Predicted impact of vaccination and active case finding measures to control epidemic of Coronavirus Disease 2019 (COVID-19) in a migrant-populated area in Thailand

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Abstract

Background: Thailand experienced the first wave of Coronavirus Disease 2019 (COVID-19) during March-May 2020 and was now facing the second wave of COVID-19 since December 2020. For the second wave, the intensity was more pronounced. The area faced the greatest hit was Samut Sakhon, a main migrant-receiving province in the country. Thus, the Thai Ministry of Public Health (MOPH) was now considering the initiation of vaccination strategies in combination with active face finding (ACF) in the epidemic area. The objective of this study was to assess the impact of various vaccination and ACF policy scenarios in terms of case reduction and deaths averted.

Methods: The study obtained data mainly from the Division of Epidemiology, Department of Disease Control (DDC), MOPH. Deterministic system dynamics and compartmental models were exercised. Basic reproductive number (R_0) was estimated at 3 from the beginning. Vaccine efficacy against disease transmission was assumed to be 50%. A total of 10,000 people were estimated as an initial population size.

Results: The findings showed that the greater the vaccination coverage was, the smaller the size of incident and cumulative cases. Compared with no-vaccination and no-ACF scenario, the 90%-vaccination coverage combined with 90%-ACF coverage contributed a reduction of cumulative cases by 33%. The case reduction benefit would be greater when R_0 was smaller (53% and 51% when R_0 equated 2 and 1.5 respectively).

Conclusion: This study reaffirmed the idea that a combination of vaccination and ACF measures contributed to favourable results in reducing the number of COVID-19 cases and deaths, relative to the implementation of only a single measure. The greater the vaccination and ACF coverage was, the greater the volume of cases could be saved. Though we demonstrated the benefit of vaccination strategies in this setting, the actual implementation needs to consider many more policy angles, such as social acceptability, cost-effectiveness and operational feasibility. Further studies that address these topics based on empirical evidence are of great value.

Introduction

In late 2019, the world firstly recognized Coronavirus Disease 2019 (COVID-19)-a disease that is undoubtedly one of the once-in-a-lifetime pandemics [1-3]. As of 14 February 2021, more than 108 million COVID-19 cases were reported in 219 countries and the infected toll appeared to increase at a speedy pace [4].

Thailand is the first country outside China that reported the presence of COVID-19. The first wave of COVID-19 outbreak in Thailand was caused by clusters of local infections related to imported cases from other countries, local transmission in boxing stadiums, entertainment venues as well as other public crowded places [5]. Most of the cases were Thai citizens. In response to this, the Thai Government introduced several measures to curb the outbreak; for instance, international travel restriction, fourteen-day quarantine for all international returnees, interprovincial travel prohibition, and social distancing [6].

The Division of Epidemiology (DOE) under the Department of Disease Control (DDC) of the Ministry of Public Health (MOPH) has played a pivotal role in containing and mitigating the outbreak. One of the key measures exercised by the DOE is intensive outbreak investigation and active case finding (ACF) in communities. Due to these combined measures and resilient health system, Thailand was recognized of its achievement in containing COVID-19 pandemic in the global health arena [7, 8].

However, Thailand is now facing a new challenge as the new wave of epidemic emerged in late December 2020, and this time, the hit was more severe than the earlier wave [9]. Before December 2021, the number of total cases nationwide was about 5,000. The national figure skyrocketed after January 2021. As of 14 February 2021, the volume of cumulative nationwide cases amounted to 24,571—almost tripled the total cases reported in 2020 [10].

The new wave of epidemic was believed to originate from migrant workers in a large shrimp market in the inner city of Samut Sakhon, a vicinity province of Bangkok. The province is a home of more than 11,000 factories with approximately 400,000 migrant workers (comprising those holding legitimate work permit and those without). The majority of them are from Myanmar. The living condition of these workers is quite crowed, making social distancing or using mask all the time is quite limited [11]. The rapid survey in early January 2021 by the DOE found about one fifth of the factories had some degree of infected workers, varying from less than 5% to more than 20%.

The daily incident cases in Samut Sakhon numbered about 100-150 throughout January 2021 [10]. On certain days when ACF was conducted, the incidence cases exceeded 800. Migrant workers accounted for approximately 80% of the total cases in Samut Sakhon and about four-fifth were identified by mass COVID-19 testing at markets, factories, and migrant communities (as part of the ACF). Moreover, city lockdown and strict social distancing campaign were implemented [12]. Although numerous measures were enforced, the case toll seemed to enlarge; and, at the time of writing, there was no sign that the case had reached its acme. The new wave of epidemic happened at the same time with the launch of COVID-19 vaccines in the global market.

Based on the interim data of many clinical trials, COVID-19 vaccine was estimated to be effective in preventing severe-to-moderate COVID-19 clinical symptoms. The efficacy varied across vaccine companies and across trial settings (62%-95%), though recent evidence showed a promising sign that the vaccine might be able to prevent disease transmission [13, 14]. This created a contentious policy discourse and widespread public debate in the Thai society whether COVID-19 vaccine could be a useful weapon to fight against COVID-19, especially in Samut Sakhon where the epidemic was still active and social distancing was difficult to implement due to crowded living conditions of migrant workers. The first batch of COVID-19 vaccines was scheduled to arrive in Thailand in the first quarter of 2021.

