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Optimizing Influenza Vaccine Allocation in Thailand

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Abstract- The purpose of this research is to study the allocation of limited influenza vaccine to get the lowest outcome cost measurement including vaccine budget, medical fee and loss of infection or death. Using data of patients with influenza in Thailand in 2013, we determined proportion of vaccine allocation for six risk populations who should receive the vaccine. The risk populations are (i) Chronic disease, (ii) people aged 65 years or older, (iii) children over six months to two years, (iv) patients with aphasia, (v) patients with thalassemia and immunodeficiency and (vi) four months pregnant woman. From an optimization method with 3 million doses, we determined the optimal vaccine allocation of populations (i) to (vi) is 0, 0, 0.87068, 1, 0, 1 respectively such that proportion 1 is 100% vaccinated population. Sensitivity analysis was performed with attentive to vaccine efficacy. We also found that the outcome measurement having the lowest cost is 12163 million Baht. Our results indicate that the cost is reduced to 5,134 million Baht or 29.68 percent of all out come measures.

***Keywords*:** Computational Epidemiology, Optimization, Influenza, Vaccine

1. Introduction

Influenza is a highly contagious viral disease which has the potential to cause a large number of illness and death. Seasonal influenza refers to the yearly outbreak that occur in temperate climates, seasonal epidemics occur mainly in winter while in tropical regions, influenza may occur throughout the year, with induced outbreaks occurring more irregularly. Influenza occurs globally with an annual attack rate estimated at 5%–10% in adults and 20%–30% in children. Worldwide, these annual epidemics are estimated to result in about 3 to 5 million cases of severe illness, and about 250,000 to 500,000 deaths. (WHO, 2015)

Vaccination is the primary method of influenza prevention thereby reducing the infection risk even for those who have not been vaccinated (Medlock, 2009). The World Health Organization (WHO) recently announced that vaccination is especially important for people at higher risk of serious influenza complications, including children aged six months to five years, elderly individuals, pregnant women, individuals with chronic medical conditions and people who live with or care for high risk individuals (WHO, 2015).

In Thailand, seasonal influenza vaccination was first used in the public sector in 2004. Currently, National Health Security Office Thailand (NHSO) purchases 3,000,000 doses of vaccines which are provided free of charge to high-risk groups: children, pregnant women, persons aged ≥65 years, and persons with chronic diseases (Jocelynn et.at, 2015). In addition, healthcare personnel and poultry cullers also received 400,000 doses of vaccines, although these were paid for by the Department of Disease Control of the Ministry of Public Health (Department of Disease Control, 2014).

Vaccines were distributed to each province by estimating the size of the risk groups. Vaccination was administered in provincial and district hospitals which were not restricted to any group. When vaccine availability is limited or ran out, optimal allocation of vaccines is necessary.

We determined influenza vaccine allocation for high-risk populations in Thailand, based on infectious in 2013, healthcare used and cost effectiveness. Using a mathematical model parametrized with data from 2009 H1N1 pandemic and Thailand infectious in 2014, the results can be used to evaluate the optimal sequencing of vaccination allocation strategies among high-risk populations.

2. Method

2. 1. Model

We used a SEIR model which are susceptible-exposed-infected-recovered epidemic model that describes how an influenza A virus would spread in a population.

Members in each group are either susceptible, infected or recovered and immune. In addition, people can be either vaccinated or unvaccinated. We studied a compartmental age-structured SEIR model of Medlock (Medlock, 2009) is of the following for

$$\begin{aligned}
\frac{dU_S}{dt} &= -\lambda U_S & \frac{dV_S}{dt} &= -\left(1-\in\right)\lambda V_S \\
\frac{dU_E}{dt} &= \lambda U_S - \tau U_E & \frac{dV_E}{dt} &= \left(1-\in\right)\lambda V_S - \tau V_E \\
\frac{dU_I}{dt} &= \tau U_E - \left(\gamma + \vartheta_U\right) U_I & \frac{dV_I}{dt} &= \tau V_E - \left(\gamma + \vartheta_V\right) V_I \\
\frac{dU_R}{dt} &= \gamma U_I & \frac{dV_R}{dt} &= \gamma V_I
\end{aligned} \qquad (1)$$

Where U_S, U_E, U_I, U_R is number of susceptible, exposed, infected and recovered respectively with unvaccinated and V_S, V_E, V_I, V_R is number of susceptible, exposed, infected and recovered respectively with vaccinated. Moreover λ is a transmission parameter, τ is infectious rate, $\in$ is vaccine efficacy, γ is removal or recovery rate, ϑ_{Ua} is mortality rate of unvaccinated population and ϑ_{Va} is mortality rate of vaccinated population.

