Participatory Mathematical Modeling Approach for Policymaking during the First Year of the COVID-19 Crisis, Jordan

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We engaged in a participatory modeling approach with health sector stakeholders in Jordan to support government decision-making regarding implementing public health measures to mitigate COVID-19 disease burden. We considered the effect of 4 physical distancing strategies on reducing COVID-19 transmission and mortality in Jordan during March 2020–January 2021: no physical distancing; intermittent physical distancing where all but essential services are closed once a week; intermittent physical distancing where all but essential services are closed twice a week; and a permanent physical distancing intervention. Modeling showed that the fourth strategy would be most effective in reducing cases and deaths; however, this approach was only marginally beneficial to reducing COVID-19 disease compared with an intermittently enforced physical distancing intervention. Scenario-based model influenced policy-making and the evolution of the pandemic in Jordan confirmed the forecasting provided by the modeling exercise and helped confirm the effectiveness of the policy adopted by the government of Jordan.

Jordan reported ≈1.1 million confirmed COVID-19 cases and ≈12,500 deaths by the end of December 2021 (*1*), accounting for ≈6.0% of the total confirmed cases and ≈4.0% of the total number of deaths in the World Health Organization (WHO) Eastern Mediterranean Region (*1*). The COVID-19 epidemiologic curve in Jordan during the first 2 years of the pandemic followed distinct phases that reflected the complex interrelation between the natural evolution of the outbreak and the implementation of public health and social measures (PHSMs), which were also modulated in relation to the COVID-19 vaccination campaign (*2*) and the introduction of different variants of concern.

Jordan was particularly successful in flattening the epidemiologic curve during the first months of the pandemic until April 2020 because of implementation of strict PHSMs (*3*). However, the progressive easing of restrictions resulted in an exponential increase in cases, and the first 2 epidemic peaks in November 2020 and March 2021 led to ≈10,000 confirmed cases per day (*4*). Throughout that and subsequent phases of the pandemic, public health policies focused on reducing COVID-19 transmission and mortality in Jordan were supported by a participatory, epidemiologic scenario-based modeling approach.

We provide an overview of lessons learned and challenges in conducting modeling efforts to simulate the transmission of SARS-CoV-2 in Jordan during the first year of the pandemic. Specifically, we assess the likely effectiveness of different combinations of physical distancing measures, and we describe the approach taken to ensure national level buy-in to the modeling results.

Efficacy of Physical Distancing Interventions

During the earliest stages of the COVID-19 pandemic, in the absence of proven antiviral medication and

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vaccines, PHSMs represented the only option available for reducing COVID-19 community transmission and mortality (*5*). Among the wide variety of PHSMs applied in different settings, physical distancing interventions (PDIs) and curfews were considered among the most effective (*6*). For the purpose of our analysis, we considered PDIs to be interventions that require persons to maintain a physical distance of ≥1 m from other persons in all essential services (e.g., services conducted by grocery stores and healthcare facilities) and the closure of public places. The purpose of such interventions was ultimately to reduce the probability of COVID-19 transmission among persons (*7*). Evidence on the importance of this variety of PHSMs in limiting the transmission of COVID-19 emerged in Europe and Asia (*8*,*9*) and in the United States, where school closures have been found to reduce COVID-19 incidence and mortality rates by as much as 60% (*10*). Of note, several PHSMs, including PDIs, were substantially more effective when implemented while incidence rates remained low (*11*).

However, PDIs are unsustainable and may have wider-reaching detrimental effects. For example, home confinement considerably increased the rate of domestic violence in many countries, affecting women and children the most (*12*), and limited access to essential services for vulnerable populations (*13*–*17*). Therefore, tailored interventions that maintain persons' livelihoods and keep economies functional while protecting persons at high risk need to be considered (*11*).

Curfews and Physical Distancing Interventions in Jordan

The PHSM strategy adopted in Jordan included imposing a nightly curfew (6 hours) from 12 AM to 6 AM, closing schools and universities, increasing community awareness of hygiene and enforcing a mask mandate in public places (*18*), and prohibiting mass gatherings (*19*). Community transmission in September 2020 triggered the imposition of an intermittent PDI, enforced on Fridays and Saturdays, lasting for 4 weeks. Shortly afterwards, physical distancing was only enforced on Fridays during October 2020–January 2021 (Figure 1). On those Fridays, all city activities, shops, and public places had to be closed (*19*). Furthermore, leaving the house was prohibited, except for persons who held a permit, such as healthcare personnel. Restrictions on other days of the week

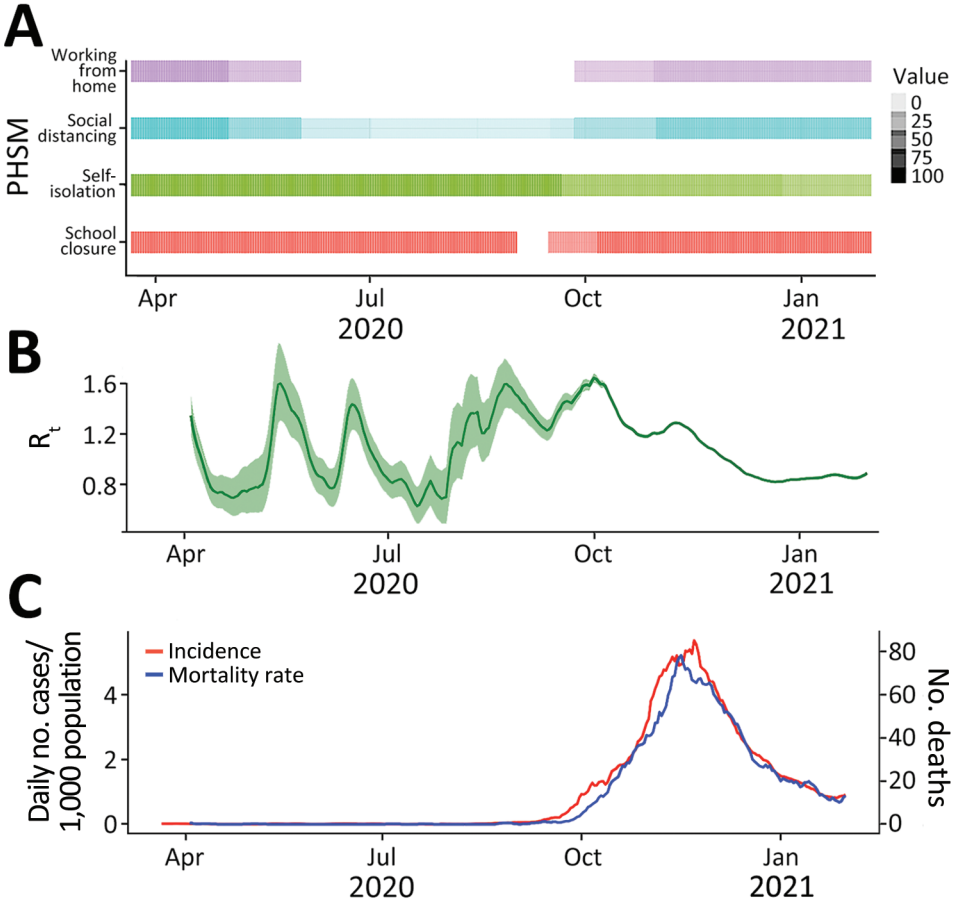

Figure 1. Epidemiologic indicators and PHSMs in a COVID-19 modeling study, Jordan, March 2020–January 2021. A) Timeline of implemented PHSMs. Colors indicate individual PHSMs; level of shading represents the coverage of each intervention in the timeline, ranging from 0% to 100%. B) Estimated R_t, calculated using the EpiEstem package in R (https://CRAN.R-project.org/package=EpiEstim), which presents the number of new case-patients infected by an average case-patient at time t. Green shading indicates 95% CI. C) Daily incidence and mortality rates for COVID-19 in Jordan. PHSM, public health and social measure; Rt, effective reproduction number.

consisted of a 6-hour curfew period after midnight (from 12 AM to 6 AM), with no restriction on persons' movement during the rest of the day (*19*). Such a unique approach was debated, and physical distancing for 1 day a week was questioned in terms of its healthcare benefit based on evidence (*20*).

The Jordan Ministry of Health, with the support of WHO, launched 3 rounds of a nationwide seroprevalence survey from the onset of the pandemic through the beginning of 2021. Findings revealed that seroprevalence steadily increased over time; only a tiny fraction of persons were seropositive in August 2020 (0.3%), a more than 20-fold increase was observed by October 2020 (7.0%), and up to one third of the overall population had been exposed by January 2021 (34.2%) (*4*).

Using Mathematical Modeling in Decision-Making

In the context of infectious diseases, epidemiologic models play a critical role in anticipating the transmission of the disease and driving public health policies designed to limit illness and death (*21*). Specifically, epidemiologic models represent a tool for policy makers to design and evaluate targeted interventions. To do so, a range of factors specific to a setting are taken into consideration, such as demographic features, healthcare capacity, and the concurrent interaction among multiple PHSMs. When limited data are available, mathematical models can provide key elements to decision-makers on the effect of various future policy scenarios (*22*,*23*).

In Jordan, including relevant country stakeholders at each stage of the modeling process ensured that data were reliable and accurate and that the analysis was focused on addressing specific policy questions (*24*,*25*). The senior management of the Ministry of Health requested a series of scenarios on a regular basis (on average, once every 5–6 weeks) and worked directly with WHO to run the model and present the model's findings to inform high-level and evidence-based decision-making. Starting after the second modeling round in October 2020, the Strategic Planning Department of the Jordanian Royal Hashemite Court supported those modeling techniques and bolstered them by expanding data availability, which was critical to initiate the process.

Model Selection

At the onset of the pandemic, the WHO Jordan Country Office approached the Minister of Health to propose the use of mathematical modeling to estimate the epidemiologic outcomes under different scenarios. We selected and adapted the COVID-19 International Modeling Consortium (CoMo) model for implementing mathematical modeling analysis because of its suitability for conducting modeling analysis in low- to middle-income countries (*26*) and because it provided other desirable features, including the ongoing support from CoMo (*26*), an active team of software developers, and epidemiologic modelers. Additional resource requirements for implementing our participatory modeling approach were minimal (e.g., a stable internet connection, the R open-source statistical software [The R Foundation for Statistical Computing, https://www.r-project.org], and standard desktop applications).

The CoMo model is an age-dependent, deterministic, susceptible–exposed–infectious–recovered compartmental design that models transmission of SARS-CoV-2 in the population and can be used to estimate the relative effect of various PHSMs (Appendix, https://wwwnc.cdc.gov/EID/article/29/9/22-1493-App1.pdf). The model considers 5 levels of infection severity: asymptomatic, symptomatic, infections requiring hospitalization, infections requiring intensive care treatment, and infections requiring ventilated intensive care treatment. Infection severity and associated mortality rates are age-dependent, in that the proportion of infected persons requiring hospitalization and the proportion who die varies with age. In addition to predicting case and death rates at various timepoints, the CoMo model also incorporates 2 submodels: hospital and critical care requirements and implementation of public health and safety measures. The CoMo model incorporates a hospital submodel that suggests when hospital and critical care requirements will exceed the capacity of the country's healthcare system (e.g., in terms of hospital beds, intensive care units, and ventilators available for use).