Therefore, this study aims to estimate the effectiveness of policy options to control COVID-19 epidemic in Samut Sakhon. These policy options included (i) extensive ACF with isolation of positive cases, (ii) vaccination measures to Samut Sakhon residents, and (iii) a combination of ACF and vaccination measures. We applied compartmental and systems dynamic model to address this research question.

Methods

Study design

We applied quantitative secondary data analysis. Most model parameters were obtained from the internal database of the DOE and Samut Sakhon Provincial Public Health Office (PPHO). A further review was performed in MEDLINE database. The review focused on articles published during 2019-2020. As the aim of the review was more of identifying key parameters to serve as inputs for the model rather than answering any specific research questions, no specific inclusion and exclusion criteria were set on the literature search. Some common search terms (such as 'COVID-19', 'SARS-CoV-2', 'generation time' and 'serial interval') were utilized. We attempted to seek parameters from domestic sources first. If no domestic literature was available, foreign literature was used instead. If the interested parameters could not be identified from the recruited literature, we would reply on the opinions of epidemiological experts of the MOPH. More details on the parameters are presented later in sub-section, 'Model validation and parameter list'.

Model framework

We used compartmental susceptible-exposed-infected-recovered (SEIR) model as the base framework to assess the likely impact in a hypothesised population (N = 10,000) if ACF and vaccination measures put into effect in Samut Sakhon. The SEIR model categorised the population into four compartments: the susceptible, the exposed (but not infectious), the infected and the recovered. Susceptible people would become infected once contacting with infected cases [15]. The rate of transferring from susceptible compartment to exposed compartment was greatly determined by reproduction number (R_0)—the number of new cases generated as a result of the contact with a case amongst susceptible population throughout the infectious period [16]. Incubation period determined the speed of switching from exposed compartment to infected compartment. Length of hospital stay governed how fast a patient transferred from infected compartment to recovered compartment. We divided the population into five categories (asymptomatic, mild, moderate, severe [needing intensive care], and dead). We also incorporated the concept of system dynamics in the base SEIR model to enable the model to reflect the actual field operation. The infected compartment was split up into two compartments in sequential order; namely, 'infected before isolation' and 'infected after isolation'. We proposed that the benefit of ACF was mainly the reduction of lag time between once infected and isolation by approximately 50%. Since, at the time of writing, the consensus on the efficacy of vaccine from various companies was yet to be finalised, we hence referred to the recommendation of the World Health Organization (WHO) that ensure that a widely deployed COVID-19 vaccine would be effective if the primary efficacy endpoint for a placebo-controlled efficacy trial should be at least 50% [17]. In this regard, we used a figure of 50% as vaccine efficacy parameter for transmission reduction (reducing the probability of transferring from susceptible compartment to exposed compartment). The simplified model framework is elicited in Figure 1.

Model assumptions and interested outcomes

The model relied on a few key assumptions. Firstly, we assumed that the ACF did not operate all the time but functioned in a biweekly fashion. Secondly, there was in- and out-migration to and from the province. Thirdly, it is presumed that mass vaccination for target population could be performed within a day without any logistic delay. Fourthly, a contact between a case and each susceptible person took place at random. Lastly, all infected persons were treated and received health services. The outcomes of interest were (i) daily incident cases, (ii) cumulative cases, (iii) cumulative deaths, and (iv) prevalent intensive-care-unit (ICU) bed demand. As, in actual operation, vaccine coverage and degree of ACF intensity might vary. Hence, we analysed nine policy scenarios to aide policy, Table 1.

Table 1 Policy scenarios of interest

Scenario	Vaccination coverage (%)	Active case finding coverage (%)
no-VAC & no-ACF	None	None
no-VAC & ACF50	None	50
no-VAC & ACF90	None	90
VAC50 & no-ACF	50	None
VAC50 & ACF50	50	50
VAC50 & ACF90	50	90
VAC90 & no-ACF	90	None
VAC90 & ACF50	90	50
VAC90 & ACF90	90	90

Model validation and parameter list

We calibrated R_0 by recent evidence on new daily cases in Samut Sakhon between 1 Jan 2021 and 21 Jan 2021. During the peak of outbreak, the effective reproduction number of Samut Sakhon exceeded 3 with a range from 0.2 to 5.6 [10]. The model results were validated against the opinions of epidemiological experts in the Thai-DDC. A couple of meetings were held. Each round contained ten to fifteen participants and lasted approximately 45 minutes. The participants were asked to brainstorm and comment on the model in terms of correctness and estimation of key parameters. The model was calibrated by running the model with all acquired parameters. We found that replacing R_0 with 3 soundly reflected the actual situation in the province. Stella 2.0 (number: 251-401-786-859) was used to run the model. Tables 2-3 display key parameters and essential formula of the model.

