interventions are modelled over a maximum of 28 weeks)

Study 2. Modelling the impact of COVID-19 upon intensive care services in New South Wales: University of Sydney

Key Question

- What will the peak demand of ICU be in NSW during the COVID-19 pandemic?

Methodology

There were two approaches used:

1. An adaptation of the results of Imperial College London's model to the NSW population (applied according to the age-distribution of NSW).
2. A compartmental (deterministic) SEIR model applied to the NSW population.

Intervention strategies considered:

1. Intervention strategies were as per Imperial's study (including case isolation, household quarantine and social distancing)
2. Intervention strategies were modelled as social isolation policies that reduced R0 from 2.4 to 1.6

Assumptions

- Assumptions were as per Imperial's study (i.e. incubation period of 5.1 days, infectious 12 hours before symptom onset and R0 of 2.4). Number of hospitalisations and fatalities in NSW were assumed to be proportional to those in the UK (adjusting for age-distribution)
- R0 was assumed to be 2.4 in the non-intervention scenario. All cases were assumed to be symptomatic, with the proportion individuals going to hospital 3.3% and the proportion of hospitalisations going to ICU 30%

Main Findings

- Peak ICU bed demand estimated in strategy (1) was forecast to be 6,965 under intensive mitigation strategies (i.e. case isolation, household quarantine and social distancing of >70 year olds) - 797% of current ICU bed capacity
- Peak ICU bed demand estimated in strategy (2) was forecast to be 5,109 under modelled social isolation policies - 584% of current ICU bed capacity

Limitations

- For strategy (1), the model was initially developed for the UK and there are key differences between the UK and NSW (evidence suggests that case detection may be higher in Australia). The model was also created based on social interactions within the UK and may differ from the Australian context
- For strategy (2), the model does not take into account any stratifications for age and other risk factors. It is also unclear which social policies will reduce the R0 values used in the intervention analysis. The model also assumes that all individuals are symptomatic and does not make a distinction for asymptomatic cases

Study 3. The Effectiveness of Social Distancing in Mitigating COVID-19 Spread: a modelling analysis: University of Western Australia

Key Questions

- What is the impact of social distancing on peak daily infection rate in Newcastle?

Methodology

- Agent-based model simulating COVID-19 spread within the population of Newcastle (N=272,409)
- Demographic and movement patterns within the city were considered (including household structure, age, employment and schooling)
- Symptomatic and asymptomatic cases considered

Intervention strategies considered

- School closure
- Workplace non-attendance
- Increased case isolation
- Community contact reduction

Assumptions

- The R0 value was assumed to be 2.2 and incubation period averaging 5.5 days
- 20% of cases assumed to be asymptomatic
- Transmission across different age groups assumed to be the same

Main Findings

- Case isolation and 70% reduction in community wide contact were found to be the most effective forms of social distancing measures
- School closure was found to be the least effective measure
- Social distancing measures were found to be effective up to 10 weeks after cases were initially introduced into the population

Limitations

- The model only considers the population of Newcastle and does not take into account continual importation of cases from outside Newcastle or travel outside of Newcastle
- Interventions are assumed to be held in place until a vaccine or treatment is available
- The model considers delays for activation of interventions from the initial import of infections into the population, however this may not be relevant now since the disease is already wide-spread

Study 4. Delaying the COVID-19 epidemic in Australia: Evaluating the effectiveness of international travel bans: James Cook University

Key Questions

What is the impact of travel bans on COVID-19 spread in Australia?

Methodology

- Stochastic meta-population SEIR model simulating COVID-19 importation into Australia from other countries (using migration pattern information), and spread within the Australian population

Intervention strategies considered

- The number of cases were simulated in both the presence and absence of travel bans.
- The potential impact of interventions reducing R0 from 2.63 to an R0 of 1.73 were also simulated

Assumptions

- R0 value assumed to be 2.63
- Equal social mixing assumed
- No distinction between symptomatic and asymptomatic cases

Main Findings

- By the beginning of March, significantly more cases were estimated to have been imported from overseas (N=70) compared to what was observed (N=15)
- Travel bands were found to have delayed widespread occurrence of local transmission by ~1 month, with further local transmission delaying local transmission by a further 5 weeks

Limitations

- Given that the disease is already wide-spread in Australia and travel bans are in place, the intervention tested may be less relevant now (although it may be useful when considering the impact of lifting travel bans)
- It is not clear how reducing the R0 value in the simulation directly corresponds to specific social policies
- The long term impact of travel bans is not explored

Study 5. We can "shrink" the COVID-19 curve, rather than just flatten it: University of New South Wales

Key Questions

- Can public health measures reduce the number of cases and deaths overall?

