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A modelling perspective

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A case for ongoing structural support to maximise infectious disease modelling efficiency for future public health emergencies: A modelling perspective

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ABSTRACT

This short communication reflects upon the challenges and recommendations of multiple COVID-19 modelling and data analytic groups that provided quantitative evidence to support health policy discussions in Switzerland and Germany during the SARS-CoV-2 pandemic.

Capacity strengthening outside infectious disease emergencies will be required to enable an environment for a timely, efficient, and data-driven response to support decisions during any future infectious disease emergency.

This will require 1) a critical mass of trained experts who continuously advance state-of-the-art methodological tools, 2) the establishment of structural liaisons amongst scientists and decision-makers, and 3) the foundation and management of data-sharing frameworks.

1. Background

In the three years since December 2019, the global spread of SARS-CoV-2 has resulted in more than 650 million recorded COVID-19 cases and over 6.7 million recorded deaths (World Health Organization, 2023). Data-driven analyses produced by mathematical and statistical models have been used to understand epidemic trends and resource needs and to support policy decisions around the globe (Heesterbeek et al., 2015; Metcalf et al., 2020). These policy decisions included establishing and relaxing non-pharmaceutical interventions (NPIs), vaccination roll-out schemes, and increasing hospital capacity and associated resources. However, the sudden arising of the SARS-CoV-2 pandemic initially led to a time-sensitive, reactive, capacity-strained, and ad-hoc response, mostly feasible through self-funded projects and existing personal connections with government agencies as experienced by the authors. As the pandemic unfolded, in many countries various new networks and data-sharing pipelines formed, leading to valuable collaborations between modellers, healthcare professionals, stakeholders, government officials, health policy decision-makers, and various local, national, and international health agencies. These liaisons should not dilute and disappear, given that the annual probability of occurrence of large-scale global epidemics has been estimated to increase up to threefold in the coming decades (Marani et al., 2021).

Here, we candidly share the experiences of five different modelling and data analysis research teams from Switzerland and Germany that addressed health policy-related questions during the COVID-19 pandemic. We describe the policy-relevant questions addressed by the teams, and summarise the challenges faced.

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Subsequently, we provide a suggestion for long-term public health protection focused on capacity strengthening during the interpandemic phase, including the establishment of structures for modelling initiatives to best support health policy discussions when future infectious disease emergencies arise.

2. Purpose and challenges from five transmission modelling and data analysis approaches

2.1. ICU occupancy forecasting

2.1.1. ETH-Zürich - health geography and policy group

The COVID-19 intensive care unit (ICU) occupancy forecasting model, developed by the Health Geography and Policy group at ETH Zurich, provided near-real time forecasts of ICU occupancy from April 2020 to March 2022 in Switzerland. The outcomes were updated daily on icumonitoring.ch, a public website. The short-term (3- or 7- day) model output was requested by the Swiss Armed Forces (SAF) for allocating medical resources in the country's ICUs, and funded by armasuisse (the procurement branch of the army). The COVID-19 ICU capacity model was a combination of a Susceptible-Exposed-Infected-Recovered model and a neural network model (Delli Compagni et al., 2022). Forecasts were based on hospital-level data on ICU occupancy from the Koordinierter Sanitätsdienst of the SAF, as well as potential covariates (weather, cases, medical personnel data, etc.) (Delli Compagni et al., 2022).

The principal challenge faced in establishing the model was locating data sources within Swiss institutions, and obtaining permissions to use these data. The delays between data request and retrieval stem from the restricted operational capacities made available to different health agencies in times of crisis and rules surrounding data protection. The development of this model was challenged and delayed by the need to increase staff capacity, which was difficult given heightened demand for mathematical modelers and overburdened personnel.

2.2. Scenario analyses

2.2.1. Swiss tropical and public health institute – disease modelling and intervention dynamics group

Per request of the Federal Office of Public Health (FOPH) via the Swiss National COVID-19 Science Task Force, key leads in the Disease Modelling and Intervention Dynamics group of the Swiss Tropical and Public Health Institute (Swiss TPH), University of Basel, addressed a wide range of national-level questions in early 2021, including 'When and by how much can NPIs be lifted when vaccine roll-out starts?' (Shattock et al., 2022). They supported these model-informed scenarios analyses with their newly developed stochastic individual-based transmission model of SARS-CoV-2 dynamics and COVID-19 disease OpenCovid (Le Rutte et al., 2022; Shattock et al., 2022). All data necessary to calibrate and inform their model were publicly available (Shattock et al., 2022). OpenCOVID was developed in late 2020 and early 2021 by the established Disease Modelling unit of Swiss TPH, well known for global health and vaccine modelling for malaria.