Table 2 List of key parameters

Parameter	Unit	Value	Reference
Reproduction number	Dimensionless	3	Model calibration
Setting population	Persons	10,000	Estimated population size of a migrant populated community in Samut Sakhon based on experience of the locals
Prevalence of infectees at the beginning of the outbreak (%)	Dimensionless	10	Expert opinions
Average incubation period	Days	5.2	Li et al [18]
Infectious duration and gap between infected and isolated	Days	7	Byrne et al [19] and expert opinions
Vaccine efficacy (%)	Dimensionless	50	World Health Organization [17]
Clinical profile: asymptomatic (%)	Dimensionless	56.6	Internal database of the Department of Disease Control
Clinical profile: mild (%)	Dimensionless	42.2	Internal database of the Department of Disease Control
Clinical profile: moderate (%)	Dimensionless	0.9	Internal database of the Department of Disease Control
Clinical profile: severe (%)	Dimensionless	0.2	Internal database of the Department of Disease Control
Clinical profile: dead (%)	Dimensionless	0.1	Internal database of the Department of Disease Control
Hospitalisation days: asymptomatic	Days	10	Internal database of the Department of Disease Control
Hospitalisation days: mild	Days	10	Internal database of the Department of Disease Control
Hospitalisation days: moderate	Days	14	Internal database of the Department of Disease Control
Hospitalisation days: severe	Days	30	Internal database of the Department of Disease Control
Hospitalisation days: death	Days	30	Internal database of the Department of Disease Control
Time horizon for the analysis	Days	90	Expert opinions

Table 3 Essential formula of the model

Change of status	Formula	Note
From susceptible to exposed	dS/dt = -(R_0/Dinf)*(1-VE)*VC*S*Ib/P	Dinf = infectious duration, Ib = Infectees (before isolation), P = total population, R_0 = basic reproduction number, S = susceptible population, VC = vaccination coverage, VE = vaccine efficacy
From susceptible to infected (before isolation)	dIb/dt = -E/Dinc	Dinc = incubation period, E = Exposed population
From infected (before isolation) to infected (after isolation) from active case finding	dIb/dt = -ACFC*(Ib/(Dlag*(1-ACFE))	ACFC = active case finding coverage, ACFE = active case finding effectiveness, Dlag = lag days from infected to isolation, Ib = Infectees (before isolation)
From infected (before isolation) to infected (after isolation) from routine health services	dIb/dt = -(1-ACFC)*(Ib/(Dlag*)	ACFC = active case finding coverage, Dlag = lag days from infected to isolation, Ib = Infectees (before isolation)
From infected to recovered	dIa/dt = -Ia/Drx	Drx = hospitalisation days, Ia = Infectees (after isolation)

Sensitivity analysis

Sensitivity analysis was performed as complementary to the main analysis. While the main analysis relied on R_0 of 3, this part analysed the change in cumulative case volume if R_0 changed to 1.5 and 2. We compared the percentage reduction of cumulative cases in each scenario against 'no-VAC & no-ACF' scenario.

Results

From a macro perspective, ACF-containing policies (eg, 'no-VAC & ACF90' and 'no-VAC & ACF50') demonstrated more daily incident cases at the very beginning of the outbreak (~200-250 cases per day) compared with 'no-VAC & no-ACF' measure. However, after a week, 'no-VAC & no-ACF' policy showed an upward trend and reached a peak of about 260 cases per day by day 25. The ACF-containing policies displayed a sharp spike of the incident cases by day 30, followed by a rapid decline in cases. Given the same ACF coverage, the greater the vaccination coverage was, the smaller the spike presented. 'VAC90 & ACF90' policy saw the least incident cases relative to other policies, Figure 2.

By day 90, 'no-VAC & ACF90' policy contributed to about 10,500 cases—the largest amongst all scenarios. 'VAC50 & no-ACF' and 'no-VAC & ACF50' policies came the second (~9,900 cases), followed by 'VAC-90 & no-ACF', 'no-VAC & ACF-90' and 'VAC50 & ACF50' policies (~9,000-9,300 cases).

If the vaccination covered 90% of the population in combination with 50% ACF coverage (VAC90 & ACF50) or vice versa (VAC50 & ACF90), the cumulative case toll dropped to approximately 8,000-8,200. 'VAC90 & ACF90' policy resulted in the least volume of cases (~7,000 cases), Figure 3.

All policies displayed almost the same number of cases during the first two weeks, then demonstrated the largest difference by day 40, and converged to same level again after day 80. The widest gap of cases needing ICU bed was observed when we compared 'no-VAC & no-ACF' (~35 cases) with 'VAC90 & ACF90' (~20 cases). The case volume of other scenarios presented somewhere between 'no-VAC & no-ACF' and 'VAC90 & ACF90' policies, Figure 4.

The death toll varied across policy scenarios by a fine margin. 'VAC50 & no-ACF', 'no-VAC & no-ACF', and 'no-VAC & ACF50' policies yielded approximately four cases by end of analysis time. 'VAC90 *& ACF90' policy exhibited fewer than three deaths in total, the smallest figure when comparing with other scenarios, Figure 5.

Sensitivity analysis revealed that vaccination and ACF measures produced the greatest benefit in the lens of percentage reduction in total case volume when R_0 was 2. Given R_0 equalling 1.5 or 3, the benefit still presented but with a lesser extent. For instance, with 'no-VAC & no-ACF' as a reference, 'VAC50 & ACF50' contributed to a 38%-decline in accumulative case number when R_0 amounted to 2, but the corresponding figure appeared to be -30% and -14% when R_0 was 1.5 and 3 respectively, Table 4.