Participatory Modeling of the COVID-19 Pandemic in Jordan

Participatory modeling approaches engage a range of stakeholders from academia, public health sectors, and government throughout the entire modeling process and promote the translation of model results into public health decision-making (*27*). We applied the participatory modeling process developed by WHO's Eastern Mediterranean Region Office (EMRO) modeling support team to analyze the COVID-19 pandemic in Jordan. Specifically, WHO EMRO established a modeling support team in mid-March 2020 as part of the information management component within its COVID-19 Incident Management Support Team with the objective of addressing imminent decision-making needs and promoting awareness of how models work (*24*). When approaching the Minister of Health at the onset of the pandemic, the WHO Jordan Country Office proposed the use of the CoMo model.

The participatory modeling began, therefore, with an initial meeting to communicate the modeling methodology and develop common expectations regarding the outcomes of the modeling exercise. The participants of this process included the WHO Jordan Country Office, the Minister of Health of Jordan, the Ministry of Health Secretary General for the COVID-19 portfolio (appointed to oversee COVID-19 response in Jordan), epidemiologic modeling researchers from the University of Oxford, and mathematical modelers, surveillance officers, and policy analysts from WHO EMRO. Although no specific declaration of interest was signed, there was no remuneration for any stakeholder.

We collected input parameters for the CoMo model by using a standardized template (developed in Excel [Microsoft, https://www.microsoft.com]) accompanied by a guidance document describing the model parameters and their definitions. We conducted 3 rounds of modeling analysis over a period of ≈3 months (November 2020–February 2021).

The participatory modeling process was instrumental in meeting recommended standards of practice associated with mathematical modeling for public health decision-making. Throughout the continued engagement of participants, communication of model uncertainty was reinforced, and key aspects of uncertainty, such as parameters related to viral transmission, were identified. Model outputs were routinely discussed among partners; satisfaction around model outputs paved the way for codevelopment of modeling results in the policy and decision-making process. In addition, patterns of reported and modeled COVID-19 disease and mortality were used for discussions regarding public health surveillance to identify possible challenges and misreporting of COVID-19 with specialists at the Ministry of Health, concerns that were evident from the experience of COVID-19 collaborative modeling in the Philippines by the WHO Western Pacific Region Office (*28*).

The participatory process helped to define the context for the modeling exercise, including questions of importance to policymakers, and make it easier to collect country-specific model inputs (Appendix). Those communications also were productive in developing interpretations of the analysis that were relevant and useful to all participants.

Scenario-Based Modeling of the COVID-19 Pandemic in Jordan

We considered 4 scenarios in the analysis: the baseline scenario and 3 other scenarios (A, B, and C). All scenarios considered interventions that were designed to reduce the rate at which persons come into contact with each other, stemming COVID-19 transmission in Jordan. Common to each scenario are 2 parameters that can be used to define the extent of the PDI: coverage and adherence. Coverage refers to the percentage of the population that is following physical distancing regulations; adherence refers to the extent individual persons follow those guidelines. An intervention with low adherence but high coverage would mean that most of the population loosely follow the physical distancing regulations. Conversely, an intervention with high adherence but low coverage would mean a small percentage of the population follow the physical distancing regulations to a high standard. All other parameters in the model were held constant throughout the duration of the simulation. We developed the scenarios considered through an iterative process of engaging with relevant policy makers, updating the scenarios as more information became available (since the last analysis), and adapting the scenarios to reflect the effect of potential future changes to PHSMs.

The baseline scenario considers the situation of no government intervention but assumed 50% of the population would continue to physically distance themselves. This percentage was suggested by public health experts in Jordan and is in line with available literature (*29*). Scenario A assumed the Jordan population would physically distance themselves for a period of 24 hours every Friday (considering Friday prayer observance), applying to all but basic services, such as hospitals and grocery stores. No government restrictions were assumed to be imposed on the other days of the week, yet, as in the baseline scenario, we assumed a portion of the population (50%) would continue to practice a degree of physical distancing regardless of government guidelines. Similarly, scenario B is an extension of scenario A in that all but essential services were required to close over the entire weekend, reducing contacts as much as possible. Last, scenario C, being the most extreme scenario considered in our analysis, assumed all but essential services were closed for the entire week until the end of the simulation period. Consistent across each scenario we assumed the interventions came into effect on October 31, 2020, and lasted until the end of the simulation period on January 31, 2021.

Estimated Effect of Continuation of Planned Measures on Health Outcomes

The timing of the predicted peak incidence, which was estimated to occur in mid-November 2020, varied only marginally across the different scenarios

(Figure 2, panel A). However, soon after the interventions in scenarios A, B, and C were implemented, their effect was observed in reduced incidence (Figure 2, panel A) and cumulative mortality (Figure 2, panel B). Unsurprisingly, the most impactful scenario was scenario C, where a sharp and rapid reduction in cases and deaths was predicted to occur shortly after implementation. However, the economic cost of such an intervention would likely have been substantial for the population.

Exploring Variation in Efficacy of Different Scenarios

We estimated the effect of scenarios A, B, and C in terms of the percentage reduction of COVID-19 cases and deaths during November 2020–January 2021 relative to the baseline scenario (Figure 3). The coverage of the PDI in each scenario was assumed to only be relevant during the days of the week the intervention was enforced. During the nonintervention days of the week, we assumed 50% of the population continued to practice physical distancing regardless of government guidelines. Consistently across each scenario, the model estimated that the greatest reduction in COVID-19 incidence and death was associated with increasing adherence to the respective physical distancing guidelines implemented by the government. When the adherence of the population was low, increasing the coverage of the PDI had relatively little effect on reducing disease. Conversely, however, if the adherence of persons who follow government regulations was high (>80%), the model estimated that increasing the coverage of the population had compounded effects on reducing COVID-19 disease incidence and death.

The greatest effect was observed under scenario C, with high coverage and high adherence (97% reduction in cases and deaths relative to the baseline scenario, assuming 100% coverage and adherence). However, assuming adherence and coverage >90% for either scenario A or B, the model predicted that reported cases and deaths would have reduced by ≈90% relative to the baseline scenario. In contrast, any scenario (either A, B, or C) with low coverage (<25%) had almost no effect, decreasing disease incidence and death by as little as 10% relative to the baseline scenario. The difference in disease incidence and death between scenarios A and C equates to roughly 7% fewer cases and deaths (assuming the coverage and adherence are both high [>90%]). As coverage and particularly adherence decreases, diseases incidence and death increase rapidly. Those results suggest that implementing scenario C during October 31, 2020–January 31, 2021, would be only marginally beneficial at reducing COVID-19 disease and death compared with scenario A or B with high coverage and adherence. The findings of our analysis and the subsequent decision-making was supported by epidemiologic and economic modeling for COVID-19 policy in Australia; although tighter

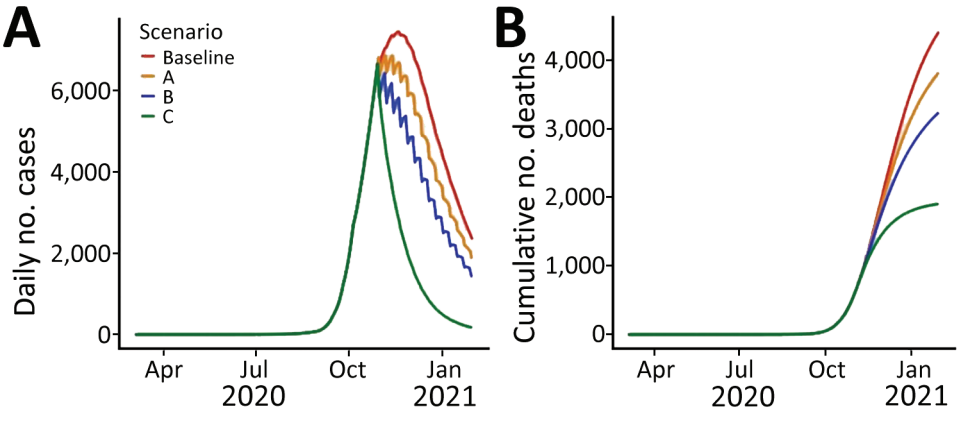

Figure 2. Model-predicted reported number of COVID-19 cases and cumulative number of associated deaths under scenarios A, B, C, and the baseline scenario in a COVID-19 modeling study, Jordan, March 2020–January 2021. Scenario A assumes the entire population, excepting essential services, will physically distance themselves for 24 hours every Friday while reverting to their usual behavior on the other days of the week. Scenario B assumes the population will physically distance themselves for the entire weekend (Friday and Saturday) while reverting to their usual behavior throughout the week. Scenario C assumes the entire population, except for essential services, will physically distance themselves for the entire week while never reverting to their usual behavior. Baseline scenario assumes no government intervention and half the population instinctively physically distancing themselves to avoid infection. Common to each scenario are 2 parameters used to define the extent of the physical distancing intervention: coverage, which refers to the percentage of the population following physical distancing regulations, and adherence, which refers to the extent to which individual persons follow those guidelines. On days when the interventions are not enforced, simulations assume 80% adherence and 50% coverage of the population practice physical distancing, while on days when the interventions are enforced it is assumed that 80% adherence and 90% coverage of the population physically distance themselves.