The primary challenges faced included time spent building relationships with new collaborators in several health agencies, explaining the models' capabilities, identifying and connecting with other Swiss modelling groups, and writing grants to fund this timely work (OpenCOVID development and use within the Swiss National COVID-19 Science Task Force was supported by PI obtained BRCCH and SNF funding). Moreover, finding additional capable personnel for software development, performing the simulations, and successfully translating the outcomes to aid policy discussions proved difficult. Further challenges included continued timely model adaptations as the pandemic and policy situation evolved, rapid turnaround of required analyses, producing publicly comprehensible graphics in a timely manner, whilst continuing to address questions and deadlines regarding other infectious diseases.

2.2.2. Technical University of Berlin - transport systems planning and transport telematics group

An established human mobility transport model was extended with the agent-based infectious disease transmission model, EpiSim (Müller et al., 2021), and supported the German Government by quantitatively predicting the consequences (especially the R-value) of changing activity participation, including completely closing activity types such as schools or restaurants and testing strategies (e.g., booster vaccination). It was developed by the Transport Systems Planning and Transport Telematics group of Technical University Berlin (TUB), Germany as an expanded version of their well-established person-centric mobile phone data-driven human mobility transport model. The mobility model contained activity chains derived from mobile phone data for as many synthetic persons as German inhabitants. The combined model included different room sizes, air exchange rates, disease import rates, changed activity participation rates over time (originating from mobility data), masks, leisure activities indoors compared to outdoors, and contact tracing. Funding was provided by the German Federal Ministry of Education and Research for a duration of four years.

A major challenge was keeping the model updated in real time to the continuously changing epidemic landscape, which included the change of seasonality, the arrival of new tools such as rapid tests and vaccinations, and the arrival of novel (but limited or incomplete) data for model quantification (e.g. on infections via aerosols). Another challenge was the added time-consuming and challenging issues around communication and preparation of model results for decision-makers and media. At the beginning of the pandemic the TUB modelling group was very well known for its transport simulation, but not for the integration of epidemiological processes. By the Alpha wave their work of integration transport with epidemiological processes had become well known and was fully integrated into the German decision making for pandemic policies.

2.2.3. ETH-Zürich - transport planning group

Agent-based transport model MATSim was also paired with EpiSim (Müller et al., 2021) at the onset of COVID-19. However, due to limited access to data this model was limited in its ability to provide support regarding COVID-19 behavioural measures and policy discussions in Switzerland. MATSim has been developed by the transport planning group at ETH-Zurich and was extended to allow changes of activity patterns and mobility behaviour due to implemented COVID-19 measures and disease incidence. The extension created a loop, where EpiSim provided the statistics on the pandemic progress (i.e., infection, hospitalization rates) which fed into the behavioural part of the MATSim transport model. Data to feed into MATSim regarding Swiss road networks (Openstreetmap) and public transport schedules (HAFAS) were openly available, however Swiss population census data (2018), a national one-day travel survey (2015), and commuting matrices, were only available upon request. The Oxford Stringency Index was used as input for the reduction of effective contacts between individuals in the MATSim model.

Initially, the main challenge was that the understanding of the population-wide behavioural change due to COVID-19 was limited. This difficulty was partially overcome with a GPS-tracking survey collected by ETH. However, the main constrain in using the model for its intended purpose was access to additional data sets to improve the population model (i.e., health index survey, information on the behavior of children and elderly).

2.2.4. Fachhochschule Nordwestschweiz

Similarly, an agent-based transport model of the trinational region of Basel was paired with EpiSim. This model was applied to analyse the impact on SARS-CoV-2 incidence of changed activity participation rates over time, e.g., due to school closures and contact reductions (Mesaric et al., 2022). It was also used to spatially differentiate the impact of NPI's, including border closures for certain types of activities, including leisure and shopping. The transport model was developed at Fachhochschule Nordwestschweiz and based on a synthetic population representative for the spatial and sociodemographic distributions of residents covering an area of 5461 km^2 across parts of Switzerland, Germany, and France. The extent to which effective contacts were reduced in the model was based on a combination of Google Mobility Reports and the Oxford Stringency Index.