Table 4 Reduction of cumulative cases by day 90 between each policy and ‘no-VAC & no-ACF’ policy

	Volume			Percent reduction		
	R_0 = 1.5	R_0 = 2	R_0 = 3	R_0 = 1.5	R_0 = 2	R_0 = 3
no-VAC & no-ACF	9132	7337	10457	Reference	Reference	Reference
no-VAC & ACF50	7755	5579	9895	−15%	−24%	−5%
no-VAC & ACF90	6616	4525	9330	−28%	−38%	−11%
VAC50 & no-ACF	7963	6022	9935	−13%	−18%	−5%
VAC50 & ACF50	6363	4556	9024	−30%	−38%	−14%
VAC50 & ACF90	5290	3812	8188	−42%	−48%	−22%
VAC90 & no-ACF	6793	5084	9187	−26%	−31%	−12%
VAC90 & ACF50	5318	3980	7960	−42%	−46%	−24%
VAC90 & ACF90	4473	3446	6971	−51%	−53%	−33%

Discussion

Overall, this study confirmed that a combination of vaccination and ACF measures contributed to favourable results in minimising the case volume and death toll. The greater the vaccination and ACF covered, the greater the volume of cases averted. In addition, the benefit of all combined strategies in terms of total case reduction would be maximised if the epidemic activity, as reflected by R_0, was not too intense.

This finding corroborated the ideas of many studies abroad that ACF is a key measure to contain and suppress the epidemic [20]. For example, China reported the use of ACF to identify patients in the epidemic communities [20]. This was performed not only by the state but also by the assistance of community network. Other countries that successfully contained COVID-19 through ACF and close-contact identification included Iceland, Mongolia, Singapore, South Korea, and Vietnam [7, 21, 22]. Singapore maximised detection of suspected patients through a public prevention clinic network and tightly implemented, legally supported home quarantine orders for patients with mild illness [23, 24]. South Korea greatly expanded the scope of testing to detect cases as early as possible with numerous screening sites capable of taking SARS-CoV-2 nucleic acid tests (including public health-care clinics, drive-through centres, and walk-in screening sites) [25, 26].

Traoré and Konané suggested that the contact tracing strategy as well as ACF can reduce R_0 to values below unity as intended for disease control, but effective control of the epidemic can be achieved when the effectiveness of contact tracing is high, and R_0 is not too large. In the population where R_0 is large, the epidemic may not be controlled using ACF strategy alone [27]. Our findings also upheld that idea that such a vaccination policy hugely complements ACF measure. The situation in Samut Sakhon is very complex because the city is extremely urbanised and migrant residents are mostly living in densely populated conditions. These conditions create a remarkable difficulty for ACF and other non-pharmaceutical interventions (NPI), such as physical distancing measure and individual risk modification. At present, ACF is the major intervention in Samut Sakhon with an aim to test all 400,000 workers and isolate those who are positive for 10 days in field hospital or factory dormitory. So far the Government has built up approximately 3,000 field hospital beds. Healthcare providers use individual nasopharyngeal swab for real-time polymerase chain reaction (Rt-PCR) testing. By average it takes at least 48 hours to obtain the swab result. This means ACF alone may not be able to detect and isolate cases as early as expected. Thus, the Thai Government should consider an urgent launch of vaccination policy in Samut Sakhon or in any settings alike once the COVID-19 vaccines are available.

The bottom line is, at the time of writing, the evidence of vaccine effectiveness against COVID-19 transmission is not yet fully understood [28]. Many different endpoints are used in vaccine research to define efficacy depending on the pathogen, consequences of infection, and transmission dynamics. Outcomes of most randomised controlled trials (RCT) are presented as a proportional decline in disease between vaccinated participants and control participants [29]. Other outcomes might include assessing sterilising immunity, severity of resultant clinical disease, and duration of infectivity. Besides, RCTs almost always represent best-case scenarios of vaccine efficacy under idealised conditions; but, in the real world, vaccine efficacy does not always predict vaccine effectiveness and such effectiveness is likely to vary across age groups and people from different walks of life as certain subpopulations in the society may always face greater risk of infection or may be more vulnerable than the others [30]. However, the findings above are of certain value for policy consideration as the vaccine efficacy parameter applied in the model was very modest (only 50%) while recent evidence demonstrated much more favourable outcomes than the 50% figure [14]. For instance, the latest interim analysis from phase 3 clinical trial in Russia by Logynov et al demonstrated that an rAd26 and rAd5 vector-based heterologous prime-boost COVID-19 vaccine (Sputnik V) showed 91·6% efficacy against COVID-19 and was well tolerated in a large cohort [13, 31, 32].