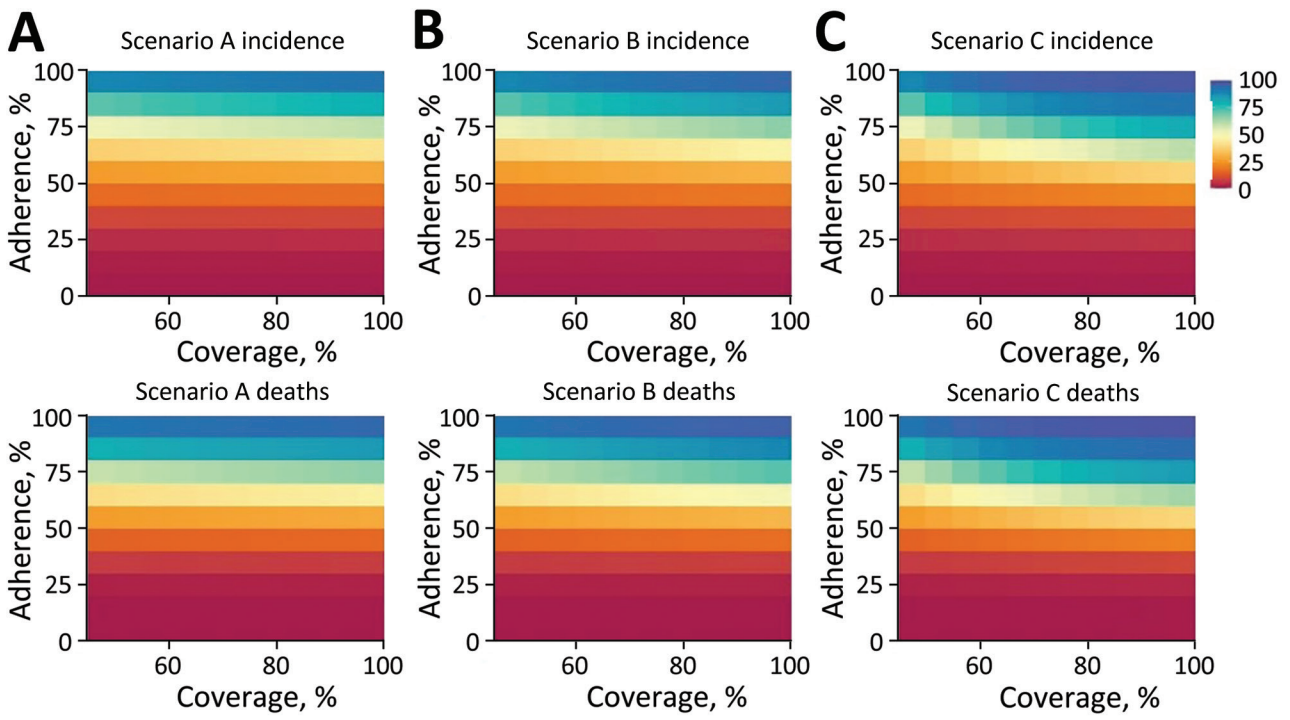

Figure 3. Model-predicted heat map showing percentage reduction in COVID-19 incidence (top row) and deaths (bottom row) in a COVID-19 modeling study in Jordan under 3 different scenarios (A, B, and C), relative to the baseline scenario, aggregated for the period November 2020–January 31, 2021. Dark blue corresponds to nearly 100% reduction in incidence and cases relative to the baseline scenario; dark red corresponds to 0% reduction. Scenario A assumes the entire population, excepting essential services, will physically distance themselves for 24 hours every Friday while reverting to their usual behavior on the other days of the week. Scenario B assumes the population will physically distance themselves for the entire weekend (Friday and Saturday) while reverting to their usual behavior throughout the week. Scenario C assumes the entire population, except for essential services, will physically distance themselves for the entire week while never reverting to their usual behavior. Baseline scenario assumes no government intervention and half the population instinctively physically distances themselves to avoid infection. Common to each scenario are 2 parameters used to define the extent of the physical distancing intervention: coverage, which refers to the percentage of the population following physical distancing regulations, and adherence, which refers to the extent to which individual persons follow those guidelines. The coverage parameter was varied between values of 50% and 100% (presented on the horizontal axis of each heat map) on the days when the physical distancing intervention was enforced. On respective days when the interventions were not enforced, simulations assume the coverage was constant at 50%. The adherence parameter varied between 0% and 100% (presented on the vertical axis of each heat map), remaining constant throughout each simulation.

stringency PHSMs remarkably reduced cumulative infections in that country, that effect had the trade-off of higher expected societal economic losses (*29*). Therefore, ranking of policy options should be based on optimality and cost-effectiveness, possibly leading to a mix of higher-stringency PHSMs (*30*).

We retrospectively compared the results of scenario A to historical reported data (Figure 4). We found the incidence under scenario A closely resembled the reported data for an assumed coverage of 60% and adherence of 80% and even more so for cumulative mortality (Figure 4). The coverage and adherence parameters for another scenario (Figure 5) closely resemble the reported Google mobility data for Jordan (*31*). We considered the average of the Google mobility data reported from retail and recreational facilities, grocery and pharmacy stores, and parks and transit locations. Changes in the average Google mobility data occurred on weekly intervals, representing the reduced mobility of persons during the weekend (Figure 5).

Challenges and Limitations

As in all modeling studies, we made various assumptions in this analysis. We cannot accurately estimate COVID-19 transmission rates and the effective reproduction number (R_t) when the burden of COVID-19 in the country is underestimated because of underreporting of cases and associated deaths. This limitation prevented us from performing model fitting, for example, using Bayesian particle filtering methods, to estimate the actual dynamics of COVID-19 and perform inference on key parameters such as the basic reproduction number (R_0). Moreover, although

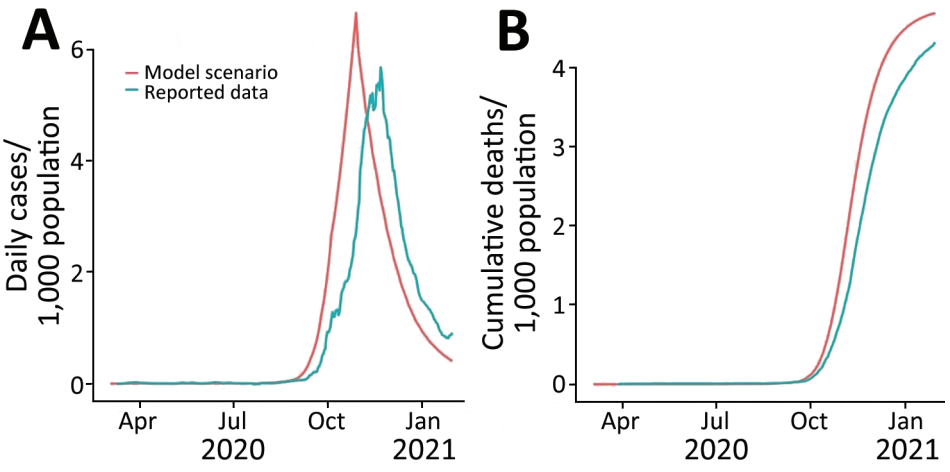

Figure 4. Comparison of COVID-19 daily incidence (A) and cumulative deaths (B) under model scenario A compared with reported data in a COVID-19 modeling study, Jordan, March 2020–January 2021. Scenario A assumes the entire population, excepting essential services, will physically distance themselves for 24 hours every Friday while reverting to their usual behavior on the other days of the week. The scenario is defined by 2 key parameters: coverage and adherence. On days when the physical distancing intervention was enforced, the simulation assumes 60% of the population is following physical distancing regulations (coverage) and that those persons spend 80% of their time adhering to the intervention (adherence).

our models included age-specific mixing patterns, geographic location–specific mixing patterns were ignored. This analysis modeled Jordan as a whole, whereas differences between governorates may have warranted a spatially explicit approach to modeling. The analysis did not account for the introduction of variants of concern and assumed that natural infection provided lifelong protection against reinfection. Ensuring policy makers understand the limitations of these assumptions through clear communication is vital to ensure the model's relevance.

Conclusions

COVID-19 modeling has been a substantial achievement (32). Strong and consistent national support and inputs from a wide range of critical stakeholders, such as the Ministry of Health and the Royal Hashemite Court, ensured that estimations of relative effect have been constantly refined over time.

The participatory scenario-based approach we describe considered the effect of intermittent PDIs on reducing COVID-19 transmission in Jordan. We show that enforcing a PDI with no intermittent periods is only marginally beneficial to reducing COVID-19 disease burden compared with an intermittently enforced PDI. The evolution of the pandemic in Jordan confirmed the forecasting provided by the modeling exercise and helped confirm the effectiveness of the policy adopted by the government of Jordan. The insights from scenario-based modeling influenced the implementation of PHSMs and PDIs; specifically, scenario-based models were used to updating PHSM and PDI guidelines in addition to other evidence-based actions, such as infection prevention and control (33).

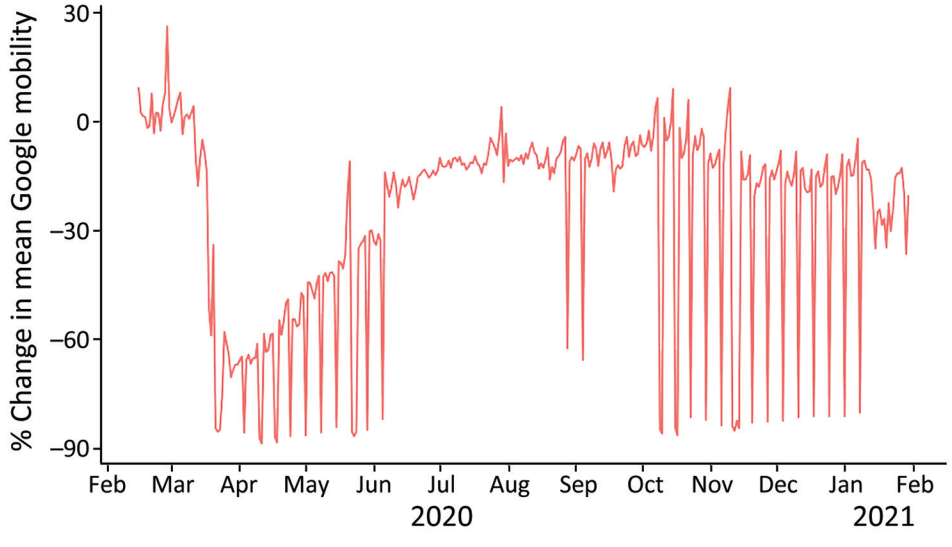

Figure 5. Percentage changes in mean mobility among the population, Jordan, February 2020–January 2021, including around retail and recreational facilities, grocery and pharmacy stores, parks, and transit locations. Google mobility data are used as a proxy for the population's coverage and adherence to COVID-19–related physical distancing interventions.

By interacting directly with the policy decision-makers, we were able to define the context of the modeling exercise and address specific policy questions they posed. Furthermore, communicating what mathematical modeling is capable of and its limitations at every stage of the analysis was vital to the success of the project. This level of engagement strengthened communication between stakeholders and encouraged insights learned through the modeling process to be incorporated into policy decisions.

This modeling initiative for the pandemic confirmed the comparative advantage in providing hands-on support to national health authorities for developing evidence-based policies. The participatory approach in running COVID-19 modeling research provided the chance to convey the model's caveats and limitations and disseminate modeling results among governing bodies and partners as appropriate. By leveraging and investing in WHO resources and providing essential assistance for the pandemic (e.g., procurement, research, and capacity building), WHO created crucial evidence to help with decision-making within and beyond Jordan's health sector.

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Dr. Bellizzi is the Emergency Team Leader for the Jordan WHO Country Office. His research interests include policy support in the area of public health emergency, with a focus on low- and middle-income countries.

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Participatory Mathematical Modeling Approach for Policymaking during the First Year of the COVID-19 Crisis, Jordan

Appendix

Model Description

Our participatory modeling approach used the COVID-19 International Modeling Consortium (CoMo) model (V17.20) (*1*). The model has been actively developed throughout the COVID19 pandemic by a global consortium of scientists including members of the EMRO modeling support team. The code is open source and publicly available. The version of the model used in this analysis (version 17.2) is available at https://github.com/ocelhay/como/releases/tag/v17.2.0.

The CoMo model is an age-dependent, deterministic, SEIR (Susceptible - Exposed - Infectious – Recovered) compartmental model that models transmission of SARS-CoV-2 in the population and can be used to investigate the relative impact of a variety of PHSM. The model considers five levels of infection severity: asymptomatic, symptomatic, infections requiring hospitalization, intensive care treatment, and ventilated intensive care treatment. Infection severity and associated mortality are age-dependent, in that the proportion of infected individuals requiring hospitalization, and the proportion that die, varies with age. In addition to predicting case and death rates at various time points, the CoMo model also incorporates two sub-models: hospital and critical care requirements and implementation of public health and safety measures. The CoMo model incorporates a hospital sub-model that suggests when hospital and critical care requirements will exceed the capacity of the country's healthcare system, including treatment in hospital beds, ICUs, and ventilators.

The CoMo model also incorporates an explicit representation of various PHSM to mitigate the spread of SARS CoV-2. These measures are: self-isolation of symptomatic individuals and self-quarantine of members of their household, screening of the contacts of individuals with a positive diagnostic test result, mass testing, school closure, workplace closure, physical distancing measures, border closure, shielding elderly individuals, handwashing, and mask-wearing. For each PHSM, users can vary the timing and duration, as well as the coverage, defined as the proportion of the population that adheres to the intervention, and adherence, defined as the proportion of time in a given day that an average individual adheres to the intervention. The coverage and adherence values act on the age- and location-dependent contact matrices (*2*). Coverage values of each PHSM in the model may vary over time to simulate interventions being relaxed and reinstated according to policy mandates.