The main challenge in analysing the impact of spatially fine-grained control measures was a lack of data. Spatially more granular information on hospitalization rates and data on changing mobility patterns (e.g., derived from mobile cell tower records) could have better described the impact of the mitigation measures on mobility flows and disease import between countries. Pre-existing contacts among policymakers and researchers within and across countries would have facilitated access to existing spatially fine-grained datasets and enhanced the exchange of knowledge on modelling approaches, ultimately leading to improved coordination and evidence-based decision making in the trinational region.

3. Summary of challenges

The main challenges during the SARS-CoV-2 outbreak as experienced by five modelling and data analysis teams across Switzerland and Germany can be categorised in five key points: A), the lack of formal, pre-existing connections between research groups, policy makers, the media and the public, within and between countries, B) limited access to critical mass of qualified and trained experts in academia and health-agencies, C) the need for high-speed ad-hoc model development and adjustments, D) restricted access to essential disease and population data, and E) limited funding to address sudden and time-sensitive questions at the highest scientific level. These challenges led to unnecessary delays in responses, and were also distressing to the researchers involved. They would best be addressed by setting up national and international structures as further outlined below and summarised in Box 1, and stressed by fellow COVID-19 researchers (Saqr and Wasson, 2020). Both challenges and recommendations are visualised in Fig. 1. These challenges overlap with the experiences of many other COVID-19 modelling groups around the world, ranging from a lack of formal data sharing policies (Nixon et al., 2022; Tacconelli et al., 2022) to interpretation challenges of modelling output (McCaw and Plank, 2022; Nixon et al., 2022). Additional challenges include and are not limited to publishing academic papers alongside providing policy advice and the constant need for parallel modelling outputs per policy question. (Brooks-Pollock et al., 2021).

4. Recommendations

1) **Established liaisons** amongst research teams, policy makers, the media and the public are required to ensure safe and swift knowledge and data transfer, correct interpretation and understanding of modelling output, rapid responses, and trust when assisting government agencies in decision-making. Which was also flagged as one of the main challenges by COVID-19 modelling teams in Australia and New Zealand. (McCaw and Plank, 2022), highlighting the global relevance of this recommendation. Further, modelling and data analytic trained experts employed by health agencies can support the use and provisions of quantitative evidence for decision making allowing them to efficiently inform the input and interpret the output of the modelling teams. The members of this liaison should be equipped and trained through simulation workshops for handling epidemics in non-crisis situations both nationally and internationally at regular intervals. For example, in the United Kingdom (UK), the head of the Modelling & Economics Unit of the UK Health Security Agency, also holds a part-time position at the Department of Infectious Disease Epidemiology, at Imperial College London.
2) **Critical mass** of trained and employed experts need to be attuned to respond to infectious disease emergencies when needed, with relevant expertise that ranges from core technical scientific knowledge to translating scientific outcomes to policy makers, the media, and the public. Coordinated advancement is required, within and between countries, of methodological approaches and tools to allow diverse challenges to be addressed outside emergencies. Having the right people in the right place for the next infectious disease emergency, both within health agencies and academic settings, will allow for swift and thorough scientific output that is well articulated to inform policy discussions. Clear research groups, funding, and career structures will allow these experts to pivot their work accordingly when novel infectious disease emergencies arise. An example being the newly formed 'Center for Forecasting and Outbreak Analytics' which exists within the United States Centres for Disease Control and Prevention (US-CDC), using data, modelling, and analytics to respond to outbreaks in real-time to drive effective decision-making.
3) Establishing a formal legal framework of **data pipelines and access** is essential for data sharing within and between public health agencies and the scientific community during non-emergent times, which can be easily and immediately activated in the event of an emergency. Such an agreement would create accountability between the parties and prevent conflict of interest on the release of epidemic data. The form of the agreement will need to be defined and ideally address data format, security, and adaptations given decision and health policy needs. The agreement also needs to address disclosure of the data for model validation and replication and its publication in scientific literature or public communication platforms while preserving patient confidentiality. Other European research teams have provided similar data suggestions after their COVID-19 responses, including mandatory standards for data collection in funding frameworks; training and capacity building for data owners; cataloguing of international use of metadata standards; and dedicated funding for identified critical areas. (Tacconelli et al., 2022)