It should be noted that this study contained a few key limitations despite complex model structure and detailed calculation. Firstly, most parameters included in the model derived from the epidemic situation in Samut Sakhon. Therefore, a generalisation of the findings to other areas should be made with caution; though one may use the approach used in this study as an analysis example in any similar settings. Secondly, during the period of epidemic, it is almost always difficult to conduct primary research to obtain empirical evidence as the utmost priority of the field operations was to curb the epidemic. Accordingly, many parameters in the model were obtained from authors' assumptions. Though we tried to validate the findings against the opinions of experts and local providers, this could not substitute the use of empirical data. Thirdly, the model applied deterministic approach as it is more convenient to communicate with policy makers, compared with stochastic approach and because most parameters in the model lacked information of the distribution characteristic, which is a prerequisite for stochastic analysis. Last but not least, though we demonstrated the benefit of vaccination strategies in this setting, in real practice, the actual implementation needs to consider many more policy angles; for instance, social acceptability (if migrants are supposed to be the vaccination target first before general Thais), cost-effectiveness of the policies, and operational feasibility. Further studies that address these topics are of great value. In addition, a close monitoring of the information in the field is useful, not only for the benefit of disease control, but also for obtaining empirical evidence which will help refine and validate the model.

Conclusion

This study reaffirmed the idea that a combination of vaccination and ACF measures contributed to favourable results in reducing the number of COVID-19 cases and deaths, relative to the implementation of only a single measure. The greater the vaccination and ACF coverage was, the greater the volume of cases could be saved. Additionally, the value of all combined strategies in terms of total case reduction would be maximised if the epidemic activity was not too pronounced. However, in reality, the actual implementation needs to consider many more policy perspectives, including social acceptability, cost-effectiveness of the policies, and operational feasibility, especially in migrant populated areas like Samut Sakhon. Further studies that address these topics are worth conducting.

Abbreviations

Active case finding (ACF)

Coronavirus Disease 2019 (COVID-19)

Department of Disease Control (DDC)

Division of Epidemiology (DOE)

Ministry of Public Health (MOPH)

Non-pharmaceutical interventions (NPI)

Provincial Public Health Office (PPHO)

Randomised controlled trials (RCT)

Real-time polymerase chain reaction (Rt-PCR)

Susceptible-exposed-infected-recovered (SEIR)

Vaccination (VAC)

World Health Organization (WHO)

Declarations

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Author Contributions

Conceptualization, R.S., P.Th., and K.U.; Data curation, R.S. and P.Te.; Formal analysis, R.S. and P.Te.; Funding acquisition, R.S.; Investigation, R.S., N.N., and P.Te; Methodology, R.S., P.Th., and P.Te.; Project administration, R.S. and K.U.; Resources, R.S. and N.N.; Supervision, K.U. and P.Th.; Writing-original draft, R.S. and N.N.; Writing-review & editing, R.S., N.N., P.Th., P.Te., and K.U. All authors approved the manuscript before submission.

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Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to the Thai-DDC’s regulation but are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study did not involve human participation, excepting the process of seeking opinions’ experts on model validity. Almost all the analysis was performed via secondary data. This study obtained ethics approval from the Institute for the Development of Human Research Protections (IHRP), letter head IHRP 985/2563.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests" in this section.