Model Equations

This Supplemental Material provides an outline of the equations and parameters describing the CoMo model (*1*). The CoMo model is written in R and deployed via a Shiny App (comomodel.net). Equations in this document are based upon the solver in v16.6.0 of the comoOdeCpp R package, which is paired with v17.2 of the CoMo model. This combination of model and solver were used in the analyses. An R script of the solver (for use with the deSolve package) is available in the tests folder of the comoOdeCpp package.

Notation in this document aims to stay consistent with 1) the code in the solver, 2) the model equations in the original paper of Aguas et al. (*1*) (which were not published for v17.2 of the model), 3) the code in R for use with the deSolve package. A few adjustments have been made for consistency across the notation (e.g., durations all use the same symbol).

Differential equations

For clarity and consistency, derivatives have been written in the following form:

derivative = ...

transmission terms

+ disease processes

+ quarantine

+ aging

+ natural mortality

+ births

Susceptible individuals

$$\frac{dS}{dt} = -S\lambda - vAS + \omega R + v_d V - q_r S + 1/v_q QS + A_{age} S - \mu S + b$$

Susceptible individuals, currently quarantining

$$\frac{dQS}{dt} = -\lambda_q QS + q_r S - 1/v_q QS + A_{age} QS - \mu QS$$

Infected and incubating

$$\frac{dE}{dt} = S\lambda - \gamma E - vAE - q_r E + 1/v_q QE + A_{age} E - \mu E$$

Infected and incubating, currently quarantining

$$\frac{dQE}{dt} = \lambda_q QS - \gamma QE + q_r E - 1/v_q QE + A_{age} QE - \mu QE$$

Infectious symptomatic individuals

$$\frac{dI}{dt} = \ldots$$

$$\gamma(1 - p_{clin})(1 - s_{screen})(1 - p_{ihr})(1 - A_u u_E)E \ldots$$

$$+\gamma(1 - p_{clinV})(1 - s_{screen})(1 - \sigma_{EV} p_{ihr})(1 - A_u u_{EV})EV \ldots$$

$$+\gamma(1 - p_{clinVR})(1 - s_{screen})(1 - \sigma_{EVR} p_{ihr})(1 - A_u u_{EVR})EVR \ldots$$

$$+\gamma(1 - p_{clinR})(1 - s_{screen})(1 - \sigma_{ER} p_{ihr})(1 - A_u u_{ER})ER \ldots$$

$$-vA_v I - \nu_i I - u_I A_u I \ldots$$

$$-q_r I + 1/v_q QI + A_{age} I - \mu I$$

Infectious individuals (currently quarantining)

$$\frac{dQI}{dt} = \gamma(1 - p_{ihr})(1 - p_{clin})QE \ldots$$

$$+\gamma(1 - \sigma_{EV} p_{ihr})(1 - p_{clinV})QEV \ldots$$

$$+\gamma(1-\sigma_{EVR}p_{ihr})(1-p_{clinVR})QEVR\ldots$$

$$+\gamma(1-\sigma_{ER}p_{ihr})(1-p_{clinR})QER\ldots$$

$$-\nu_i QI + q_r I - 1/v_q QI + A_{age}QI - \mu QI$$

Symptomatic and reported cases

$$\frac{dCL}{dt} = \gamma p_{clin}(1-A_u u_E)(1-c_{iso})(1-p_{ihr})(1-q_r)E\ldots$$

$$+\gamma p_{clinV}(1-A_u u_{EV})(1-c_{iso})(1-\sigma_{EV}p_{ihr})(1-q_r)EV\ldots$$

$$+\gamma p_{clinVR}(1-A_u u_{EVR})(1-c_{iso})(1-\sigma_{EVR}p_{ihr})(1-q_r)EVR\ldots$$

$$+\gamma p_{clinR}(1-A_u u_{ER})(1-c_{iso})(1-\sigma_{ER}p_{ihr})(1-q_r)ER\ldots$$

$$-u_{CL}A_u CL - \nu_i CL + 1/v_q QC + A_{age}CL - \mu CL$$

$$\frac{dQC}{dt} =\ldots$$

$$\gamma p_{clin}(1-c_{iso})(1-A_u u_E)(1-p_{ihr})q_r E\ldots$$

$$+\gamma p_{clinV}(1-c_{iso})(1-A_u u_{EV})(1-\sigma_{EV}p_{ihr})q_r EV\ldots$$

$$+\gamma p_{clinVR}(1-c_{iso})(1-A_u u_{EVR})(1-\sigma_{EVR}p_{ihr})q_r EVR\ldots$$

$$+\gamma p_{clinR}(1-c_{iso})(1-A_u u_{ER})(1-\sigma_{ER}p_{ihr})q_r ER\ldots$$

$$+\gamma(1-p_{ihr})p_{clin}QE\ldots$$

$$+\gamma(1-\sigma_{EV}p_{ihr})p_{clinV}QEV\ldots$$

$$+\gamma(1-\sigma_{EVR}p_{ihr})p_{clinVR}QEVR\ldots$$

$$+\gamma(1-\sigma_{ER}p_{ihr})p_{clinR}QER\ldots$$

$$-\nu_i QC - 1/v_q QC + A_{age}QC - \mu QC$$

Self-isolating

$$\frac{dX}{dt} =\ldots$$

$$\gamma c_{iso}(1-A_u u_E)p_{clin}(1-p_{ihr})E\ldots$$

$$+\gamma s_{screen}(1-A_u u_E)(1-p_{clin})(1-p_{ihr}\ )E\ldots$$

$$+\gamma c_{iso}(1-A_u u_{EV})p_{clinV}(1-p_{ihr}\ )EV\ldots$$

$$+\gamma s_{screen}(1-A_u u_{EV})(1-p_{clinV})(1-p_{ihr}\ )EV\ldots$$

$$+\gamma c_{iso}(1-A_u u_{EVR})p_{clinVR}(1-p_{ihr}\ )EVR\ldots$$

$$+\gamma s_{screen}(1-A_u u_{EVR})(1-p_{clinVR})(1-p_{ihr}\ )EVR\ldots$$

$$+\gamma c_{iso}(1-A_u u_{ER})p_{clinR}(1-p_{ihr}\ )ER\ldots$$

$$+\gamma s_{screen}(1-A_u u_{ER})(1-p_{clinR})(1-p_{ihr}\ )ER\ldots$$

$$-\nu_i X + A_{age}X - \mu X$$

Quarantined due to testing

$$\frac{dZ}{dt} =\ldots$$

$$\gamma u_E A_u(1-p_{ihr})E\ldots$$

$$+\gamma u_{EV} A_u(1-p_{ihr})EV\ldots$$

$$+\gamma u_{EVR} A_u(1-p_{ihr})EVR\ldots$$

$$+\gamma u_{ER} A_u(1-p_{ihr})ER\ldots$$

$$+u_I A_u I + u_{CL}A_u CL + u_{HC}A_u HC + u_{HCICU}A_u HCICU + u_{HCV}A_u HCV\ldots$$

$$-1/v_{iso}Z - \mu Z$$

Recovered and immune individuals

$$\frac{dR}{dt} = -\lambda\sigma_R R + \nu_i I + \nu_i X + \nu_i CL - \omega R+\ldots$$

$$\nu_H p_{O2}\,(1-d_{O2}\delta_{HO2})p_{ifr}H+\ldots$$

$$\nu_H(1-p_{O2})\,(1-\delta_H)p_{ifr}H+\ldots$$

$$\nu_{HC}p_{O2}\,(1-\delta_{HCO2})p_{ifr}HC+\ldots$$

$$\nu_{HC}(1-p_{O2})\,(1-\delta_{HC})p_{ifr}HC+\ldots$$

$$\nu_{ICU} p_{O2} \, (1 - d_{O2} \delta_{ICUO2}) p_{ifr} ICU + \ldots$$

$$\nu_{ICU} (1 - p_{O2}) \, (1 - \delta_{ICU}) p_{ifr} ICU + \ldots$$

$$\nu_{ICUC} p_{O2} \, (1 - d_{O2C} \delta_{ICUCO2}) p_{ifr} ICUC + \ldots$$

$$\nu_{ICUC} (1 - p_{O2}) \, (1 - \delta_{ICUC}) p_{ifr} ICUC + \ldots$$

$$\nu_{VENT} (1 - d_{VENT} \delta_{VENT}) p_{ifr} VENT + \ldots$$

$$\nu_{VENTC} (1 - d_{VENTC} \delta_{VENTC}) p_{ifr} VENTC + \ldots$$

$$\nu_{VENTC} (1 - d_{VENTC} \delta_{VENTC}) p_{ifr} ICUCV + \ldots$$

$$\nu_{HC} p_{O2} (1 - \delta_{HCICUO2}) p_{ifr} HCICU + \ldots$$

$$\nu_{HC} (1 - p_{O2}) (1 - \delta_{HCICU}) p_{ifr} HCICU + \ldots$$

$$\nu_{VENTC} (1 - \delta_{HCVENT}) p_{ifr} HCV + \ldots$$

$$v_{dr} VR - vAR + \ 1/v_{iso} Z \ - q_r R + \ 1/q_r QR + \ A_{age} R \ - \ \mu R$$

Previously infected individuals, currently quarantining

$$\frac{dQR}{dt} = \nu_i QI + \nu_i QC + v_{d_r} QVR \ + \ q_r R - 1/v_q QR + \ A_{age} QR \ - \ \mu QR$$

Infected and incubating, from previously vaccinated individuals

$$\frac{dEV}{dt} = (1 - p_V) * \lambda V - \gamma EV \ - q_r EV + 1/v_q QEV \ + \ A_{age} EV \ - \ \mu EV$$

Infected and incubating, from previously vaccinated individuals, currently quarantining

$$\frac{dQEV}{dt} = \ (1 - p_V) * \lambda_q QV - \gamma QEV + \ q_r EV - 1/v_q QEV + \ A_{age} QEV - \mu QEV$$

Infected and incubating, from previously infected

$$\frac{dER}{dt} = \lambda \sigma_R R - \gamma ER \ - q_r ER + 1/v_q QER \ + \ A_{age} ER \ - \ \mu ER$$

Infected and incubating, from previously infected, currently quarantining

$$\frac{dQER}{dt} = \lambda_q \sigma_R \quad QR \ - \gamma QER + \ q_r ER - 1/v_q QER + \ A_{age} QER - \mu QER$$

Vaccinated individuals from susceptible

$$\frac{dV}{dt} = vAS - (1 - p_V) * \lambda V + \omega VR - v_d V - q_r V + A_{age} V - \mu V$$

Vaccinated individuals from susceptible, currently quarantining

$$\frac{dQV}{dt} = -(1 - p_V) * \lambda_q QV + \omega QVR + q_r V - 1/v_q QV + A_{age} QV - \mu QV$$

Vaccinated individuals (after being previously infected, recovered)

$$\frac{dVR}{dt} = vAE + vAI + vAR - (1 - p_{VR}) * \lambda VR - v_{d_r} VR - \omega VR - q_r VR + 1/v_q QVR + A_{age} VR - \mu VR$$

Vaccinated individuals (after being previously infected, recovered) (currently quarantining)

$$\frac{dQVR}{dt} = -(1 - p_{VR}) * \lambda QVR - v_{dr} QVR - \omega QVR + q_r VR + A_{age} QVR - \mu QVR$$

