Institute and Faculty of Actuaries

ICAT – PAN1: Pandemic Model Meta-research

Tranche 1: Reviews of models published at the start of the outbreak

10 December 2020

1 Scope of work

The main objective of this workstream is to evaluate the main pandemic-related models being referred to in the press, or used for decision making, by public and private institutions. The results of the analysis will be communicated to actuaries, working groups, and other interested parties.

The detailed scope is attached here and is also available on the IFoA ICAT website: Scope for PAN1 workstream

2 Model selection and review procedure

The 11 models in the first tranche were identified in June 2020 with the following principles stated in the PAN1 scope: models selected for review are the main models being referred to in the press, or used for decision making, by public and private institutions, in the context of the COVID-19 pandemic. These models would also be of particular interest to IFoA members in the course of their work.

The models were individually reviewed by the workstream, by applying a standardised rapid review procedure tailored to this workstream. Each model was independently reviewed by 2 reviewers, who subsequently discussed their reviews in order to produce consolidated summaries of their review, in the forms of a scoring system (Section 3) and a descriptive summary (Section 4).

3 Summary of Results – scores

The review procedure included using a set of actuarial model review criteria to assess model quality, and a published critical appraisal method to assess risk of bias.

The maximum scores for each category is determined through assigning a rating to a structured set of questions addressing each review category. The rating is based on the extent to which the model and associated paper under review meets the requirements of each question. For example, for data adequacy, there are 3 questions under the model quality assessment. Each question is designed to critically assess the extent that data sources used are adequate for the intended purpose of the paper. The question responses are either “Yes”, “Partial” or “No”, with scores of 1, ½ and 0 respectively. If the paper addresses all 3 questions fully, i.e. a “Yes” response, it receives a score of 3 under this section and the scoring adjusts downwards if any of the question responses are “Partial” or “No”. Rationale must be included for the rating of each question.

	Paper name	Model Quality: Use & Purpose	Model Quality: Data Adequacy	Model Quality: Methodology Robustness	Model Quality: Accuracy & Validation	Risk of bias: Use & Purpose	Risk of bias: Data Adequacy	Risk of bias: Methodology Robustness	Risk of bias: Accuracy & Validation
	Max	***3***	***3***	***6***	***6***	***5***	***1***	***3***	***4***
1.	Epidemix: online disease modelling	2	0	3	2.5	4	0	1.5	1
2.	Vital Surveillances	2	2.5	2.5	1.5	2.5	0	0	1
3.	Johns Hopkins University	2.5	2.5	5	2.5	4.5	0.5	2	3
4.	Data-Based Analysis, Modelling, Forecasting of COVID-19	2.5	1.5	4	3	4.5	0.5	2	1.5
5.	Washington Post: Flattening the curve	2	0	0.5	1	2.5	0	0.5	1
6.	Evaluation: Effectiveness of Surveillance, Containment Measures	3	1.5	4	3	3.5	0.5	0.5	3
7.	COVID-19: Possible Transmission During the Incubation Period	2.5	1.5	2	1.5	3	0	0	2
8.	Discrete-time-evolution model to forecast progress of Covid-19	1.5	1.5	5	0.5	4.5	0.5	0.5	1
9.	Estimating R for the UK using Publicly Available Data	2	2.5	4.5	1	3.5	1	2.5	2
10	Risk factors for COVID-19-related mortality in people with type 1 and type 2 diabetes in England: a population-based cohort study	3	2	4	3	3	0	0	3.5
11	Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand	3	1.5	4	2	3.5	0.5	1.5	2.5

4 Summary of Results – descriptive

A description of each of the paper reviewed and the key findings are given below. Note that SEIR refers to "susceptible-exposed-infectious-recovered" models:

	Paper name	Author / Institute	Key words	Summary & Purpose	Key findings / flags / limitations
1.	Epidemix: online disease modelling	Guillaume Fournie and Dirk Pfeiffer. Royal Veterinary College and City University Hong Kong	Health insurance, SEIR, projections, visualisation, communication	This application is intended to be used by scientists teaching mathematical modelling short courses to non-specialists and wishing to develop practicals illustrating key concepts of disease dynamics and control.	No empirical findings are reported as they are dependent on the data supplied by the model user. The limitations of the models have not been elaborated upon. The authors could have done more here to allay concerns around improper use, for example, by providing a tutorial. Confidence intervals at various levels of significance could be added. For comparing actual with expected transmissions, additional analysis would be required.
2.	Vital Surveillances	Zijian Feng, Qun Li, Yanping Zhang et al. The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team	Health insurance, policy, trend analysis, mortality	To documents and chronicle the spread of the epidemic through analysing all cases diagnosed between early Dec 2019 and 11 Feb 2020 in Hubei province, China. This location that is widely seen to be the origin of the COVID-19 outbreak. (2) Provides information to policymakers internationally to help contain the spread of the disease in their respective countries.	The results are a description of the trend in number of cases from a retrospective observational study of 72,314 hospital patient records. These cases were broken down into confirmed, suspected, clinically diagnosed, asymptomatic and fatal cases. Case fatality rates were also estimated. The study states that it interpreted the trend as describing a 'mixed outbreak pattern — the data appear to indicate a continuous common source pattern of spread in December and then from early January through February 11, 2020, the data appear to have a propagated source pattern ', without adequate justification or further epidemiological analysis. Separately from this report, we note that there was a sudden surge in number of cases in China on 12th February 2020. It is unclear whether these cases were the ones already considered as "suspected" within this study, or whether considering those cases might have had any difference in results.
3.	Johns Hopkins University	Aleksa Zlojutro, David Rey, Lauren Gardner and Ensheng Dong. Johns Hopkins University, University of New South Wales	Policy, SEIR, projections, interventions	To identify optimal control strategies for passenger screening at airports during the initial stages of infectious disease outbreaks, over a period of 50 days. The underlying model investigated a number of control strategies (interventions) on the pattern of transmission rates.	This study extended the SEIR framework by modelling the whole population as a network of local, city-level, populations connected only through passenger air travel between cities. Results for the number of imported vs reported cases were reported for each country. The top 50 airports in China and outside of China were also ranked by risk of case importation. The modelling approach assumes the same SEIR dynamics across different subpopulations and in practice these are likely to differ. The case study in the report considers only US airports and may not be generalisable to other settings. Model parameters were based on up to date empirical evidence and limitations were clearly set out. However, the limitations of the model structure were not highlighted. Significant sensitivity analysis was performed but no goodness of fit tests were reported.
4.	Data-Based Analysis, Modelling,	Cleo Anastassopoulou, Lucia Russo, Athanasios Tsakris and Constantinos	Health insurance, life insurance, policy, SEIR,	Purpose: To provide estimates of the main epidemiological parameters: R, per day infection	The analysis was based on 40,235 confirmed cases and 909 deaths in Wuhan China, between 1 Dec 2019 and 10 Feb 2020. The number of cases were forecasted to reach 180,000 by 29 Feb (with a very large 90% confidence