Methodology

- Stochastic individual based contact model simulating the spread of COVID-19 in a hypothetical population of 100,000

Intervention strategies considered

- Self-isolation
- Social distancing
- Lock-down

Assumptions

- Average of 10 interpersonal contacts per day, 5% probability of infection following interaction with an infected individual

Main Findings

- All interventions were found to flatten and shrink the epidemic (i.e. reduce the peak number of cases, but also the number of cases and deaths overall)

Limitations

- This is more of a theoretical type model and is not calibrated to real world parameters

Study 6. The effectiveness of full and partial travel bans against COVID-19 spread in Australia for travellers from China -University of New South Wales

Key Questions

- What is the effect of full and partial travel bans for travellers from China on COVID-19 spread in Australia?

Methodology

- Deterministic age-structured compartmental model simulating the spread following importation of cases from China
- Policies were modelled over 400 days

Intervention strategies considered

- No travel ban from China (i.e. a ban was never put in place)
- Complete travel ban from China, lifted after March 8th
- Complete travel ban from China followed, partial lifting after March 8th (allowing university students, but not tourists to enter the country)

Assumptions

- Cases were only imported from China
- Infected and uninfected individuals equally as likely travel to Australia
- R0 value assumed to be 2.2, and incubation period assumed to be 5.2 days
- 34.6% of cases were assumed to be asymptomatic and 80% of cases were identified for home quarantine

Main Findings

- The travel ban was estimated to have averted 87% of cases and deaths
- The number of imported cases was low in the partial travel ban scenario, and switching from full to partial travel ban had little effect

Limitations

- Cases imported from other countries not considered
- Long term impact of travel bans not considered
- Risk factors for transmission and disease are not considered

Study 7. University of Tasmania Model

Key Questions

- What is the impact of mitigation strategies on peak number of cases, deaths and ICU bed capacities in Tasmania?

Methodology

- SEIR compartmental model simulating the spread in Tasmania

Intervention strategies considered

- Used mitigation strategies as per Imperial College's paper (i.e. case isolation, home quarantine, social distancing and closure of schools)

Main findings

- Estimated that peak infections could be reduced from 138,642 to 5,194, and mortality reduced from 6,017 to 1,670

Limitations

- Details of the model are not available

Table 2: Model descriptions

Model	Type	Structure	Stochastic	Age stratifications	Severity stratifications	Testing stratifications	Social mixing considerations	Community + imported infections?
Model 1 University of Sydney - ACEMod	Agent based model	SEIR	Yes	Yes	None	Testing not considered	Considers contact rates within different social contexts: households, community, schools and workplaces	Community transmission seeded from international airports before travel restrictions
Model 2 University of Sydney - SEIR Model	SEIR compartmental model	SEIR	No	No	Hospitalised cases and ICU cases	Testing not considered	Equal mixing	Community transmission only
Model 3 University of Western Australia	Agent based model	SEIR	No	Yes	None	Testing not considered	Considers contact rates within different social contexts: households, community, schools and workplaces	Community transmission only
Model 4 James Cook University	Stochastic meta-population model	SEIR	Yes	No	None	Testing not considered	Equal mixing	Community transmission + imported cases
Model 5 University of New South Wales	Stochastic individual contact model	SEIR (with modifications)	Yes	No	Hospitalised cases	Testing not considered	Equal mixing	Community transmissions only
Model 6 University of New South Wales (Kirby)	Deterministic compartmental model	SEIR (with modifications)	No	Yes		Testing not considered	Equal mixing	Community transmissions and imported cases
Model 6 University of Tasmania	Compartment model	SEIR	No	Yes	Hospitalised cases and ICU cases	Testing not considered	Unknown	Unknown

Table 3: Parameter comparison

Model	R0 (no intervention)	Incubation period	Asymptomatic / symptomatic cases considered?	Percent assumed symptomatic	Relative transmission rate of asymptomatic cases	R0 (no intervention)	Incubation period	Asymptomatic/ symptomatic cases considered?
Model 1 University of Sydney - ACEMod	2.2	5	Yes	67% adult cases, 13.4% of child cases	30% of symptomatic cases	2.2	5	Yes
Model 2 University of Sydney - SEIR Model	2.4	4.1	No	-	-	2.4	4.1	No
Model 3 University of Western Australia	2.2	5.5	Yes	80% (65% used in sensitivity)	Same as symptomatic	2.2	5.5	Yes
Model 4 James Cook University	2.63	5.2	No	-	-	2.63	5.2	No
Model 5 University of New South Wales	Unknown	Unknown	No	-	-	Unknown	Unknown	No
Model 6 University of New South Wales (Kirby)	2.2	5.2	Yes	65.4% (20% and 50% used in sensitivity)	Same as symptomatic	2.2	5.2	Yes
Model 6 University of Tasmania	2.68	5.2	Yes	Unknown	Unknown	2.68	5.2	Yes

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