Infected and incubating, from previously infected and vaccinated

$$\frac{dEVR}{dt} = (1 - p_{VR}) * \lambda VR - \gamma EVR - q_r EVR + 1/v_q QEVR + A_{age} EVR - \mu EVR$$

Infected and incubating, from previously infected and vaccinated (currently quarantining)

$$\frac{dQEVR}{dt} = (1 - p_{VR}) * \lambda_q QVR - \gamma QEVR + q_r EVR - 1/q_d QEVR + A_{age} QEVR - \mu QEVR$$

States involving hospitalization (or requiring hospitalization)

Hospitalized

$$\frac{dH}{dt} = \ldots$$

$$\gamma p_{ihr}(1 - p_{ICU})(1 - p_{crit}) r_H E \ldots$$

$$+\gamma p_{ihr}(1 - p_{ICU})(1 - p_{crit}) r_H QE \ldots$$

$$+\gamma p_{ihr} \sigma_{EV}(1 - p_{ICUV})(1 - p_{critH}) r_H EV \ldots$$

$$+\gamma p_{ihr} \sigma_{ER}(1 - p_{ICUV})(1 - p_{critH}) r_H QEV \ldots$$

$$+\gamma p_{ihr} \sigma_{EVR}(1 - p_{ICUVR})(1 - p_{critH}) r_H EVR \ldots$$

$$+\gamma p_{ihr}\sigma_{EVR}(1-p_{ICUVR})(1-p_{critH})r_H QEVR\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}(1-p_{ICUR})(1-p_{critH})r_H ER\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}(1-p_{ICUR})(1-p_{critH})r_H QER\ldots$$

$$-\nu_H H + A_{age}H - \mu H$$

Requiring hospitalization, not hospitalized due to capacity

$$\frac{dHC}{dt} =\ldots$$

$$+\gamma p_{ihr}(1-p_{ICU})(1-r_H)E$$

$$+\gamma p_{ihr}(1-p_{ICU})p_{crit}r_H E$$

$$+\gamma p_{ihr}(1-p_{ICU})(1-r_H)QE$$

$$+\gamma p_{ihr}(1-p_{ICU})p_{crit}r_H QE$$

$$+\gamma p_{ihr}\sigma_{EV}(1-p_{ICUV})(1-r_H)EV$$

$$+\gamma p_{ihr}\sigma_{EV}(1-p_{ICUV})p_{crit}r_H EV$$

$$+\gamma p_{ihr}\sigma_{EVR}(1-p_{ICUVR})(1-r_H)EVR\ldots$$

$$+\gamma p_{ihr}\sigma_{EVR}(1-p_{ICUVR})p_{crit}r_H EVR\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}(1-p_{ICUR})(1-r_H)ER\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}(1-p_{ICUR})p_{crit}r_H ER\ldots$$

$$+\gamma p_{ihr}\sigma_{EV}(1-p_{ICUV})(1-r_H)QEV\ldots$$

$$+\gamma p_{ihr}\sigma_{EV}(1-p_{ICUV})p_{crit}r_H QEV\ldots$$

$$+\gamma p_{ihr}\sigma_{EVR}(1-p_{ICUVR})(1-r_H)QEVR\ldots$$

$$+\gamma p_{ihr}\sigma_{EVR}(1-p_{ICUVR})p_{crit}r_H QEVR\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}(1-p_{ICUR})(1-r_H)QER\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}(1-p_{ICUR})p_{crit}r_H QER\ldots$$

$$+u_{HC}A_u HC\ldots$$

$$-\nu_{HC}HC + A_{age}HC - \mu HC$$

Severe infection, hospitalized, but placed in surge ward

$$\frac{dHCV}{dt} = \ldots$$

$$+\gamma(1 - r_{ICU})p_{ihr}p_{ICU}p_{VENTD}E\ldots$$

$$+\ \gamma(1 - r_{ICU})p_{ihr}p_{ICU}p_{VENTD}QE\ldots$$

$$+\gamma(1 - r_{ICU})\sigma_{EV}p_{ihr}p_{ICUV}p_{VENTV}EV\ldots$$

$$+\gamma(1 - r_{ICU})\sigma_{EV}p_{ihr}p_{ICUV}p_{VENTV}QEV\ldots$$

$$+\gamma(1 - r_{ICU})\sigma_{EVR}p_{ihr}p_{ICUVR}p_{VENTVR}EVR\ldots$$

$$+\gamma(1 - r_{ICU})\sigma_{EVR}p_{ihr}p_{ICUVR}p_{VENTVR}QEVR\ldots$$

$$+\gamma(1 - r_{ICU})\sigma_{ER}p_{ihr}p_{ICUR}p_{VENTR}ER\ldots$$

$$+\gamma(1 - r_{ICU})\sigma_{ER}p_{ihr}p_{ICUR}p_{VENTR}QER\ldots$$

$$-u_{HCV}A_uHCV\ldots$$

$$-\nu_{VENTC}HCV\ +\ A_{age}HCV\ -\ \mu HCV$$

Severe infection, hospitalized, requiring ICU, not but not granted ICU due to capacity

$$\frac{dHCICU}{dt} = \ldots$$

$$+\gamma p_{ihr}p_{ICU}(1 - r_{ICU})(1 - p_{VENTD}\ \ )E\ldots$$

$$+\gamma p_{ihr}p_{ICU}(1 - r_{ICU})(1 - p_{VENTD})QE\ldots$$

$$+\gamma p_{ihr}\sigma_{EV}p_{ICUV}(1 - r_{ICU})(1 - p_{VENTV})EV\ldots$$

$$+\gamma p_{ihr}\sigma_{EV}p_{ICUV}(1 - r_{ICU})(1 - p_{VENTV})QEV\ldots$$

$$+\gamma p_{ihr}\sigma_{EVR}p_{ICUVR}(1 - r_{ICU})(1 - p_{VENTVR})EVR\ldots$$

$$+\gamma p_{ihr}\sigma_{EVR}p_{ICUVR}(1 - r_{ICU})(1 - p_{VENTVR})QEVR\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}p_{ICUR}(1 - r_{ICU})(1 - p_{VENTR})ER\ldots$$

$$+\gamma p_{ihr}\sigma_{ER}p_{ICUR}(1 - r_{ICU})(1 - p_{VENTR})QER\ldots$$

$$- u_{HCICU} A_u HCICU. ..$$

$$- \nu_{HC} HCICU + A_{age} HCICU - \mu HCICU$$

Severe infection, requiring ICU

$$\frac{dICU}{dt} = \frac{1}{2}(1 - p_{crit})ICUC + ...$$

$$+\gamma r_{ICU} p_{ihr} p_{ICU}(1 - p_{crit})(1 - p_{VENTD})E. ..$$

$$+\gamma r_{ICU} p_{ihr} p_{ICU}(1 - p_{crit})(1 - p_{VENTD})QE. ..$$

$$+\gamma r_{ICU} \sigma_{EV} p_{ihr} p_{ICUV}(1 - p_{crit})(1 - p_{VENTV})EV. ..$$

$$+\gamma r_{ICU} \sigma_{EV} p_{ihr} p_{ICUV}(1 - p_{crit})(1 - p_{VENTV})QEV. ..$$

$$+\gamma r_{ICU} \sigma_{EVR} p_{ihr} p_{ICUVR}(1 - p_{crit})(1 - p_{VENTVR})EVR. ..$$

$$+\gamma r_{ICU} \sigma_{EVR} p_{ihr} p_{ICUVR}(1 - p_{crit})(1 - p_{VENTVR})QEVR. ..$$

$$+\gamma r_{ICU} \sigma_{ER} p_{ihr} p_{ICUR}(1 - p_{crit})(1 - p_{VENTR})ER. ..$$

$$+\gamma r_{ICU} \sigma_{ER} p_{ihr} p_{ICUR}(1 - p_{crit})(1 - p_{VENTR})QER. ..$$

$$-\nu_{ICU} ICU + A_{age} ICU - \mu_{ICU}$$

Severe infection, requiring ICU but not receiving ICU due to capacity

$$\frac{dICUC}{dt} = -\frac{1}{2}(1 - p_{crit})ICUC. ..$$

$$+\gamma r_{ICU} p_{ihr} p_{ICU} p_{crit}(1 - p_{VENTD})E. ..$$

$$+\gamma r_{ICU} p_{ihr} p_{ICU} p_{crit}(1 - p_{VENTD})QE. ..$$

$$+\gamma r_{ICU} \sigma_{EV} p_{ihr} p_{ICUV} p_{crit}(1 - p_{VENTV})EV. ..$$

$$+\gamma r_{ICU} \sigma_{EV} p_{ihr} p_{ICUV} p_{crit}(1 - p_{VENTV})QEV. ..$$

$$+\gamma r_{ICU} \sigma_{EVR} p_{ihr} p_{ICUVR} p_{crit}(1 - p_{VENTVR})EVR. ..$$

$$+\gamma r_{ICU} \sigma_{EVR} p_{ihr} p_{ICUVR} p_{crit}(1 - p_{VENTVR})QEVR. ..$$

$$+\gamma r_{ICU} \sigma_{ER} p_{ihr} p_{ICUR} p_{crit}(1 - p_{VENTR})ER. ..$$

$$+\gamma r_{ICU} \sigma_{ER} p_{ihr} p_{ICUR} p_{crit}(1 - p_{VENTR})QER. ..$$

$$-\nu_{ICUC}ICUC + A_{age}ICUC - \mu ICUC$$

Severe infection, hospitalized, requiring ventilator but placed in a surge ward

$$\frac{dICUCV}{dt} = -\frac{1}{2}(1 - p_{critV})ICUCV\ldots$$

$$+\gamma r_{ICU}p_{ihr}p_{ICU}p_{crit}\ p_{VENTD}E\ \ldots$$

$$+\gamma r_{ICU}\sigma_{EV}p_{ihr}p_{ICUV}p_{crit}\ p_{VENTV}EV\ldots$$

$$+\gamma r_{ICU}\sigma_{EVR}p_{ihr}p_{ICUVR}p_{crit}\ p_{VENTVR}EVR\ \ldots$$

$$+\gamma r_{ICU}\sigma_{ER}p_{ihr}p_{ICUR}p_{crit}\ p_{VENTR}ER\ \ldots$$

$$+\gamma r_{ICU}p_{ihr}p_{ICU}p_{crit}\ p_{VENTD}QE\ \ldots$$

$$+\gamma r_{ICU}\sigma_{EV}p_{ihr}p_{ICUV}p_{crit}\ p_{VENTV}QEV\ldots$$

$$+\gamma r_{ICU}\sigma_{EVR}p_{ihr}p_{ICUVR}p_{crit}\ p_{VENTVR}QEVR\ \ldots$$

$$+\gamma r_{ICU}\sigma_{ER}p_{ihr}p_{ICUR}p_{crit}\ p_{VENTR}QER\ \ldots$$

$$-\nu_{VENTC}ICUCV + A_{age}ICUCV - \mu ICUCV$$

Severe infection, hospitalized in ICU on a ventilator

$$\frac{dVENT}{dt} = \ldots$$

$$\frac{1}{2}(1 - p_{critV})VENTC + \frac{1}{2}(1 - p_{critV})ICUCV\ldots$$

$$+\gamma r_{ICU}p_{ihr}p_{ICU}(1 - p_{crit})(1 - p_{critV})\ p_{VENTD}E\ldots$$

$$+\gamma r_{ICU}p_{ihr}p_{ICU}(1 - p_{crit})(1 - p_{critV})\ p_{VENTD}QE\ldots$$