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	Forecasting of COVID-19	Siettos. University of Athens and Universit`a degli Studi di Napoli Federico II	projections, R, mortality	mortality and recovery rates, by estimation of case fatality and case recovery ratios using the SIRD model. In addition, the spread was forecasted for the 3 weeks of 10-29 Feb 2020.	interval, as its lower bound was 45,000), while the death toll was forecasted to exceed a lower bound of 2,700. The analysis did not include mild or asymptomatic cases, which may lead to underreporting. Due to the limited data collection period and location, and international skepticism of the credibility of data collected during the initial outbreak, these assumptions could be skewed. The underlying data has since been superseded by the collection of higher quality and longer term data, which would also help to reduce uncertainties around the estimates of these parameters.
5.	Washington Post: Flattening the curve	Harry Stevens. Washington Post	Policy, SEIR, projections, interventions	Statistical simulation infographic that illustrates spread of a fictional disease through the population and the possible impacts of 3 scenarios: imposing a quarantine and moderate vs extensive social distancing.	No empirical findings are reported, and a comparison of simulated proportions of healthy/sick/recovered for each of the 3 scenarios was displayed. This model may have very low applicability beyond explaining concepts of disease transmission, as it did not appear to be based on empirical data or knowledge of infectious disease dynamics. In addition, it has poor credibility as the source of the model was not stated and results were not checked against empirical analysis of any infectious disease. The assumptions used in this SIR model structure were strong: people move at random with 100% chance of transmission on contact, no incubation period, infectious throughout sickness, 100% chance of survival and no chance of reinfection.
6.	Evaluation: Effectiveness of Surveillance, Containment Measures	Yixiang Ng, Zongbin Li, Yi Xian Chua et al. Ministry of Health, National Centre for Infectious Diseases, Tan Tock Seng Hospital, Nanyang Technological University and National University of Singapore	Policy, trend analysis	Purpose: To examine effective surveillance (identifying cases) and containment (isolating cases) methods, by analysing the first 100 cases in Singapore reported between 2 Jan-29 Feb 2020.	This study found that the mean duration from symptom onset to isolation for the first 100 cases in Singapore was 5.6 days and declined after approximately 1 month, and suggested that the epidemic curve peaked on 30 Jan. The sample size was therefore very small. Data was assumed to be complete and correct, which may have been a more appropriate assumption in the Singaporean context compared to other contexts. Statistical tests were only conducted on the characteristics of confirmed cases, and details of analysis were not supplied. Later evidence beyond Feb showed that the peak was not in Jan, and that a differential pattern of transmission by community setting had emerged (important for surveillance and containment studies). The results may have been significantly different if it analysed a later time period.
7.	COVID-19: Possible Transmission During the Incubation Period	Ping Wang, Zhiyong Lian, Ye Chen, Ying Qi, Huijie Chen and Xiangdong An. Shenyang Center for Disease Control and Prevention	Policy, transmission mechanics	Case report of a cluster of 4 confirmed cases in Shenyang, China. To explore the mechanism of transmission during the incubation period.	The case report of this very small study collected data from in-person interviews. It found that the index patient likely transmitted COVID-19 to the other 3 close contacts during her incubation period, and may have transmitted COVID-19 to one other person that she came into contact with. Due to the nature of the data, insights from this study are very limited. This was one of the earliest studies of incubation transmission that supported prevailing Chinese governmental guidelines on close contact, and since then much larger