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Figures

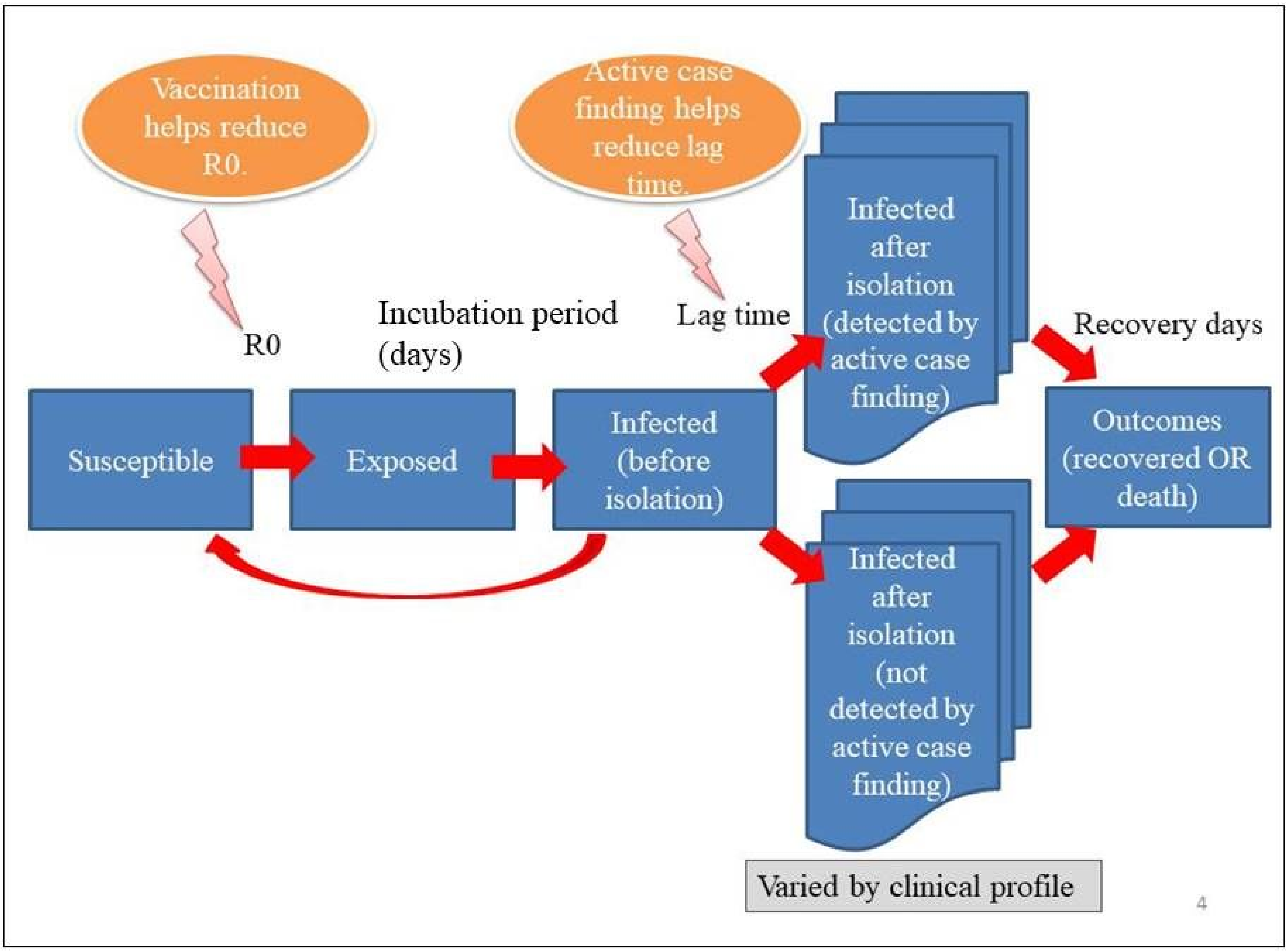

Figure 1

Simplified model framework

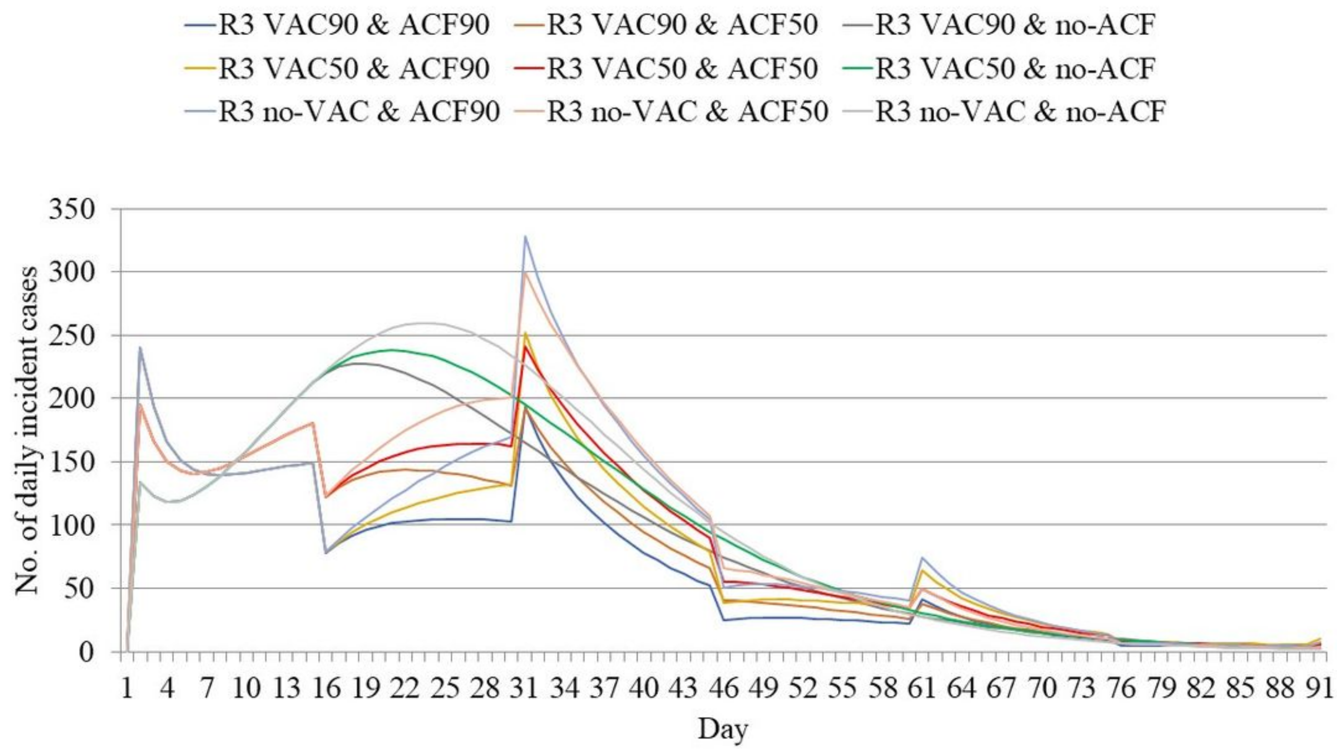

Figure 2

Daily incident cases by policy scenarios.