$$+\gamma r_{ICU}\sigma_{EV}p_{ihr}p_{ICUV}(1 - p_{crit})(1 - p_{critV})\ p_{VENTV}EV\ldots$$

$$+\gamma r_{ICU}\sigma_{EV}p_{ihr}p_{ICUV}(1 - p_{crit})(1 - p_{critV})\ p_{VENTV}QEV\ldots$$

$$+\gamma r_{ICU}\sigma_{EVR}p_{ihr}p_{ICUVR}(1 - p_{crit})(1 - p_{critV})\ p_{VENTVR}EVR\ldots$$

$$+\gamma r_{ICU}\sigma_{EVR}p_{ihr}p_{ICUVR}(1 - p_{crit})(1 - p_{critV})\ p_{VENTVR}QEVR\ldots$$

$$+\gamma r_{ICU}\sigma_{ER}p_{ihr}p_{ICUR}(1 - p_{crit})(1 - p_{critV})\ p_{VENTR}ER\ldots$$

$$+\gamma r_{ICU}\sigma_{ER}p_{ihr}p_{ICUR}(1 - p_{crit})(1 - p_{critV})\ p_{VENTR}QER\ldots$$

$$-\nu_{VENT}VENT + A_{age}VENT - \mu VENT$$

Severe infection, hospitalized in ICU requiring a ventilator but not on one due to capacity

$$\frac{dVENTC}{dt} =\ldots$$

$$-\frac{1}{2}(1-p_{critV})VENTC\ldots$$

$$+\gamma r_{ICU}p_{ihr}p_{ICU}(1-p_{crit})p_{critV}\ p_{VENTD}E\ldots$$

$$+\gamma r_{ICU}p_{ihr}p_{ICU}(1-p_{crit})p_{critV}\ p_{VENTD}QE\ldots$$

$$+\gamma r_{ICU}\sigma_{EV}p_{ihr}p_{ICUV}(1-p_{crit})p_{critV}\ p_{VENTV}EV\ldots$$

$$+\gamma r_{ICU}\sigma_{EV}p_{ihr}p_{ICUV}(1-p_{crit})p_{critV}\ p_{VENTV}QEV\ldots$$

$$+\gamma r_{ICU}\sigma_{EVR}p_{ihr}p_{ICUVR}(1-p_{crit})p_{critV}\ p_{VENTVR}EVR\ldots$$

$$+\gamma r_{ICU}\sigma_{EVR}p_{ihr}p_{ICUVR}(1-p_{crit})p_{critV}\ p_{VENTVR}QEVR\ldots$$

$$+\gamma r_{ICU}\sigma_{ER}p_{ihr}p_{ICUR}(1-p_{crit})p_{critV}\ p_{VENTR}ER\ldots$$

$$+\gamma r_{ICU}\sigma_{ER}p_{ihr}p_{ICUR}(1-p_{crit})p_{critV}\ p_{VENTR}QER\ldots$$

$$-\nu_{VENTC}VENTC + A_{age}VENTC - \mu_{VENTC}$$

Force of infection **(**lambda, lam, λ**)**

$$\lambda = \left(1 - max(hand, mask)\right) p.s.W$$

$$\frac{\rho E + I + CL + m + (1 - s_{iso}\ \ )(X + HC + HCICU + HCV) + \rho_s(H + ICU + VENT + ICUC + ICUCV + VENTC)}{P} \ldots$$

$$+(1 - max(hand, mask))p.s.(1 - q_{other})W_{other}\frac{\rho QE + QI + QC + QEV + QEVR + QER)}{P}$$

where

$$mask = maskeff * maskcov;\ hand\ =\ handeff * handcov$$

For those under quarantine, this is adjusted in the following manner:

$$\lambda_q = \left(1 - max(hand, mask)\right) ps(1 - q_{home})W_{home}$$

$$\frac{(1 - s_{iso}\ \ )(X + HHC + \rho QE + QI + QC + QEV + QEVR + QER)}{P} \ldots$$

$$+ \left(1 - max(hand, mask)\right) ps(1 - q_{other})W_{other}$$

$$\frac{\rho E + I + CL + m + (1 - s_{iso}\ \ )(X + HC + HCICU + HCV) + \rho_s(H + ICU + VENT + ICUC + ICUCV + VENTC)}{P}$$

where

$$P = S + E + I + R + X + Z + CL \ldots$$

$$+V + EV + ER + EVR + VR \ldots$$

$$+H + HC + ICU + ICUC + ICUCV + Vent + VentC + HCICU + HCV \ldots$$

$$+QS + QE + QI + QR + QC + QEV + QV + QER + QEVR + QVR$$

Quarantine rate **(q_r)**

Quarantine rate (for all non-hospitalized compartments that transition into a quarantine state) is calculated in the following manner (see here):

$$q_{r\,=}\, r_q(1 + exp(-10(\sigma_q/2\, -\, Q))$$

Proportion of the population in quarantine:

$$Q\, = (\, \Sigma QS + \Sigma QE + \Sigma QI + \Sigma QC + \Sigma QR + \Sigma QV + \Sigma QEV + \Sigma QEVR + \Sigma QER + \Sigma QVR)/(\Sigma P)$$

Vaccination rate (v)

Vaccination rate is calculated in the following manner (see here):

$$v = -log(1 - v_{cov})/v_c$$

Model Parameterization

Several pieces of data were used to parameterize the model for simulations of the COVID-19 outbreak in Jordan. Parameters governing population size (of ≈100 million individuals), demographic age-structure, fertility, and natural mortality were taken from the 2019 UN Revision of World Population Prospects. Contact data were informed using Prem et al. (*2*) and average household size is 4.7 (Jordan MoH). Parameters governing infection and disease progression follow the literature on SARS-CoV-2 and COVID-19 and are provided in detail in the supplemental data. Parameters governing healthcare capacity were determined via discussions with in-country partners. Jordan country partners specified in the model that all ICUs are with ventilators with the assumption that sever, and critical patients are admitted to the ICU when requiring mechanical ventilation. Other patients receive care in normal hospital beds with or without oxygen supply. We assumed that the maximum number of hospital beds (3894), the maximum number of ICU beds with ventilators (834) during this period. Parameters governing the time course of hospitalized infections were determined via discussions with in-country partners and are specific to Jordan. Because of various travel restrictions imposed by the Jordanian government in 2020, we assumed that there were no imported cases over the modeled period. Waning immunity was not included in this model.

Within the CoMo model framework, model calibration was performed by adjusting the probability of transmission given an infectious contact and the date of introduction of SARS-CoV-2 into the country. These calibrations were performed visually using the CoMo model application. We were justified in performing visual calibrations given the interactive nature of the user platform, the short time frame in which results were required by the Jordanian government, and a focus on the relative impact of different interventions on future transmission rather than absolute numbers of cases or deaths.

Using the calibrated model, we simulated several different scenarios of the implementation of PHSM for Jordan in 2020 from end of October 2020 until end of January 2021. Parameters governing the PHSM scenarios were set according to discussions with the Jordan Ministry of Health as part of our participatory modeling process. We set parameter values to simulate the changing of PHSM in Jordan at various time points throughout 2020.

Model Inputs

Appendix Tables 3–11 describe the model inputs.

References

1. Aguas R, White L, Hupert N, Shretta R, Pan-Ngum W, Celhay O, et al.; CoMo Consortium. Modelling the COVID-19 pandemic in context: an international participatory approach. BMJ Glob Health. 2020;5:e003126. PubMed https://doi.org/10.1136/bmjgh-2020-003126

2. Prem K, Cook AR, Jit M. Projecting social contact matrices in 152 countries using contact surveys and demographic data. PLOS Comput Biol. 2017;13:e1005697. PubMed https://doi.org/10.1371/journal.pcbi.1005697

Appendix Table 1. Variables. There are 31 different variables that make up the population, 35 derivatives returned from the solver (4 for convenience).

Symbol	Definition
S	Susceptible
E	Infected and incubating
I	Infectious and asymptomatic following incubation
R	Recovered and immune
X	Self-isolating
H	Severe infection: hospitalized (Aguas et al., 2020)
HC	Severe infection, requiring hospitalization, not hospitalized due to lack of capacity (Aguas et al., 2020)
HCICU	Severe infection, hospitalized, requiring ICU, not but not granted ICU due to capacity
HCV	Severe infection, hospitalized, but placed in surge ward
ICU	Severe infection, requiring ICU
ICUC	Severe infection, requiring ICU, not hospitalized due to capacity
ICUCV	Severe infection, hospitalized, requiring ventilator but placed in surge ward
Vent	Severe infection, hospitalized in ICU on a ventilator
VentC	Severe infection, hospitalized in ICU requiring a ventilator but not on one
C	Infectious and mildly symptomatic following incubation (not in the total popn count, L416 comoOde.cpp)
CM	(not in the total popn count, L416 comoOde.cpp)
V	Vaccinated (from susceptible)
QS	Susceptible, quarantining
QE	Infected and incubating, quarantining
QI	Infectious and asymptomatic following incubation, quarantining
QR	Recovered and immune, quarantining
CL	Total cases?
Z	Quarantined due to testing
EV	Infected and incubating, from previously vaccinated individuals
ER	Infected and incubating, from previously infected individuals
EVR	Vaccinated (from previously infected), exposed (from ineffective vaccine).
VR	Vaccinated (from previously infected)
QV	Vaccinated (from susceptible), quarantining
QEV	Vaccinated (from susceptible), exposed (from ineffective vaccine), quarantining
QEVR	Previously infected, exposed (from ineffective vaccine), quarantining
QER	Exposed, quarantining, previously infected
QVR	Vaccinated, quarantining, previously infected
Ab	Those with antibody response. Not part of the population, simply calculated in the solver.

