Modelling Travel-Capable Infectious Population for a Transport-Based Early Warning System

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Abstract

Global connectivity allows for the possibility of infectious diseases to spread internationally before local surveillance systems recognise sustained transmission. Public health authorities must therefore consider novel disease importation risk alongside local known threats.

Existing early warning systems draw on diverse data streams, including clinical and hospital reporting, syndromic and digital indicators, meteorological or environmental variables, social media signals, and wastewater monitoring. These systems can detect anomalous patterns and generate timely warning signals, but are designed primarily for the detection and forecasting of infectious diseases originating within their own population, ignoring those imported from abroad. Moreover, such systems are rarely designed to generate mechanistic projections of infectious disease prevalence in endemic countries for use in mobility-based importation risk assessment. In this context, transport-based early warning systems can complement existing tools with an emphasis on importation threats.

In parallel, compartmental models that incorporate travel and border measures commonly model infectiousness using a single or a small number of aggregate infectious stock variables. They implement mobility through flows, restrictions, or quarantine assumptions, but usually do not provide a dedicated travel-relevant infectious prevalence metric as a modular output for early warning systems.

In this study, we develop an SEIR System Dynamics model of infectious disease transmission in a region of concern, using mpox from the Democratic Republic of the Congo, where mpox clade I is endemic, as a case study. This model distinguishes presymptomatic, asymptomatic, mild symptomatic, and severe symptomatic infectious population stock variables. We define a travel-relevant travel-capable infectious population as the subset of infectious individuals assumed to remain capable of travel following infection, based on light or no symptoms; we use this quantity as the primary model output. Although the case study focuses on mpox, the modelling framework is formulated to be disease-agnostic for human-to-human transmission. We parameterise the model to epidemiological data from the DRC, supplementing with information from neighbouring countries where existing data are sparse, and generate time-varying estimates of travel-relevant infectious prevalence. These estimates can serve as upstream inputs to early warning systems and can support prioritisation of targeted surveillance, such as wastewater sampling along high-risk routes.

As a component of an early warning system, the travel-relevant infectious prevalence estimated for the region of concern provides the origin-side input to a transport-based importation risk assessment. For each conveyance leaving the region for a given destination, whether an aircraft or a seagoing vessel, this prevalence sets the probability that one or more travel-capable infectious individuals are on board at departure; combined with transport network data such as flight or shipping schedules, passenger or crew number estimates, and journey durations, together with a model of within-journey transmission, it yields the probability that a transmissible case is still present on arrival. Because journey times range from hours by air to weeks by sea, the same origin-side estimate supports importation risk across both modes, with the within-journey component capturing how the chance of an onboard case surviving to arrival declines with travel time. These per-route and per-conveyance estimates can then prioritise limited surveillance at points of entry, for example, by ranking incoming flights or vessels and by guiding wastewater sampling at airports and seaports. The SEIR model thus serves as the upstream, origin-side component of our early warning system, supplying the time-varying importation pressure that downstream transport and detection models translate into targeted surveillance priorities.

Keywords: System Dynamics, Early Warning System, Infectious disease modelling, wastewater-based epidemiology