

# Canadian Emerging Infectious Disease Modelling

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## 1 Overview of the Field

Infectious disease modelling, in its modern form, encompasses expertise in key areas such as One-Health, infectious disease forecasting, behaviour, genomics, evolution, and economics. Modellers provided essential support during the COVID-19 pandemic, answering critical questions like: How will case numbers change, and will we have sufficient hospital capacity? What are the projected impacts of travel restrictions? How effective are potential interventions and what are their costs and harms?

The Canadian Infectious Disease Modelling (CEIDM) group evolved out of five Emerging Infectious Disease Modelling (EIDM) networks funded by NSERC and PHAC in 2021, and the CIHR-funded CAMEO network. The broad network, of over 100 researchers, consistently demonstrated its capacity to provide rapid, policy-relevant, insights during the COVID-19 pandemic.

We have identified structural and research gaps, which, if resolved, will support Canada to be prepared for future pandemics and infectious disease emergencies. In our BIRS Now! workshop, we came together to articulate these gaps, to briefly summarize what the modelling community accomplished in the COVID-19 pandemic, and to outline what CEIDM's plans are as a network, particularly if we are successful in our proposal to the Canadian Institute for Health Research (CIHR)'s Pandemic Preparedness call.

## 2 Modelling in the COVID-19 pandemic

Our network provided extensive support through the COVID-19 pandemic, and one aspect of our BIRS Now! workshop was to concisely summarize what was done and what gaps remain. We found it helpful to note that most pandemic-related modelling can be considered to be under two broad umbrellas: *risk and surveillance*, and *response and intervention*.

Under the risk and surveillance banner, models seek to characterize risk (geographically, in terms of social, demographic and clinical factors, risk to economic and social activities, risk as related to ecology, agriculture or climate) and interpret infectious disease surveillance data. CEIDM developed tools – both new theory, and accessible software implementations – that addressed numerous questions from decision-makers. These include: Where are novel pathogens with pandemic potential most likely to arise? Can travel restrictions prevent the establishment of community transmission? How many people would be infected if transmission becomes established? Will we have enough hospital capacity? What are the broader risks to health and wellbeing?

Under the response and intervention umbrella, models address scenarios, forecasts, and the likely results of interventions. CEIDM addressed questions from health-governing bodies that included: How will interventions like isolation, quarantine, masks, social distancing, school closures, travel measures, or vaccination

affect disease and hospitalization forecasts? What are the economic and social harms of these interventions? Will the spread of new variants affect these forecasts?

### 3 Key Knowledge Gaps

We identified three major knowledge gaps that were highlighted during the COVID-19 pandemic:

1. **Economics and Behaviour:** Pandemics disrupt economies at every level, and public health and individual responses have cascading effects across sectors. These effects influence everything from household income and consumer behaviour, to education and workforce productivity, to supply chains and economic stability. Despite recognition of this complexity, behavioural and economic factors are not well integrated into epidemiological models of pandemic risk and response.
2. **Pathogen Evolution:** Evolution can cause the spread of new pathogen genotypes into populations and can undermine our interventions through vaccine and immune escape, resistance to therapeutics, and other adaptations. Modelling tools that address these concerns are limited. There is also a lack of effective forecasting tools that can be used to design intervention strategies accounting for evolution.
3. **One-Health:** Climate-driven change in ecosystems, coupled with an increasing human population size has resulted in a growing concern over zoonotic spillovers and the potential for another pandemic. In Canada we face risks from both emerging and reemerging pathogens (e.g., H5N1, Lyme disease, SARS-CoV-2). Validated models of multi-species interactions and environmental drivers are needed to inform risk and response strategies.

We propose to address these knowledge gaps in the following ways.

**Economics and behaviour:** Supporting risk and surveillance, CEIDM will produce economic models that can be rapidly integrated into epidemiological analyses to estimate the economic consequences of pandemics and public health policy. This includes models of macroeconomic and productivity impacts at the local, provincial, and national levels, and by industry. It also includes models for estimating the consequences of other measures, such as school closures, on education outcomes, market fundamentals, and on labor markets, inequality, and economic growth. CEIDM will collaborate with iCARE, a platform gathering behavioural data, and use data on behavioural responses to public health messaging and pandemic circumstances to build a behaviour-informed model of risk, risk inequity and inequitable impacts.