5. Conclusion

Appropriate structures at the national and international level are necessary within governmental health and emergency agencies if there is a need for efficient quantitative modelling support during health crises for policy decision making. Ongoing investments and establishment of much-needed communication and expertise networks offers advancement of methodology and collaborations, allowing the right people with

Box 1
Recommendations for proactive and sustained structures for multidisciplinary infectious disease teams at national and international levels outside of infectious disease emergencies.

1. Establishment of **structural liaisons** amongst scientists and decision makers,
2. Funding of a **critical mass of trained experts** to be employed for continuously advancing state-of-the-art methodological tools, and
3. Development and management of **data sharing frameworks**.

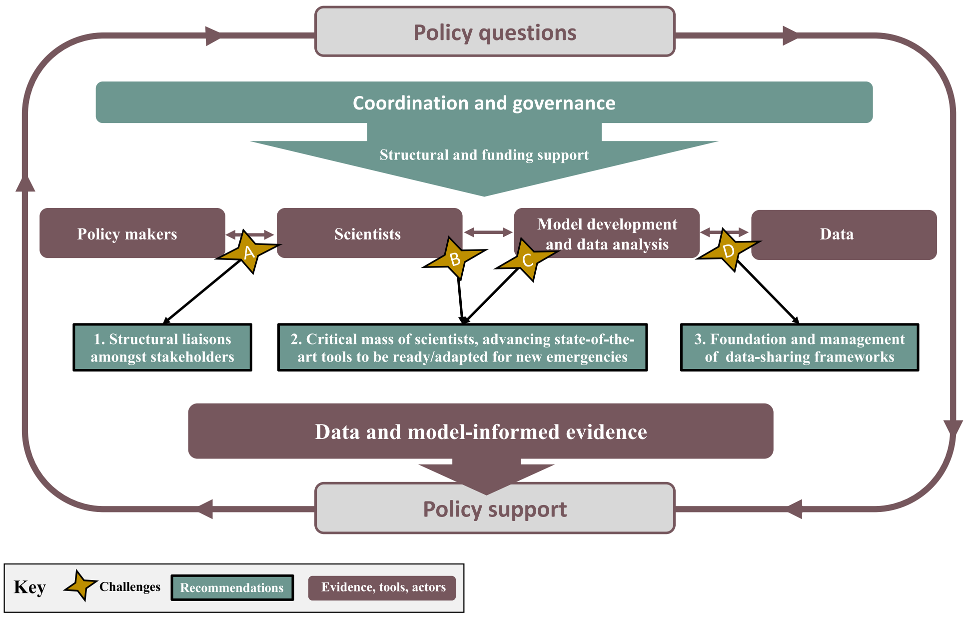

Fig. 1. Schematic overview of the challenges identified and recommendations to counter the challenges and strengthen capacity for data and model-informed evidence to support policy, outside infectious disease emergencies. The challenges include; A) lack of formal, pre-existing connections, B) limited access to trained experts, C) need for high-speed ad-hoc model development, D) restricted access to disease and population data.

the right tools and connections to be at the right place to serve the public in times of health crises.

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I certify that all authors have seen and approved the final version of the manuscript. as submitted. This article is original work by the authors, which hasn't been published anywhere prior, and isn't under consideration for publication elsewhere.

CRediT authorship contribution statement

Epke A Le Rutte: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Andrew J Shattock**: Conceptualization, Visualization, Writing – review & editing. **Cheng Zhao** : Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Soushieta Jagadesh**: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Miloš Balać**: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Sebastian A. Müller**: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Kai Nagel**: Conceptualization, Validation, Writing – review & editing, Supervision. **Alexander L Erath**: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Kay W Axhausen**: Conceptualization, Supervision, Validation, Writing – review & editing. **Thomas P Van Boeckel**: Conceptualization, Supervision, Validation, Writing – review & editing. **Melissa A Penny**: Conceptualization, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of Competing Interest

None, the authors have no relevant financial or non-financial interests to disclose.

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