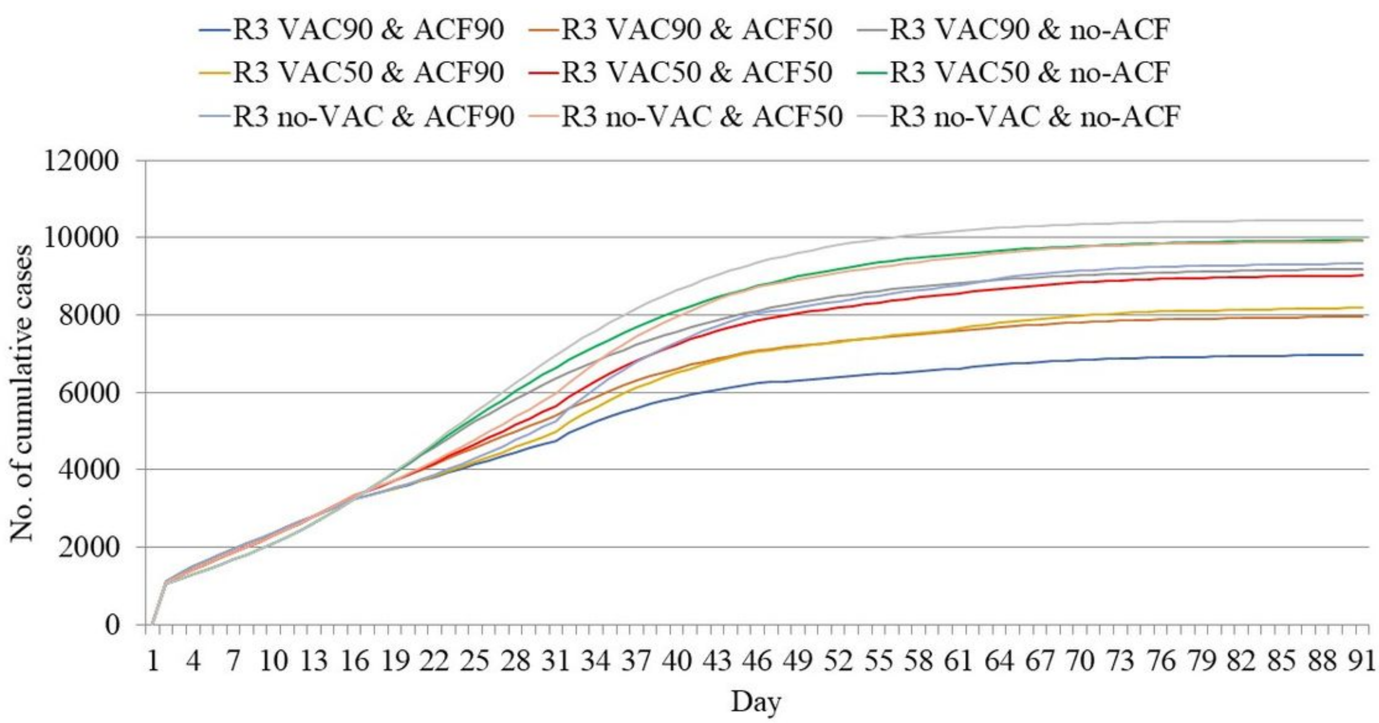

Figure 3

Cumulative cases by policy scenarios

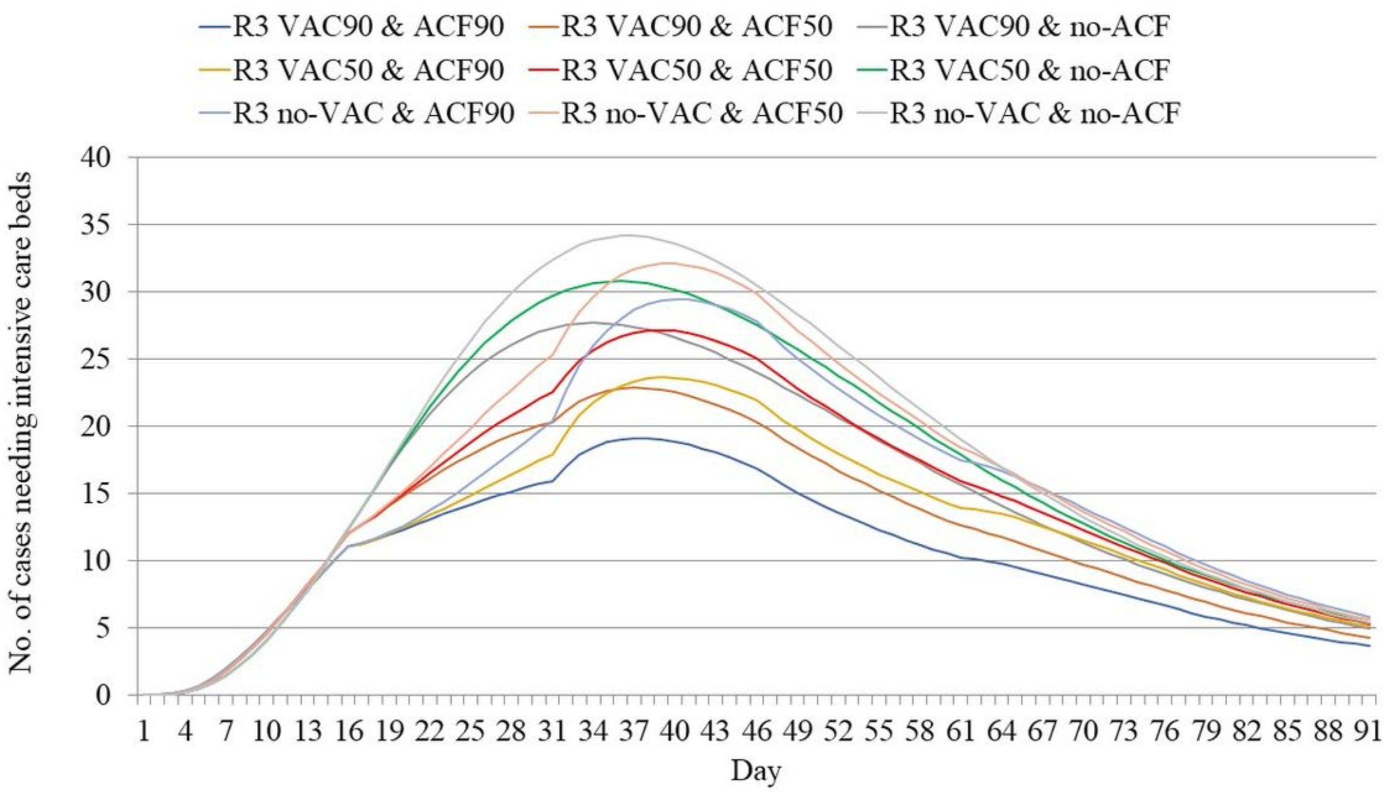

Figure 4