We will expand CEIDM's suite of behavioural and economic models that can be integrated into established epidemiological frameworks and rapidly adapted and applied to any public health scenario. This includes refining and expanding the suite of fit-for-purpose tools to help compare the cost-effectiveness of alternative vaccination rollouts and NPI. We will update and make more widely available analytical dashboards that incorporate these models and ensure that these frameworks are not only informative during a crisis, but also when considering policies to prevent future crises.

**Pathogen evolution:** CEIDM will leverage recent advances in deep mutational scans to model risks associated with the emergence of new variants. In SARS-CoV-2, these data tell us which mutations are likely to evade immunity, and which improve cell binding. In H5N1, they tell us which mutations affect viral binding preferences, cell entry, and protein stability at low pH. CEIDM will build models that connect this information with genomic surveillance data and within-host models to forecast the risks associated with different genotypes of emerging and re-emerging infectious diseases. This will characterize the evolutionary risk of pandemics.

CEIDM members developed models that successfully predicted elements of SARS-CoV-2 evolution during the pandemic, but accurate forecasting that accounts for evolutionary change remains a challenge. To address this, CEIDM will couple population-genetic models of infectious diseases and genomic surveillance tools, with macpan2 to provide a simple, operationalizable, forecasting and response tool that incorporates pathogen evolution. This work aligns with ongoing international collaborations in France and at the Big Data Institute in the UK

**One-Health:** Multispecies models will be used to estimate the epidemiological risk of zoonotic pandemics, complementing the work on evolutionary risk. These models will be grounded in empirical data using our One-Health data portal, genomic surveillance, data from farms and wildlife, and environmental

monitoring. We will cross-reference data sources with occurrences of zoonotic spillover events to identify environmental and human conditions that facilitate spillover. In this process we will likely encounter substantial data gaps, where additional information would be of high value for understanding risk. These needs will be brought to our partner network in the One Health area.

The knowledge gaps in One Health regarding response and intervention stem from our insufficient understanding of how to effectively manage the ongoing circulation of pathogens with significant zoonotic potential in non-human populations. The current H5N1 outbreak is illustrative. In some situations, culling animals, treatments, and prophylaxis (preventative treatment) are all plausible options for livestock and other domesticated animals, as is prophylaxis of people having high contact with these populations. CEIDM will develop One Health models of these interventions to determine their short- and long-term epidemiological and economic impacts.

## 4 Outcome of the Meeting

Having outlined key gaps, and the major areas in which the gaps are situated, our group developed a proposal and submitted it to CIHR on the February 4, 2025 deadline.

CEIDM's Proposed Activities include:

1. Develop a centralized Digital Modelling Infrastructure including: (a) a portal of models that are documented, validated, and ready, with data connections to wastewater, genomic surveillance, serological surveillance; (b) a digitized historical data archive, supporting model validation; (c) a searchable database of expertise forming a 'reserve' of Canadian experts ready to assist decision-makers.
2. Integrate the network and train students and postdoctoral fellows, filling the knowledge gaps in behavioural science and economics, evolution, and One Health. We planned a series of week-long workshops and other network events and operations.
3. Knowledge translation and capacity-building, though partnering with the National Collaborating Centre for Infectious Diseases (NCCID) and other knowledge translation activities. We will produce articles, summaries, reports, videos, and infographics to improve understanding of math modelling for public health.

The network, however it proceeds in the years ahead, is likely to continue to have impact. CEIDM has already provided critical support to federal and provincial decision-makers during COVID-19. By maintaining a national reserve of modeling expertise and data-ready tools, CEIDM ensures rapid, evidence-based responses to future health crises. We proposed an inclusive governance structure for CEIDM, to ensure accountability and transparency. CEIDM emphasizes open science and the creation of a transparent evidence base. Governance and management will also support equity, diversity, and inclusion (EDI) in all aspects of recruitment and retention and in embedding EDI in research.

The BIRS Now! workshop was a focal point of this effort, allowing the creativity, collaboration and intensity of effort that can only happen at an in-person meeting.