2. 2. Optimization Technique

We consider vaccine allocation amount 3,000,000 doses which are provided for high-risk from influenza in Thailand. Following the 2014 recommendation by Thailand's Advisory Committee on Immunization Practice (ACIP), the high-risk population were categorized into six groups, (i) people with chronic disease, (ii) people aged 65 years and over, (iii) over children 6 months to 2 years, (iv) patients with aphasia, (v) patients with thalassemia and immunodeficiency and (vi) four months pregnant woman (Department of Disease Control, 2014). Let p_a is a proportion of vaccinated in each group such that proportion 1 represents 100% vaccinated population. We determined optimal vaccine allocation or p_a for three outcome measures: vaccine budget, medical fee and loss of infection or death.

Thus the optimal function is formulated as

$$Minimize: Z = bN_V + \sum_a c_{Ua} N_{UIa} + c_{Va} N_{VIa} + d_a N_{Da} \qquad (2)$$

Subject to

$$0 \le p_a \le 1 \qquad (3.1)$$

$$N_V = \sum_a p_a N_a(0) \le Y \tag{3.2}$$

$$N_{UIa} = U_{Sa}(0) - U_{Sa}(T) \tag{3.3}$$

$$N_{VIa} = V_{Sa}(0) - V_{Sa}(T) \tag{3.4}$$

$$U_{Sa}(0) = (1 - p_a) N_a(0) \tag{3.5}$$

$$N_{Da} = N_a(0) - N_a(T) \tag{3.6}$$

$$V_{Sa}(0) = p_a N_a(0) \tag{3.7}$$

Where b is cost of vaccine, N_V is total vaccinated people, c_{Ua} is cost of unvaccinated influenza infectious in each group , N_{UIa} is unvaccinated influenza infectious, c_{Va} is cost of vaccinated influenza infectious in each group, N_{VIa} is vaccinated influenza infectious, d_a *is* cost of deaths from influenza, N_{Da} is total number of deaths from influenza and subscript "*a*" represents the population group (i)-(vi).

The objective function (2) minimizes the expected cost from three possible outcomes. Constraints (3.2) limit the total number of vaccines to the number of doses available. Constraints (3.3)-(3.7) state that the amount of people at initial time and time (T) computated from SEIR model (1).

2. 3. Data

We parametrized the model with a distribution of values for the epidemiological parameters from the published literatures (Table1) and epidemiological data from Bureau of Epidemiology, Thailand in 2013.

Table 1. Model Parameters

Parameters	Value	Refference
c_{Ua}	4,719 Bath	(Jitlada, 2012)
c_{Va}	1,324 Bath	(Jitlada, 2012)
d_a	37,312 Bath	(Jitlada, 2012)
λ	0.762	(Herbert, 2014)
$\in$	0.8	(Medlock, 2009)

3. Results

From an optimization method with 3 million doses, we determined the optimal vaccine allocation of populations (i) to (vi) is 0, 0, 0.87068, 1, 0, 1 respectively. For minimizing all cost outcomes, these results suggest that patients with aphasia (iv) and the pregnant woman gestation 4 months (vi) should be receiving vaccine 100% , children aged six months to two years should receive vaccine at 87.07% and vaccine may not be available for people with chronic disease (i), people aged 65 years and over (ii) and patients with thalassemia and immunodeficiency (v).

In Figure 1 shows the result of varying doses of vaccine for investigated an allocation of each group (i)-(vi). There were no changes on people with chronic disease (i), people aged 65 years and over (ii), patients with aphasia (iv), and four months pregnant woman (vi). The children aged six months to two years have direct relation to the increasing doses of vaccine. Patients with thalassemia and immunodeficiency (v) should receive vaccine attention when total free vaccination offered for these risk groups are more than 3,300,000 doses.

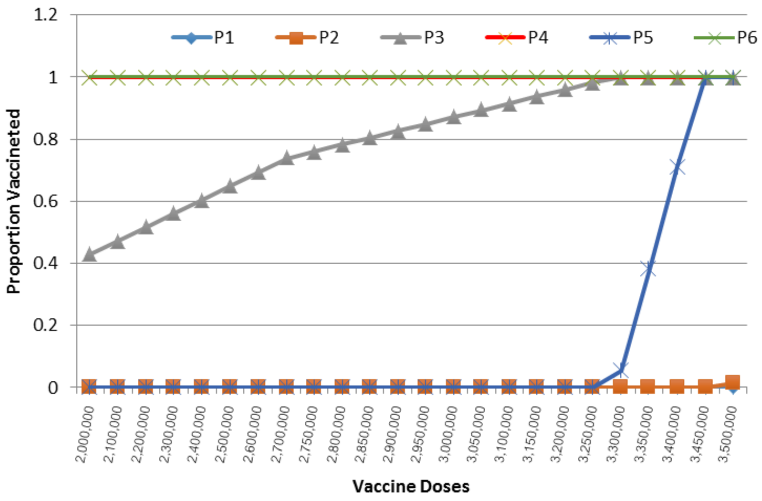

Fig. 1. The proportion vaccinated with vaccine doses varying

Moreover, the optimization results show that vaccination has greatly reduced the cost of measurement (Fig. 2) and the infectious.