Prevalent cases needing intensive care beds

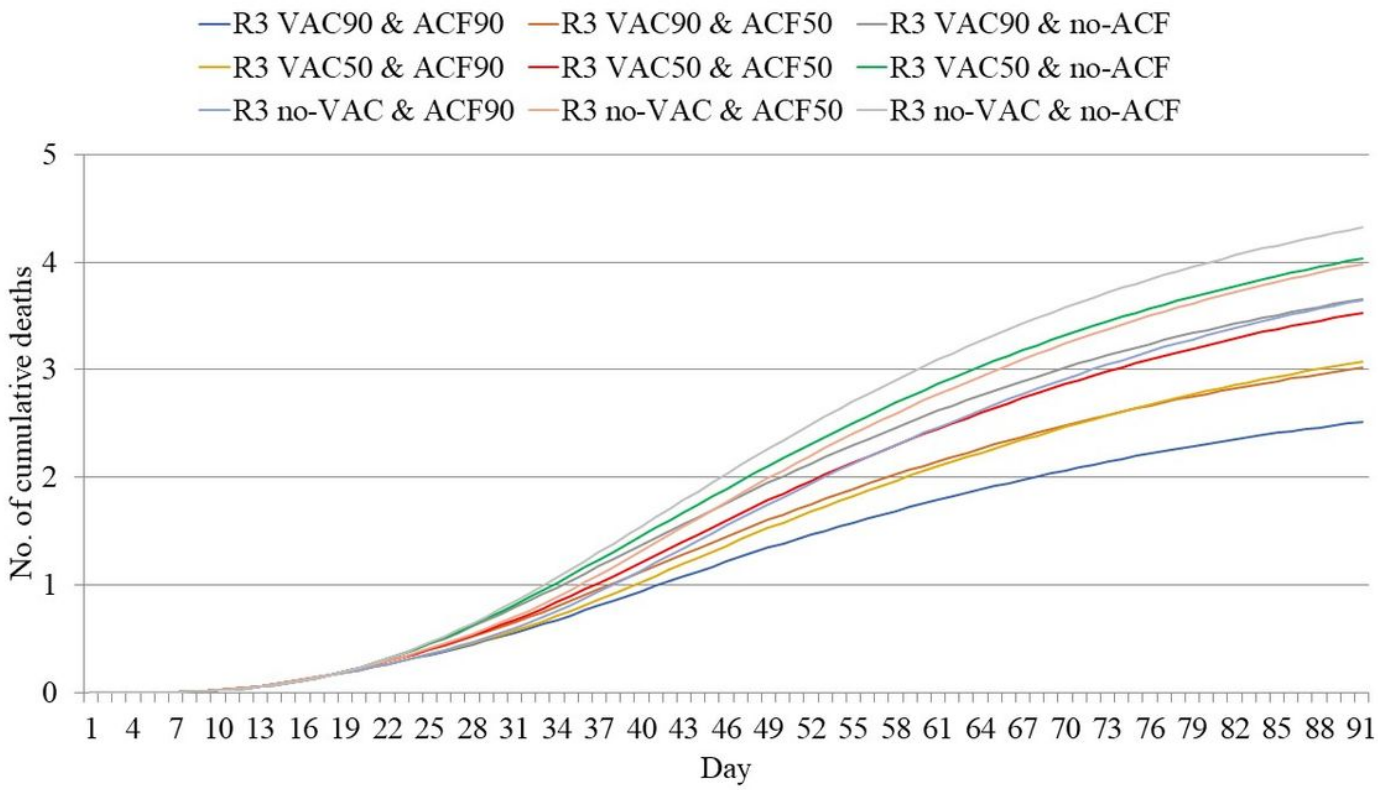

Figure 5

Cumulative deaths by policy scenarios