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					studies have been published that confirm this phenomena and provide estimates of transmission rates.
8.	Discrete-time-evolution model to forecast progress of Covid-19	Evaldo Curado and Marco Curado. Centro Brasileiro de Pesquisas Físicas and National Institute of Science and Technology for Complex Systems	Policy, SEIR, projections	To provide one-day forecasts of the spread of COVID-19 using well-established SEIR modelling methods.	One-day forecasts of total numbers of infected people for Brazil, UK and South Korea using data published by Johns Hopkins University were produced and were similar to actual numbers of confirmed cases. This model has low applicability due to its very short projection period. Standard deterministic SEIR assumptions were clearly stated, but not always clearly justified – these would not be material for this short projection period. Due to the deterministic model structure, uncertainties were not available.
9.	Estimating R for the UK using Publicly Available Data	Stuart McDonald, Covid-19 Actuaries Response Group	Policy, health insurance, life insurance, R	To estimate value for R over time (1 Mar to 10 May 2020) from publicly available intensive care unit admissions and mortality data, to track progress of the epidemic and containment measures.	Time-varying weekly estimates of R from early Mar (2.8) to early May 2020 (as low as 0.6) based on mortality data alone were reported. The report stated that updates to the estimates, region-specific estimates and estimates for specific infection and death scenarios would be produced in future. The estimation approach was restricted to mortality data only, and to intensive care unit admissions in a sensitivity analysis, as these was the only data sources deemed to be publicly available and reliable. The reported limitation of being unable to pinpoint the effect of interventions in smoothed estimates of R is an artefact of the smoothing approach used. Since this report was published, consolidated results from multiple models considered by the scientific advisory group to the UK government have been released.
10	Risk factors for COVID-19-related mortality in people with type 1 and type 2 diabetes in England: a population-based cohort study	Naomi Holman, Peter Knighton, Partha Kar et al. National Health Service, Public Health England, Diabetes Research Centre, MRC Epidemiology Unit, Diabetes UK, Imperial College	Health insurance, life insurance, risk factors, interventions	To investigate the relationship between health risk factors for diabetes and COVID-19 related death in an English cohort of 3 million people with diabetes from Feb-May 2020.	This study found a sharp rise in all-cause mortality in diabetes during this period and showed that mortality related to COVID-19 in people with diabetes was associated with cardiovascular and renal complications of diabetes, and also independently associated with glycaemic control and BMI. It suggested that risk factor control could be used to reduce the impact of COVID-19 for those with diabetes. As this is a study of biological risk factors for disease that used standard epidemiological approaches (Cox models), its findings may be more generalisable, however the comparisons with other studies were not reported in detail.
11	Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand	Neil Ferguson, Daniel Laydon, Gemma Nedjati-Gilani et al. Imperial College COVID-19 Response Team	Health insurance, life insurance, policy, SEIR, projections, interventions	The report covers the projection of intervention impact, to forecast peak healthcare demand and deaths under possible non-pharmaceutical intervention (NPI) scenarios for the UK (in detail) and the US (high-level) in order to inform public policy response options. It provides an opinion on	This report stated that optimal mitigation policies might reduce peak healthcare demand by 2/3 and deaths by half but would still result in health systems being overwhelmed, and recommended that countries that were able to implement suppression measures implement these measures. There was no information on model fit and the justification of some key assumptions was lacking. There was little discussion of how the analysis related to previous pandemic models published by the same authors or other groups.

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				the choice between two strategies to address the pandemic: mitigation or suppression.	These limitations do not appear to be commensurate with the magnitude of its impact on public policy. This model relied substantially on model parameters and structure determined in an earlier report published by the same group, and is continually being updated by the group as new data emerges. It is recommended that users scrutinise the earlier report and that the follow-up reports are reviewed in future tranches.

5 Conclusions

The papers reviewed in the first tranche were mostly those that were published toward the early stages of the COVID-19 outbreak, and they have been instrumental in gaining an understanding of the spread of the pandemic in specific locations, especially when there was little or poor quality data available. However, no single robust model could be identified through this review that:

1. shared similar objectives,
2. was applicable to multiple locations, and
3. had reliable parameters or results, regardless of whether they have been peer reviewed.

The majority of the models (7 out of 11 models) applied the SEIR model or variations of this model for projecting the expected cases. No other types of projection models were used by these papers. This reflects the wider ubiquitousness of SEIR models in the forecasting of COVID-19 cases. The remaining models focused on analysing past trends (2 models), estimating the value of the reproductive number R (1 model) and assessing the impact of a health risk factor on COVID-19 outcomes (1 model). Of the 7 projection models reviewed, the model by Johns Hopkins University seems to provide the greatest support for its choice of parameters, although this model was limited to the investigation of the impact of passenger screening strategies in airports. The remaining 4 non-projection models were based on data from populations ranging from 4 cases to a cohort of 3 million people.

In the months of March to May 2020, it became evident that government policies in at least the US and UK were informed by the Johns Hopkins and Imperial College models, perhaps as a consequence of their analytical design (projections of the effect of different interventional scenarios). We will continue to monitor model updates from these groups and their impact on government policy. Additionally, we will look out for the emergence of other influential models, and input from IFoA members on the up-to-date models that they find most useful in their actuarial work is also welcomed.

6 Further references

The model reviews summarised in this report are also available on the PAN1 website: https://icat-pan1.ifoagroups.org.uk/. In addition to the detailed reviews, this website also contains further details on the PAN1 workstream and the methodology for the review process. The website will be continually updated with model reviews in future tranches.