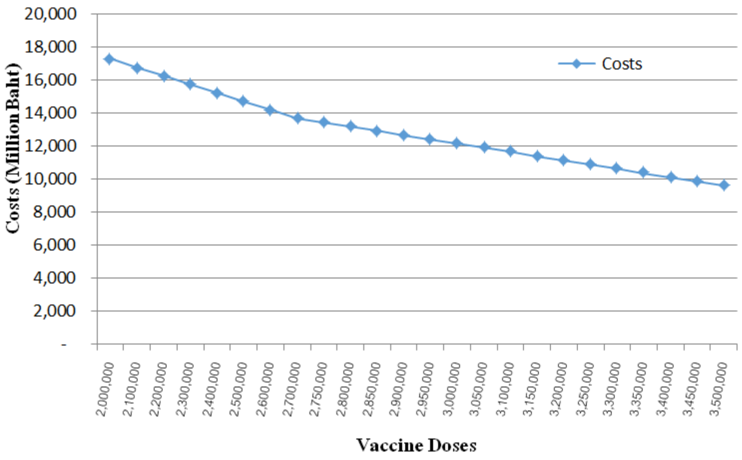

Fig. 2. The outcome cost with vaccine doses varying

4. Conclusion

In the allocation of limited influenza vaccine from this study, we get the lowest outcome cost measurement including vaccine budget, medical fee and loss of infection or death. We also found that the outcome measurement which makes it the lowest cost is 12,163 million Baht. Our results indicate that cost is reduced to 5,134 million Baht or 29.68 percent for all out come measures as shown in Fig. 3- Fig. 5. The model in this paper, and therefore the results generated are not designed to calibrate the exact outcomes for vaccination but rather to suggest a prioritisation of risk group for Thailand and to present an optimization of which strategy would be most cost effective in a future.

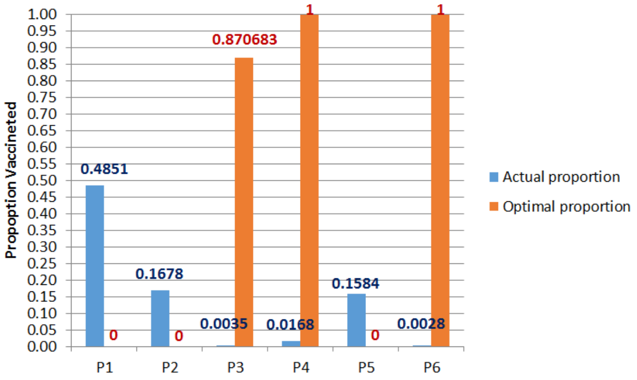

Fig. 3. The comparison of actual vaccine proportion and optimal proportion

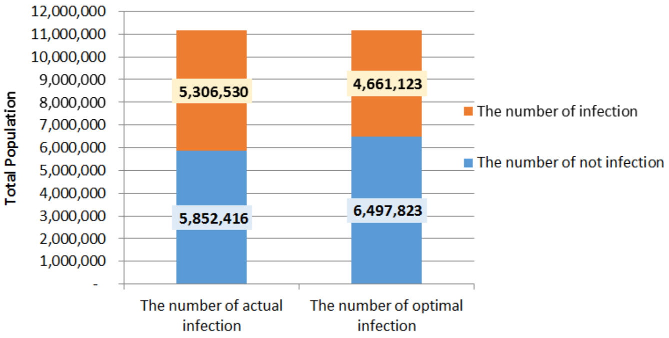

Fig. 4. The comparison of actual infectious and optimal infectious

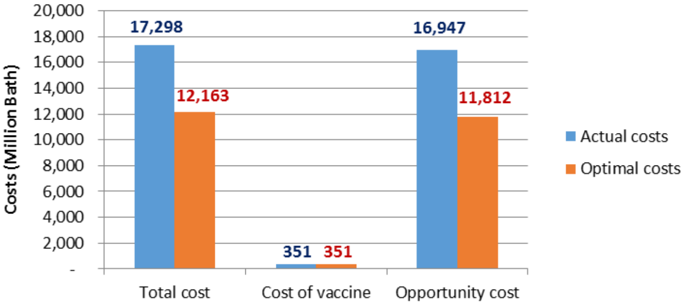

Fig. 5. The comparison of actual costs and optimal costs

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