Appendix Table 2. Parameters

Parameter name (as used in code)	Symbol	Description	Units
Severity-Mortality Parameters			
ifr?	p_{ifr}	Age-based relative fatality rate in well-resourced scenario	%
ihr_col2	p_{ihr}	Probability of an infection being severe (requiring hospitalization) by age	%
Population parameters			
mu	μ	1/age-dependent non-Covid-19-related death rate	days
B	b	1/ age-dependent fertility rate	days
General parameters			
date_range_simul_start	t_0	Date range of simulation – START	
date_range_simul_end	t_T	Date range of simulation – END	
init	–	Number of exposed people at start date	
pre	–	Proportion of population with partial immunity at the start date	
p	p_E	Probability of infection given contact	
report	p_{ar}	Percentage of all asymptomatic infections that are reported	%
reportc	p_{cr}	Percentage of all symptomatic infections that are reported	%
reporth_g	p_{gr}	Percentage of denied hospitalizations that are reported	%
reporth	r_H	Percentage of non-severe hospitalizations that are appropriately treated (realized)	%
reporth_ICU	r_{ICU}	Percentage of severe hospitalizations that are appropriately treated (realized)	%
report_v	p_{avr}	Percentage of all asymptomatic infections in previously vaccinated people that are reported	
report_vr	p_{avrr}	Percentage of all asymptomatic infections in previously vaccinated and exposed people that are reported	
report_r	p_{arr}	Percentage of all asymptomatic infections in previously infected people that are reported	

Parameter name (as used in code)	Symbol	Description	Units
report_cv	p_{cvr}	Percentage of all symptomatic infections in previously vaccinated people that are reported	
report_cvr	p_{cvrr}	Percentage of all symptomatic infections in previously vaccinated and exposed people that are reported	
report_cr	p_{crr}	Percentage of all symptomatic infections in previously infected people that are reported	
iterations	–	Iterations (1 to 10,000)	
noise	–	Noise (0.01 to 0.2)	
confidence	–	Confidence (5 to 25)	
sample_size	–	Average sample size for seroprevalence	
Country Area parameters			
country_contact	C	Country, used for social Contacts Data	
household_size	h	Mean Household size	individuals
mean_imports	m	Mean number of infectious migrants per day; note that the code includes a 'travel ban efficacy' parameter but assumed set to zero (see here).	individuals
Virus parameters			
rho	ρ	relative infectiousness of incubation phase	
gamma	γ	incubation period	Days
nui	ν_i	Average duration of symptomatic infection period	Days
phi	ϕ	Month of peak infectivity of the virus (1, 2, …, 12)	
amp	a	Annual variation in infectivity of the virus	
omega	ω	duration of naturally acquired immunity	Years
pclin	p_{clin}	Probability upon infection of developing clinical symptoms	
prob_icu	p_{ICU}	Probability upon hospitalization of requiring ICU admission	%
prob_vent	p_{VENT}	Probability upon admission to the ICU of requiring a ventilator	%
propo2	p_{O2}	Proportion of hospitalized patients needing O2	
pclin_v	p_{clinV}	Probability upon infection of developing clinical symptoms if previously vaccinated	
pclin_vr	p_{clinVR}	Probability upon infection of developing clinical symptoms if previously vaccinated and exposed	
pclin_r	p_{clinR}	Probability upon infection of developing clinical symptoms if previously infected	
prob_icu_v	p_{ICUV}	Probability upon hospitalization of requiring ICU admission if previously vaccinated	%
prob_icu_vr	p_{ICUVR}	Probability upon hospitalization of requiring ICU admission if previously vaccinated and exposed	%
prob_icu_r	p_{ICUR}	Probability upon hospitalization of requiring ICU admission if previously infected	%
prob_v	p_{VENTD}	Derived. Probability upon admission to the ICU of requiring a ventilator. Essentially the same as prob_vent, if dexamethsone is being used then this param is prob_vent*vent_dex, else it is prob_vent (see here).	
prob_v_v	p_{VENTV}	Probability upon admission to the ICU of requiring a ventilator if previously vaccinated	%
prob_v_vr	p_{VENTVR}	Probability upon admission to the ICU of requiring a ventilator if previously vaccinated and exposed	%
prob_v_r	p_{VENTR}	Probability upon admission to the ICU of requiring a ventilator if previously infected	%
sigmaR	σ_R	Probability of infection of people that have recovered from a previous infection	
sigmaEV	σ_{EV}	Probability of requiring hospitalization if previously vaccinated	
sigmaER	σ_{ER}	Probability of requiring hospitalization if previously infected	
sigmaEVR	σ_{EVR}	Probability of requiring hospitalization if previously infected and vaccinated	
seroneg	$seroneg$	Days from seropositve to seronegative	Days
Hospitalization parameters			
beds_available	–	Maximum number of hospital surge beds	beds
icu_beds_available	–	Maximum number of ICU beds without ventilators	beds
ventilators_available	–	Maximum number of ICU beds with ventilators	beds
rhos	ρ_s	Relative percentage of regular daily contacts when hospitalized	
ihr_scaling	–	Scaling factor for infection hospitalization rate: (0.1 to 5)	
pdeath_h	δ_H	Probability of dying when hospitalized (not requiring O2)	
pdeath_ho	δ_{HO2}	Probability of dying when hospitalized if requiring O2	
pdeath_hc	δ_{HC}	Probability of dying when denied hospitalization (not requiring O2)	
pdeath_hco	δ_{HCO2}	Probability of dying when denied hospitalization if requiring O2	
pdeath_icu	δ_{ICU}	Probability of dying when admitted to ICU (not requiring O2)	

Parameter name (as used in code)	Symbol	Description	Units
pdeath_icuo	δ_{ICUO2}	Probability of dying when admitted to ICU if requiring O2	
pdeath_icuc	δ_{ICUC}	Probability of dying when admission to ICU denied (not requiring O2)	
pdeath_icuco	δ_{ICUCO2}	Probability of dying when admission to ICU denied if requiring O2	
pdeath_vent	δ_{VENT}	Probability of dying when ventilated	
pdeath_ventc	δ_{VENTC}	Probability of dying when ventilator denied	
pdeath_vent_hc	δ_{HCVENT}	Probability of dying when ventilator required and not going to hospital	
pdeath_icu_hc	δ_{HCICU}	Probability of dying when ICU required (not O2) and not going to hospital	
pdeath_icu_hco	$\delta_{HCICUO2}$	Probability of dying when ICU required (requiring O2) and not going to hospital	
nus	ν_H	Average duration of hospitalized infection	Days
nusc	ν_{HC}	Average duration of infection requiring hospitalization but not receiving it due to capacity (assumed same as nus parameter).	Days
nu_icu	ν_{ICU}	Average duration of ICU infection	Days
nu_icuc	ν_{ICUC}	Average duration of infection of individual requiring ICU infection but not receiving it due to capacity (assumed same as nu_icu parameter).	Days
nu_vent	ν_{VENT}	Average duration of ventilated infected.	Days
nu_ventc	ν_{VENTC}	Average duration of infection requiring ventilation but not receiving it due to capacity (assumed same as nu_vent parameter).	Days
Interventions Parameters			
selfis_eff	s_{iso}	Adherence to self-isolation	%
screen_overdispersion	–	Overdispersion: (1, 2, 3, 4 or 5)	
screen_test_sens	s_{screen}	Test sensitivity	%
(*Self-isolation) Household Isolation Parameters			
quarantine_days	v_q	Days in isolation for average person	Days
quarantine_effort	e_q	Days to implement maximum quarantine coverage (1 to 5)	days
quarantine_eff_other	q_{other}	Decrease in the number of other contacts when quarantined	%
quarantine_eff_home	q_{home}	Increase in the number of contacts at home when quarantined	%
Social Distancing Parameters			
dist_eff	$disteff$	Adherence to social distancing	%
Handwashing Parameters			
hand_eff	$handeff$	Efficacy of handwashing (0%–25%); note that only the maximum of handwashing or mask-wearing (efficacy * coverage) is used in transmission calculations. Coverage of handwashing (proportion of individuals following handwashing guidelines) is denoted with $handcov$.	%
Mask-wearing Parameters			
mask_eff	$maskeff$	Efficacy of mask wearing (0%–35%); note that only the maximum of handwashing or mask-wearing (efficacy * coverage) is used in transmission calculations. Coverage of mask wearing (proportion of population following mask wearing guidelines) is denoted with $maskcov$.	%
Working at Home Parameters			
work_eff	$workeff$	Efficacy of working from home	%
w2h	–	Home contacts inflation due to working from home:	%
School Closures Parameters			
s2h	–	Home contacts inflation due to school closure	%
Shielding the Elderly Parameters			
cocoon_eff	–	Efficacy of shielding the elderly	%
age_cocoon	–	Minimum age for elderly shielding (0 to 100)	y.o.
Vaccination Parameters			
vac_campaign	v_c	Time to reach target coverage in vaccination campaign (1 to 52)	weeks
vac_dur	v_d	1 / duration of vaccine efficacious period	Years
vac_dur_r	v_{dr}	1 / duration of vaccine efficacious period if previously infected	Years
vaccine_eff	p_V	Vaccine efficacy	
vaccine_eff_r	p_{VR}	Vaccine efficacy if previously infected	
Mass Testing Parameters			
mass_test_sens	s_{mass}	Sensitivity of mass testing	%
isolation_days	v_{iso}	Isolation days	days
Dexamethasone Parameters			
dexo2	d_{O2}	Relative risk of dying if needing O2 and taking dexamethasone	%
dexv	d_{VENT}	Relative risk of dying if needing ventilation and taking dexamethasone	%
dexo2c	d_{O2C}	Relative risk of dying if needing but not receiving O2 and taking dexamethasone	%
dexvc	d_{VENTC}	Relative risk of dying if needing but not receiving ventilation and taking dexamethasone	%

Parameter name (as used in code)	Symbol	Description	Units
vent_dex	–	Change in ventilation requirement if given dexamethasone (multiplier on prob_vent). See description of prob_v parameter.	%
Derived parameters			
aging	A_{age}	Aging matrix (assuming states are vectors with elements for each age).	
quarantine_rate	q_r	Quarantine rate (see below)	
vaccinate	v	Vaccination rate	
age_vaccine_vector	A_v	Vector of vaccination uptake by age	
lam	λ	Force of infection including impact of PHSM (lambda)	
lamq	λ_q	Force of infection including impact of PHSM (lambda) for those under quarantine	
critH	p_{critH}	Calculated from splines.	
crit	p_{crit}		
critV	p_{critV}		
age_testing_vector	A_u	Vector of test rates by age	
ratetestE	u_E	Testing rate of the E class	
ratetestEV	u_{EV}	Testing rate of the EV class	
ratetestEVR	u_{EVR}	Testing rate of the EVR class	
ratetestER	u_{ER}	Testing rate of the ER class	
ratetestI	u_I	Testing rate of the I class	
ratetestC	u_{CL}	Testing rate of the CL class	
ratetestHC	u_{HC}	Testing rate of the HC class	
ratetestHCICU	u_{HCICU}	Testing rate of the HCICU class	
ratetestHCV	u_{HCV}	Testing rate of the HCV class	
screen_eff	s_{screen}	Efficacy of screening	
seas	s	Seasonality factor; $s = 1 + a\ cos\ (2\pi(t - (365.25\phi/12))/365.25)$	
P	P	Total population	
selfis_cov	c_{iso}	Coverage of self-isolation	
selfis (here)			

Appendix Table 3. Cases

Inputs	Value(s)	Input Source
Number of reported COVID19 cases per day	Cases reported between 24/02/2020 and 15/10/2020	Jordan MoH
Daily COVID19 deaths	deaths reported between 14/02/2020 and 15/10/2020	Jordan MoH

Appendix Table 4. Severity and Mortality

Age category	Age-based relative fatality rate in well-resourced scenario (%) data source: https://science.sciencemag.org/content/sci/suppl/2020/05/12/science.abc3517.DC1/abc3517_Salje_SM_rev2.pdf	Age-stratum-specific hospitalization (proportion of all (asymptomatic + symptomatic) infections that lead to hospitalization) (%)
0–5 y.o.	0.6	0.1
5–10 y.o.	0.6	0.1
10–15 y.o.	0.6	0.1
15–20 y.o.	0.6	0.1
20–25 y.o.	1.1	0.5
25–30 y.o.	1.1	0.5
30–35 y.o.	1.9	1.1
35–40 y.o.	1.9	1.1
40–45 y.o.	3.3	1.4
45–50 y.o.	3.3	1.4
50–55 y.o.	6.5	2.9
55–60 y.o.	6.5	2.9
60–65 y.o.	12.6	5.8
65–70 y.o.	12.6	5.8
70–75 y.o.	21	9.3
75–80 y.o.	21	9.3
80–85 y.o.	31.6	26.2
85–90 y.o.	31.6	26.2
90–95 y.o.	31.6	26.2
95–100 y.o.	31.6	26.2
100+ y.o.	31.6	26.2

Appendix Table 5. Population

Age category	Population Data Source: UN 2019 Revision of World Population Prospects.	Number of births per person (ie 0.5* births per woman) per day Data Source: UN 2019 Revision of World Population Prospects[7.]	Deaths per person per day Data Source: UN 2019 Revision of World Population Prospects[7.]
0–4 y.o.	1058122	0	9.5131E-06
5–9 y.o.	1154441	0	8.927E-07
10–14 y.o.	1139559	0	7.212E-07
15–19 y.o.	1040294	3.33108E-05	1.3306E-06
20–24 y.o.	940151	0.000141126	1.8731E-06
25–29 y.o.	862385	0.000206421	2.0039E-06
30–34 y.o.	777482	0.000183412	2.3882E-06
35–39 y.o.	713126	0.000110293	3.1029E-06
40–44 y.o.	606717	3.27423E-05	4.7969E-06
45–49 y.o.	534628	2.2533E-06	7.8137E-06
50–54 y.o.	433223	0	1.23955E-05
55–59 y.o.	322368	0	1.99431E-05
60–64 y.o.	217239	0	3.30424E-05
65–69 y.o.	149039	0	5.96328E-05
70–74 y.o.	111528	0	0.000103811
75–79 y.o.	79223	0	0.000169096
80–84 y.o.	43119	0	0.000280179
85–89 y.o.	16283	0	0.000437
90–94 y.o.	3741	0	0.000637149
95–99 y.o.	444	0	0.001002645
100+ y.o.	28	0	0.015899091

Appendix Table 6. Country Area Parameters

Inputs	Value(s)	Input Source
Social Contacts Data:	Jordan	Prem, K., A.R. Cook, and M. Jit, *Projecting social contact matrices in 152 countries using contact surveys and demographic data.* PLoS Comput Biol, 2017. 13(9): p. e1005697.
Mean Household size:	4.7 individuals	Jordan MoH
Mean number of infectious migrants per day:	0 individuals	As the travel restrictions were implemented early in the pandemic it was assumed to be 0 if effective isolation of infectious migrants were in place.

Appendix Table 7. Calibration Parameters

Parameter	Scenario: 10% of the population infected	Source
Date range of simulation - START	1/3/2020	fitted
Date range of simulation - END	31/1/2021	assumed
Number of exposed people at start date	1	fitted
Probability of infection given contact (0 to 0.2)	0.029	fitted

Appendix Table 8. Virus Parameters

Relative infectiousness of incubation phase:	10%	Assumed value
Average incubation period:	3.5 d	Linton, N.M., et al., *Incubation Period and Other Epidemiologic Characteristics of 2019 Novel Coronavirus Infections with Right Truncation: A Statistical Analysis of Publicly Available Case Data.* J Clin Med, 2020. 9(2). Khalili, M., et al., *Epidemiologic Characteristics of COVID-19; a Systematic Review and Meta-Analysis.* Plos One, 2020. Submitted. Bi, Q., et al Epidemiology *and Transmission of COVID-19 in Shenzhen China: Analysis of 391 cases and 1,286 of their close contacts.* medRxiv, 2020: p. 2020.03.03.20028423. *Coronavirus disease 2019 (COVID-19) pandemic: increased transmission in the EU/EEA and the UK – seventh update*. Available from: https://www.ecdc.europa.eu/sites/default/files/documents/RRA-seventh-update-Outbreak-of-coronavirus-disease-COVID-19.pdf.
Average duration of symptomatic infection period:	4.5 d	Linton, N.M., et al., *Incubation Period and Other Epidemiologic Characteristics of 2019 Novel Coronavirus Infections with Right Truncation: A Statistical Analysis of Publicly Available Case Data.* J Clin Med, 2020. 9(2).
Probability upon infection of developing clinical symptoms:	55%	Mizumoto, K., et al., *Estimating the Asymptomatic Proportion of 2019 Novel Coronavirus onboard the Princess Cruises Ship, 2020.* medRxiv, 2020: p. 2020.02.20.20025866. Day, M., *Covid-19: four fifths of cases are asymptomatic, China figures indicate.* BMJ, 2020. 369: p. m1375. *Coronavirus disease 2019 (COVID-19) pandemic: increased transmission in the EU/EEA and the UK – seventh update*. Available from: https://www.ecdc.europa.eu/sites/default/files/documents/RRA-seventh-update-Outbreak-of-coronavirus-disease-COVID-19.pdf.
Probability upon hospitalization of requiring ICU admission with mechanical ventilation:	10%	Jordan MoH

Appendix Table 9. Hospitalization Parameters

Inputs	Value(s)	Input Source
Maximum number of hospital beds	3894 beds	Jordan MoH
Maximum number of ICU beds with ventilators	834 ventilators	Jordan MoH
Relative percentage of regular daily contacts when hospitalized:	15%	Assumed value
Probability of dying when hospitalized:	35%	https://www1.nyc.gov/site/doh/covid/covid-19-data.page. Zhou, F., et al., *Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study.* Lancet, 2020. 395(10229): p. 1054–1062.
Probability of dying when denied hospitalization:	50%	Petrilli, C.M., et al., *Factors associated with hospitalization and critical illness among 4,103 patients with COVID-19 disease in New York City.* medRxiv, 2020: p. 2020.04.08.20057794.
Probability of dying when admitted to ICU:	68%	value was recalculated from: Petrilli, C.M., et al., *Factors associated with hospitalization and critical illness among 4,103 patients with COVID-19 disease in New York City.* medRxiv, 2020: p. 2020.04.08.20057794. Lewnard, J.A., et al., *Incidence, clinical outcomes, and transmission dynamics of hospitalized 2019 coronavirus disease among 9,596,321 individuals residing in California and Washington, United States: a prospective cohort study.* medRxiv, 2020: p. 2020.04.12.20062943. To reflect the hospital system in Jordan

Inputs	Value(s)	Input Source
Probability of dying when admission to ICU denied:	85%	value was recalculated from: Petrilli, C.M., et al., *Factors associated with hospitalization and critical illness among 4,103 patients with COVID-19 disease in New York City.* medRxiv, 2020: p. 2020.04.08.20057794. To reflect the hospital system in Jordan
Duration of hospitalized infection:	7 d	Jordan MoH
Duration of ICU with ventilation infection:	14 d	Jordan MoH

Appendix Table 10. Public health and social measures parameters

Self-isolation if Symptomatic	Parameter	Value	Source
	Adherence:	65%	Jordan MoH
(*Self-isolation) Screening			Jordan MoH
	Overdispersion: (1, 2, 3, 4 or 5)	4	Jordan MoH
	Test Sensitivity:	80%	Jordan MoH
(*Self-isolation) Household Isolation			
	Days in isolation for average person:	14 d	Jordan MoH
	Days to implement maximum quarantine coverage: (1 to 5)	2 d	Jordan MoH
	Decrease in the number of other contacts when quarantined:	20%	Jordan MoH
	Increase in the number of contacts at home when quarantined:	100%	Jordan MoH
Social Distancing			
	Adherence:	Varied %	Jordan MoH
Handwashing			
	Efficacy: (0%–25%)	5%	Jordan MoH
Mask Wearing			
	Efficacy: (0%–35%)	35%	Jordan MoH
Working at Home			
	Efficacy:	95%	Jordan MoH
	Home contacts inflation due to working from home:	10%	Jordan MoH
School Closures			
	Home contacts inflation due to school closure:	10%	Jordan MoH

Appendix Table 11. Interventions

Intervention	Date Start	Date End	Value	Unit	Source
Self-isolation if Symptomatic	3/16/2020	9/20/2020	85	%	Jordan MoH
Self-isolation if Symptomatic	9/21/2020	1/31/2021	50	%	Jordan MoH
Social Distancing	3/15/2020	5/1/2020	70	%	Jordan MoH
Social Distancing	5/2/2020	6/1/2020	45	%	Jordan MoH
Social Distancing	6/2/2020	7/1/2020	15	%	Jordan MoH
Social Distancing	7/2/2020	9/15/2020	10	%	Jordan MoH
Social Distancing	9/16/2020	9/25/2020	15	%	Jordan MoH
Social Distancing	9/26/2020	10/29/2020	35	%	Jordan MoH
Social Distancing	10/30/2020	10/31/2020	80	%	Jordan MoH
Social Distancing	11/1/2020	11/5/2020	50	%	Jordan MoH
Social Distancing	11/6/2020	11/7/2020	80	%	Jordan MoH
Social Distancing	11/8/2020	11/12/2020	50	%	Jordan MoH
Social Distancing	11/13/2020	11/14/2020	80	%	Jordan MoH
Social Distancing	11/15/2020	11/19/2020	50	%	Jordan MoH
Social Distancing	11/20/2020	11/21/2020	80	%	Jordan MoH
Social Distancing	11/22/2020	11/26/2020	50	%	Jordan MoH
Social Distancing	11/27/2020	11/28/2020	80	%	Jordan MoH
Social Distancing	11/29/2020	12/3/2020	50	%	Jordan MoH
Social Distancing	12/4/2020	12/5/2020	80	%	Jordan MoH
Social Distancing	12/6/2020	12/10/2020	50	%	Jordan MoH
Social Distancing	12/11/2020	12/12/2020	80	%	Jordan MoH
Social Distancing	12/13/2020	12/17/2020	50	%	Jordan MoH
Social Distancing	12/18/2020	12/19/2020	80	%	Jordan MoH
Social Distancing	12/20/2020	12/24/2020	50	%	Jordan MoH
Social Distancing	12/25/2020	12/26/2020	80	%	Jordan MoH
Social Distancing	12/27/2020	12/31/2020	50	%	Jordan MoH
Social Distancing	1/1/2021	1/2/2021	80	%	Jordan MoH
Social Distancing	1/3/2021	1/7/2021	50	%	Jordan MoH
Social Distancing	1/8/2021	1/9/2021	80	%	Jordan MoH
Social Distancing	1/10/2021	1/14/2021	50	%	Jordan MoH
Social Distancing	1/15/2021	1/16/2021	80	%	Jordan MoH
Social Distancing	1/17/2021	1/21/2021	50	%	Jordan MoH
Social Distancing	1/22/2021	1/23/2021	80	%	Jordan MoH
Social Distancing	1/24/2021	1/28/2021	50	%	Jordan MoH
Social Distancing	1/29/2021	1/30/2021	80	%	Jordan MoH
Social Distancing	1/31/2021	2/4/2021	50	%	Jordan MoH
Social Distancing	2/5/2021	2/6/2021	80	%	Jordan MoH
Social Distancing	2/7/2021	2/11/2021	50	%	Jordan MoH
Social Distancing	2/12/2021	2/13/2021	80	%	Jordan MoH
Social Distancing	2/14/2021	1/31/2021	50	%	Jordan MoH
Handwashing	2/25/2020	2/15/2021	100	%	Jordan MoH
Working at Home	3/17/2020	5/1/2020	70	%	Jordan MoH
Working at Home	5/2/2020	6/1/2020	45	%	Jordan MoH
Working at Home	6/2/2020	9/25/2020	15	%	Jordan MoH
Working at Home	9/26/2020	1/31/2021	35	%	Jordan MoH
School Closures	3/14/2020	9/1/2020	100	%	Jordan MoH
School Closures	9/15/2020	10/5/2020	70	%	Jordan MoH
School Closures	10/6/2020	1/31/2021	100	%	Jordan MoH